Mean Total Arsenic Concentrations in Chicken 1989–2000 and Estimated Exposures for Consumers of Chicken

Tamar Lasky, Wenyu Sun, Abdel Kadry, and Michael K. Hoffman

Office of Public Health and Science, Food Safety and Inspection Service, U.S. Department of Agriculture, Washington, DC, USA

The purpose of this study was to estimate mean concentrations of total arsenic in chicken liver tissue and then estimate total and inorganic arsenic ingested by humans through chicken consumption. We used national monitoring data from the Food Safety and Inspection Service National Residue Program to estimate mean arsenic concentrations for 1994–2000. Incorporating assumptions about the concentrations of arsenic in liver and muscle tissues as well as the proportions of inorganic and organic arsenic, we then applied the estimates to national chicken consumption data to calculate inorganic, organic, and total arsenic ingested by eating chicken. The mean concentration of total arsenic in young chickens was 0.39 ppm, 3- to 4-fold higher than in other poultry and meat. At mean levels of chicken consumption (60 g/person/day), people may ingest 1.38–5.24 µg/day of inorganic arsenic from chicken alone. At the 99th percentile of chicken consumption (350 g chicken/day), people may ingest 21.13–30.59 µg inorganic arsenic/day and 32.50–47.07 µg total arsenic/day from chicken. These concentrations are higher than previously recognized in chicken, which may necessitate adjustments to estimates of arsenic ingested through diet and may need to be considered when estimating overall exposure to arsenic. ***Key words:*** **arsenic, chicken, dose, drug residue, exposure, food safety, risk assessment.** ***Environ Health Perspect*** **112:18–21 (2004). doi:10.1289/ehp.6407 available via** ***http://dx.doi.org/*** **[Online 1 October 2003]**

We quantified the concentrations of total arsenic in poultry using national monitoring data from the Food Safety and Inspection Service National Residue Program (NRP) [U.S. Department of Agriculture (USDA) Food Safety and Inspection Service 2001)]. These are the first reports of arsenic concentrations in national samples of poultry in the United States and may be useful in risk assessments of arsenic exposure and its consequences. We also estimated the dose of inorganic, organic, and total arsenic delivered with varying levels of chicken consumption, and the percentage of the U.S. population at risk for high levels of arsenic exposure through chicken consumption alone.

Arsenic is a heavy metal that is found in inorganic and organic forms in water, food, soil, dust, wood, and other materials. Inorganic forms of arsenic have been classified as human carcinogens and are more toxic than organic forms, but variation in toxicity among inorganic and organic forms is considerable. Chronic arsenic exposure in the range of 0.01–0.04 mg/kg/day has been associated with skin cancer in Taiwan (Hsueh et al. 1995); respiratory cancers in Montana (Lubin et al. 2000); bladder cancer in Finland (Kurttio et al. 1999); increased mortality from hypertensive heart disease, nephritis and nephrosis, and prostate cancer in Utah (Lewis et al. 1999); increased incidence of lung cancer, bladder cancer, and all cancers in Taiwan (Chiou et al. 1995); late fetal mortality, neonatal mortality, and postnatal mortality in Chile (Hopenhayn-Rich et al. 2000); and cytogenetic damage in Mexico (Gonsebatt et al. 1997). The general population is exposed to arsenic through drinking water, dust, fumes, and dietary sources, with the highest concentrations of arsenic reported in seafood, rice, mushrooms, and poultry (Tao and Bolger 1999).

The NRP conducts monitoring and surveillance of meat, poultry, and egg products to determine the presence of chemical residues, including animal drug residues, pesticides, and environmental contaminants (USDA Food Safety and Inspection Service 2001). We used monitoring data from the NRP to estimate mean arsenic concentrations in meat and poultry during the years 1989–2000 and to calculate possible dose exposures acquired through consumption of chicken. Arsenic is an approved animal dietary supplement and is found in specifically approved drugs added to poultry and other animal feeds. Roxarsone (4-hydroxy-3-nitrophenyl arsonic acid) is the most frequently used additive among a group of organic arsenic compounds added to feed of broiler chickens to control coccidial intestinal parasites. Roxarsone contains organic arsenic in the +5 oxidation state. Most of the excreted arsenic (found in litter) remains as the parent compound or as the amino-metabolite. The forms found in chicken muscle have not been reported in the literature.

Previous summaries report the number and percentage of instances where levels exceeded allowable limits as categorical data falling in one of three categories: above allowable levels (violative), detectable but within allowable levels (positive, nonviolative), and not quantifiable. Such reports are used to monitor and correct factors contributing to occurrence of levels exceeding allowable limits (USDA Food Safety and Inspection Service 2001). The monitoring data, however, can also be expressed as quantitative values that can in turn be used to provide a preliminary estimate of mean arsenic concentrations in poultry and meat.

Materials and Methods

NRP database. The NRP collects samples of meat and poultry for laboratory analysis of a wide range of chemical residues including veterinary drugs and pesticides. Random sampling is conducted on an annual, national basis and is described elsewhere (USDA Food Safety and Inspection Service 2001). Sampling for arsenicals began in 1989 with 384 samples and rose to 4,420 domestic samples in 2000. The database for 1989–2000 contained observations for 20,559 monitoring samples analyzed for total arsenic. More than 99% (20,542) of the samples were of liver tissue; the 14 muscle, 2 kidney, and 1 egg samples were excluded from the analysis. The species were grouped into five categories: young chickens (n = 3,611), mature chickens (n = 1,582), turkeys (n = 2,763), hogs/sows/roaster pigs/boars/stags (n = 5,522), and all other species (horse, bull, steer, beef cow, heifer, dairy cow, bob veal, formula-fed veal, non-formula-fed veal, heavy calves, mature sheep, lamb, goat, duck, rabbit; n = 7,064). The mean total arsenic concentrations and 95% confidence intervals (CIs) around the means for each category for each year were calculated by averaging the nonquantifiable results with positive values. All values < 0.20 ppm were considered nonquantifiable; we assumed the value to be halfway between 0 and 0.20, or 0.10 (zero would underestimate the level, and 0.20 would overestimate the level).

Converting liver values to muscle values. We used NRP arsenic monitoring measurements from liver tissue samples to estimate concentrations in muscle tissue, the most frequently consumed part of the chicken. Because the ratio between arsenic concentrations in poultry liver and muscle tissue is not described, we relied on manufacturer's data presented in

Address correspondence to T. Lasky, National Institute of Child Health and Development, MSC 7510, 6100 Executive Boulevard, Bethesda, MD 20892 USA. Telephone: (301) 594-8670. Fax: (301) 480-1222. E-mail: TL177G@nih.gov

The authors declare they have no competing financial interests.

Received 22 April 2003; accepted 1 October 2003.

their technical bulletin (Alpharma Inc. 1999). They reported tissue arsenic concentrations at 0, 3, 4, and 5 days after withdrawal from roxarsone (3-Nitro) in chickens fed 50 ppm for 7 weeks (Alpharma Inc. 1999). Liver arsenic concentrations were 1.1 ppm, compared with 0.1 ppm in muscle at 0 days, 0.3 and 0.07 ppm, respectively, at 3 days, and 0.2 and 0.07 ppm, respectively, at 5 days, yielding liver-to-muscle ratios of 11, 4.2, and 2.9, respectively, for each time point. We applied these reported ratios to adjust the measured liver tissue values in the NRP sample and produce estimates of values in muscle tissue. Muscle tissue values were estimated under three different assumptions: *a*) consistent adherence with the 5-day withdrawal period; *b*) variable adherence averaging 3 days of withdrawal; and *c*) 0 days of withdrawal.

Assumptions regarding the inorganic/organic proportions. We used data collected in Canada regarding arsenic speciation in Canadian food samples suggesting that 65% of arsenic in poultry and meat is inorganic (Levine et al. 1988; Weiler 1987). This estimate was used in the 1988 U.S. Environmental Protection Agency risk assessment regarding the risk of skin cancer associated with ingested inorganic arsenic (Levine et al. 1988) and is currently used as the basis of discussions of arsenic exposure and health effects (Abernathy 2001).

Calculation of arsenic exposure concentrations associated with varying levels of chicken consumption. Chicken consumption data from the Continuing Survey of Food Intakes by Individuals 1994–1996 survey (USDA Agricultural Research Service 2000) were summarized using the Dietary Exposure Evaluations Model software to produce estimates of the mean number of grams of chicken consumed by the U.S. population at the 50th, 95th, and 99th percentiles (Novigen Sciences 2000; USDA Agricultural Research Service 2000). The amount of chicken consumed was then multiplied by estimates of inorganic and organic arsenic in chicken muscle tissue to calculate the estimated doses of arsenic ingested at the 50th, 95th, and 99th percentiles in the U.S. population and in various subgroups.

Results

Numbers of positive and violative results. The percentages nonquantified, positive, and violative were calculated for each of the five groups. The percentage nonquantified was lowest in young chickens (0.30); higher in mature chickens, turkeys, and hogs; and highest in all other species (0.93) (Table 1). The percentages of violations were < 0.01 for all categories (ranging from 0 to 0.28). The percentage positive and/or violative was highest for young chickens (0.70); moderate for mature chickens, turkeys, and hogs; and lowest for all other species (0.07). The trend in percentage positive for young chickens showed a decline between 1993 and 1999 with a slight upturn in 2000.

Mean arsenic concentrations. During the years 1994–2000 mean arsenic concentrations in young chickens ranged from 0.33 to 0.43 ppm, and the mean for the entire period was 0.39 ppm (Figure 1). During the same period, the mean values for mature chickens, turkeys, hogs, and all other species was between 0.10 and 0.16 ppm (Figure 1). The mean concentrations of arsenic in young chickens declined from 0.43 ppm (95% CI, 0.4–0.47) to 0.33 (95% CI, 0.30–0.36) between 1994 and 1999, with a slight upturn to 0.39 (95% CI, 0.37–0.41) in 2000 (Figure 1). Arsenic concentrations in young chickens appear to be 3- to 4-fold higher than in other species categories sampled in the NRP. We observed variation in mean arsenic concentrations by U.S. state, ranging from < 0.10 ppm to > 0.51 ppm, but the small number of samples in each state resulted in wide CIs around each estimate and limited further statistical analysis. Data were not available to correlate levels in chickens with feeding additives, brand of chicken, or season of the year.

Chicken consumption in the United States. Chicken consumption in the United States rose from 40.1 lb/person/year in 1970 to 71.8 lb/person/year in 1997 (USDA Economic Research Service 2002). In 1970 about 90% of chicken consumption was young chicken, but by 1997 > 99% of chicken was consumed as young chicken. Per capita daily consumption in 1994–1996 ranged from a mean of 57 g/day for non-Hispanic whites, 64 g/day for Hispanics, to 72 g/day for non-Hispanic blacks, and varied by age (Table 2) (USDA Agricultural Research Service 2000).

Arsenic dose associated with chicken consumption. Based on our calculation of a mean concentration of 0.39 ppm in liver tissue during the years 1994–2000, the Alpharma estimated ratios of liver to muscle tissue levels of 2.9, 4.2, and 11 (Alpharma Inc. 1999), the assumption that the proportion of inorganic arsenic is 0.65, and chicken consumption levels at and above the 50th percentile, we produced a range of inorganic, organic, and total arsenic intake measures (Table 3). Under the assumption of a 5-day withdrawal period (and a liver-to-muscle arsenic concentration ratio of 2.9), the estimated inorganic arsenic intake ranged from 5.24 to 30.59 µg for those consuming 60–350 g chicken/day. If one assumes incomplete adherence to the recommended withdrawal period and an average withdrawal period of 3 days, the estimated inorganic arsenic intake ranged from 3.62 to 21.13 µg for the same levels of chicken consumption. Under the extreme assumption of no compliance with the withdrawal period, inorganic arsenic concentrations ranged from 1.38 to 8.07 µg/day. At the mean level of chicken consumption (60 g/person/day), estimated inorganic arsenic intake ranged from 1.38 to

Table 1. Arsenic test results [*n* (%)] by five categories of animal species: 1989–2000 NRP data.

Species	Not quantified	Positive but not violative	Violation	Total
Young chickens	1,089 (30)	2,512 (69)	10 (< 1)	3,611
Mature chickens	1,195 (76)	387 (24)	0	1,582
Turkeys	2,043 (74)	712 (26)	8 (< 1)	2,763
Hogs, sows, etc.	4,560 (83)	962 (17)	0 (< 1)	5,522
All other species	6,576 (93)	478 (7)	10 (< 1)	7,064
Total	15,463 (75)	5,051 (25)	28 (< 1)	20,542

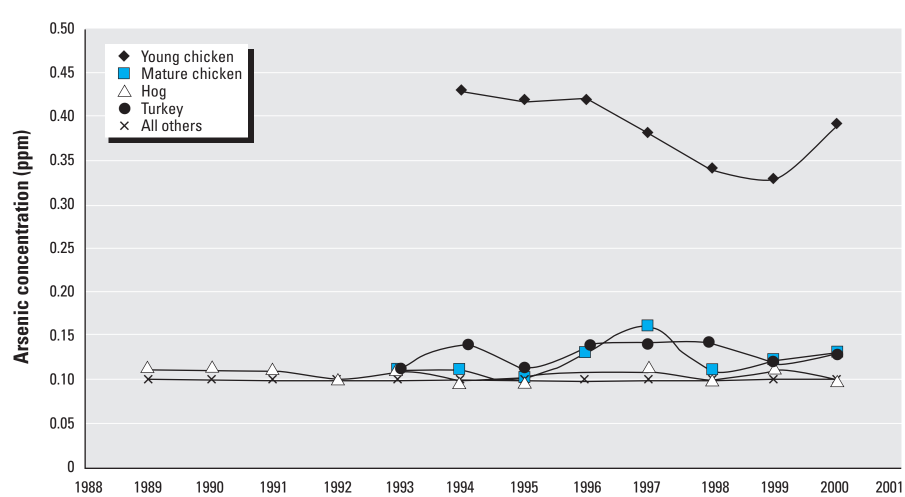

Figure 1. Mean total arsenic in chickens and other meats and poultry, 1989–2000.

5.24 μg/day, varying with the assumptions regarding withdrawal periods.

Discussion

The ability of trace elements ingested by chickens to affect the dose delivered to humans through chicken consumption has been shown for iodine, iron, zinc, uranium, and potassium (Izak-Biran et al. 1989; Kaufmann et al. 1998; Leonhardt et al. 1997). It is reasonable to assume that arsenic ingested through chicken consumption may similarly affect the dose delivered to humans.

The data presented here suggest that arsenic concentrations in young chickens may be approximately 3-fold greater than in other meat and poultry products. The higher arsenic concentrations observed in chickens compared with other poultry and meat products is consistent with the use of chicken feed containing additives including arsenic compounds. This preliminary data analysis can be refined with greater understanding of sources of variation in arsenic concentrations in meat products, for example, regional and seasonal variation. Samples were selected for analysis from plants with varying production levels, and future analyses may require plant estimates to be weighted by production volume in calculating a summary estimate. The present analysis is the first step in progressing from a categorical count of violations and positive tests to a quantitative measure of arsenic concentrations in meat and poultry. Despite the preliminary nature of the analysis, the relative values of arsenic concentrations in chickens and other species may be expected to persist in future data analyses, because uniform methods were applied to collecting and sampling arsenic concentrations in all species monitored by the NRP. Furthermore, these preliminary analyses were consistent with published data from the United States and Canada. Our estimate of 0.33–0.43 ppm total arsenic in liver tissue is similar to that observed in Canadian poultry livers (Korsrud et al. 1985; Salisbury et al. 1991), and our estimate of 0.13 μg/g total arsenic in chicken muscle tissue is somewhat higher than that found in market studies in the United States during 1991–1996 (0.030–0.086 μg/g; Tao and Bolger 1999) and in Canada between 1985 and 1988 (0.029 μg/g; Dabeka et al. 1993). Further studies would help define the range of variation of total, inorganic, and organic arsenic in chicken, and the factors such as seasonality or geography that might affect such variation.

The proportion of inorganic and organic arsenic in chicken was estimated to be 0.65 and 0.35, respectively, based on Canadian data from 1987 (Levine et al. 1988; Weiler 1987). Proportions of inorganic and organic arsenic in chickens in the United States during 1996–2000 may differ from those in Canada, but until U.S. studies are conducted, the Canadian data provide a reasonable starting point for analysis. The relationship between the amount of arsenic in liver tissue compared with muscle tissue was based on data published by a pharmaceutical company in 1999 marketing arsenic-containing additives for poultry feed and showing changes in the relationship with the number of days of withdrawal (Alpharma Inc. 1999). Further studies are needed to describe more fully the correlation between liver and muscle tissue values and their variation with the withdrawal period. It might then be useful to describe the withdrawal period in actual practice. We assumed compliance with the withdrawal period, which suggested that the ratio of liver to muscle arsenic concentrations might be between 2.9 and 4.2. We thus assumed that the pharmaceutical data were accurate with respect to liver and muscle values at 0–5 days of withdrawal. It would be helpful to have more detailed laboratory information about the forms of inorganic and organic arsenic remaining in chicken muscle, as well as the effects of cooking on these forms, and the metabolism of the ingested arsenic.

Under these assumptions, and relying on the ratios of 2.9 and 4.2 (excluding the extreme ratio of 11), a mean chicken consumption rate of 60 g/day may result in an intake of 3.62–5.24 μg inorganic arsenic/day and 5.57–8.07 μg total arsenic/day. However, 1% of the U.S. population consumes > 350 g chicken/day and may ingest 21.13–30.59 μg inorganic arsenic/day and 32.50–47.07 μg total arsenic/day from chicken. For a person weighing 70 kg (154 lb), this would be 0.30–0.44 μg/kg/day inorganic arsenic intake, below the Food and Agriculture Organization of the United Nations and the World Health Organization (FAO/WHO) Joint FAO/WHO Expert Committee on Food Additives (JECFA) tolerable daily intake of 2 μg/kg/day of inorganic arsenic (WHO 1983) but comprising a sizable proportion of the tolerable daily intake. A smaller percentage of people (0.1%) consume ≥ 612 g chicken/day and may ingest as much as 36.94–53.50 μg inorganic arsenic/day and 56.83–82.30 μg total arsenic/day through chicken consumption alone. For a person weighing 70 kg (154 lb), this would be 0.53–0.76 μg/kg/day inorganic arsenic intake, and if we assume a higher body weight of 100 kg (consistent with a high daily intake of chicken), inorganic arsenic ingestion might be 0.37–0.54 μg/kg/day. Again, these estimates are below the FAO/WHO JECFA tolerable daily intake of 2 μg/kg/day of inorganic arsenic (WHO 1983) but may account for a sizable proportion of tolerable daily intake.

Calculations of arsenic intake have been used to recommend and adjust arsenic levels in the environment, most notably in water. These calculations have not taken into account the higher concentrations of arsenic measured in chicken compared with other poultry and meats. Furthermore, chicken consumption in the United States has increased steadily from 32.1 lb/person in 1966 to 81.2 lb/person in 2000. The higher than previously recognized concentrations of arsenic in chicken combined with the increasing levels of chicken consumption may indicate a need to review assumptions regarding overall ingested arsenic intake.

Table 2. Mean daily chicken consumption in the U.S. population.

Population	Mean grams per person	95th percentile	99th percentile
Total population	60	214	358
Ethnic group			
Hispanic	64	217	369
Non-Hispanic white	57	208	346
Non-Hispanic black	72	237	414
Age (years)			
Infants < 1	7	44	80
Children 1–6	38	129	205
Seniors ≥ 55	44	193	297

Adapted from USDA Agricultural Research Service (2000).

Table 3. Estimates of inorganic, organic, and total arsenic intake assuming a mean concentration of 0.39 ppm total arsenic in chicken liver tissue, and three possible ratios of liver to muscle arsenic concentrations.

Adjustment for ratio of liver arsenic to muscle arsenic[a]	Percentile consumption	Chicken consumption (g/day)	Arsenic intake (μg/day) Inorganic	Organic	Total
2.9	50th	60	5.24	2.82	8.07
	95th	200	17.48	9.41	26.90
	99th	350	30.59	16.47	47.07
	99.9th	612	53.50	28.81	82.30
4.2	50th	60	3.62	1.95	5.57
	95th	200	12.07	6.50	18.57
	99th	350	21.13	11.38	32.50
	99.9th	612	36.94	19.89	56.83
11.0	50th	60	1.38	0.74	2.13
	95th	200	4.61	2.48	7.09
	99th	350	8.07	4.34	12.41
	99.9th	612	14.10	7.59	21.70

[a]Based on data from Alpharma Inc. (1999).

References

Abernathy C. 2001. Exposure and health effects. In: UN Synthesis Report on Arsenic in Drinking Water. Washington, DC:World Health Organization, 1–100. Available: http://www.who.int/water_sanitation_health/dwq/en/arsenicun3.pdf [accessed 4 November 2003].

Alpharma Inc. 1999. 3-Nitro Is Safe for the Consumer and Environment. Fort Lee, NJ:Alpharma Inc.

Chiou HY, Hsueh YM, Liaw KF, Horng SF, Chiang MH, Pu YS, et al. 1995. Incidence of internal cancers and ingested inorganic arsenic: a seven-year follow-up study in Taiwan. Cancer Res 55:1296–1300.

Dabeka RW, McKenzie AD, Lacroix GM, Cleroux C, Bowe S, Graham RA, et al. 1993. Survey of arsenic in total diet food composites and estimation of the dietary intake of arsenic by Canadian adults and children. J AOAC Int 76:14–25.

Gonsebatt ME, Vega L, Salazar AM, Montero R, Guzman P, Blas J, et al. 1997. Cytogenetic effects in human exposure to arsenic. Mutat Res 386:219–228.

Hopenhayn-Rich C, Browning SR, Hertz-Picciotto I, Ferreccio C, Peralta C, Gibb H. 2000. Chronic arsenic exposure and risk of infant mortality in two areas of Chile. Environ Health Perspect 108:667–673.

Hsueh YM, Cheng GS, Wu MM, Yu HS, Kuo TL, Chen CJ. 1995. Multiple risk factors associated with arsenic-induced skin cancer: effects of chronic liver disease and malnutritional status. Br J Cancer 71:109–114.

Izak-Biran T, Schlesinger T, Weingarten R, Even O, Shamai Y, Israeli M. 1989. Concentrations of U and Po in animal feed supplements, in poultry meat and in eggs. Health Phys 56:315–319.

Kaufmann S, Wolfram G, Delange F, Rambeck W. 1998. Iodine supplementation of laying hen feed: a supplementary measure to eliminate iodine deficiency in humans? Z Ernahrungswiss 37:288–298.

Korsrud G, Meldrum J, Salisbury C, Houlahan B, Saschenbrecker P, Tittiger F. 1985. Trace element levels in liver and kidney from cattle, swine and poultry slaughtered in Canada. Can J Comp Med 49:159–163.

Kurttio P, Pukkala E, Kahelin H, Auvinen A, Pekkanen J. 1999. Arsenic concentrations in well water and risk of bladder and kidney cancer in Finland. Environ Health Perspect 107:705–710.

Leonhardt M, Kreuzer M, Wenk C. 1997. Available iron and zinc in major lean meat cuts and their contribution to the recommended trace element supply in Switzerland. Nahrung 41:289–292.

Levine T, Marcus W, Chen C, Rispin A, Scott CS, Gibb H. 1988. Special Report on Ingested Inorganic Arsenic: Skin Cancer, Nutritional Essentiality. Washington, DC:U.S. Environmental Protection Agency.

Lewis DR, Southwick JW, Ouellet-Hellstrom R, Rench J, Calderon RL. 1999. Drinking water arsenic in Utah: a cohort mortality study. Environ Health Perspect 107:359–365.

Lubin JH, Pottern LM, Stone BJ, Fraumeni JF Jr. 2000. Respiratory cancer in a cohort of copper smelter workers: results from more than 50 years of follow-up. Am J Epidemiol 151:554–565.

Novigen Sciences. 2000. Dietary Exposure Evaluation Model (DEEM). Washington, DC:Novigen Sciences, Inc.

Salisbury C, Chan W, Saschenbrecker P. 1991. Multielement concentrations in liver and kidney tissues from five species of Canadian slaughter animals. Assoc Off Anal Chem 74:587–591.

Tao SS, Bolger PM. 1999. Dietary arsenic intakes in the United States: FDA Total Diet Study, September 1991-December 1996. Food Addit Contam 16:465–472.

USDA Agricultural Research Service. 2000. Continuing Survey of Food Intakes by Individuals (CSFII) 1994–1996, 1998 [CD-ROM]. Beltsville, MD:U.S. Department of Agriculture Agricultural Research Service. NTIS Accession No. PB2000-500027. Springfield, VA:National Technical Information Service.

USDA Economic Research Service. 2003. Food Consumption (Per Capita) Data System. Washington, DC:U.S. Department of Agriculture Economic Research Service. Available: http://www.ers.usda.gov/data/foodconsumption/DataSystem.asp?ERSTab = 2 [accessed 28 August 2003].

USDA Food Safety and Inspection Service. 2001. 2000 FSIS National Residue Program Data. Washington, DC:U.S. Department of Agriculture Food Safety and Inspection Service, Office of Public Health and Science.

Weiler R. 1987. Percentage of Inorganic Arsenic in Food: A Preliminary Analysis. Report No. 87-48-45000-057. Toronto, Canada:Ontario, Canada Ministry of the Environment.

WHO. 1983. Evaluation of Certain Food Additives and Contaminants (Twenty-Seventh Report of the Joint FAO/WHO Expert Committee on Food Additives). World Health Organization Technical Report Series No. 696. Geneva:World Health Organization.