PEANUT SCIENCE

The Journal of the American Peanut Research and Education Society

ARTICLE

A Heavy Metals Survey of Farmers' Stock Peanuts

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ARTICLE INFORMATION

Keywords:
Arsenic, cadmium, farmers' stock peanuts, lead, mercury, nickel

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DOI: 10.3146/0095-3679-53-PS1679

ABSTRACT

A survey to sample heavy metal concentration levels in the U.S. peanuts was conducted during the harvest of the 2023-2025 crops. A sampling plan specifying the number of peanut buying points, the number of samples by peanut type, and production region was developed based on the relative production by region and market type. The kernels from the farmers' stock grade sample, after splitting and inspecting for visible *Aspergillus flavus* and internal damage, were retained and accumulated daily at selected peanut buying points. At the end of the day, a composite 1-kg sample was obtained from the accumulated peanuts. All samples were sent to a central location for blinding, then sent to a commercial laboratory and analysed for arsenic, cadmium, lead, mercury, and nickel. Data were analysed accounting for any censored values (concentrations below the limits of detection). Based on the average of all regions, the likelihood of a random sample having a concentration of arsenic, lead, and mercury test below the respective limits of detection was 0.82, 0.73, and 1.00 respectively. The mean concentration of cadmium across all three years and all three production regions was 0.09 ppm. The mean concentration of nickel across all three years and production regions was 1.06 ppm. Based on a typical 28-g serving of peanuts and the observed concentrations, consumers would have to consume a minimum of 805 servings or 23 kg daily to exceed any of the current daily reference values for any of the heavy metals tested.

INTRODUCTION

The European Food Safety Authority (EFSA) has assembled the Panel on Contaminants in the Food Chain (CONTAM) to examine, monitor, and recommend exposure limits of various contaminants in the food chain. The effects of exposure to heavy metals on human health are well documented (Järup, 2003; EFSA CONTAM, 2020). Arsenic is widely present in the environment because of both natural occurrence and human activity. Chronic human exposure is associated with the occurrence of skin, bladder, and lung cancers as well as spontaneous abortions, stillbirth, and neurodevelopmental problems. EFSA CONTAM (2024) recommended benchmark dose lower confidence limit for an extra/relative risk of 5% ($BMDL_{05}$) for arsenic of 0.06 µg/kg bw (body weight).

The cardiovascular system as well as kidneys, liver, lungs, and pancreas are known to be affected by accumulations of cadmium. Most chronic effects of cadmium are observed in the liver (Järup, 2003). The CONTAM Panel confirmed the tolerable weekly intake (TWI) for cadmium is 2.5 µg/kg bw (EFSA CONTAM, 2011). The European Union has set a contamination limit for cadmium of 0.2 ppm.

Lead is known to affect the central nervous system and cause pulmonary and cardiovascular dysfunction, anemia, and liver damage (Munir *et al.*, 2022). The effect of lead toxicity on the central nervous system is greater in children than in adults (Wani *et al.*, 2015). Prior to 2010, the probable tolerable weekly intake (PTWI) for lead was 25 µg/kg bw. However, EFSA re-evaluated that assessment and determined that the PTWI was inappropriate, and that there was no acceptable threshold (EFSA CONTAM, 2010), particularly for children aged 1-7 years old. The U.S. Food and Drug Administration maintained action levels for lead contamination in food, and

began a campaign entitled "Closer to Zero" toward reducing lead in food, especially for children and women of child-bearing age. The most recent recommended maximum daily intake for children is 2.20 µg/kg bw and for women is 8.80 µg/kg bw (FDA, 2025).

Central nervous system injury, renal dysfunction, and gastrointestinal ulceration are some known effects of accumulation of mercury (Järup, 2003). EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM, 2012) has determined that the tolerable weekly intake (TWI) of mercury depends on the form. The TWI for inorganic mercury is 4 µg/kg bw, while the TWI for methylmercury is lower at 1.3 µg/kg bw.

Some heavy metals such as nickel are essential human micronutrients, but in excess, can be detrimental to human health (Munir *et al*., 2022). Long-term over exposure to nickel can cause cardiovascular, renal, and pulmonary illnesses (Munir *et al*., 2022). EFSA-CONTAM (2020) report that nickel is ubiquitous in the environment and exposure may lead to adverse hypersensitivity reactions such as systemic contact dermatitis. The tolerable daily intake (TDI) for nickel is reported as 13 µg/kg body weight (EFSA CONTAM, 2020).

Exposure to heavy metals may be due to environmental contamination, occupational hazards, or ingestion of contaminated food or water (Mahaffey *et al.,*1975). In a survey for crop years 2013-2015, Blair and Lamb (2017) conducted a survey to determine concentrations of heavy metals and certain pesticides in peanuts. They reported very low levels of arsenic, cadmium, lead, and mercury in samples of peanut collected from across the peanut producing region of the U.S. They reported the upper 95% confidence limit (UCL95) for cadmium and lead was 0.0814 and 0.0367 ppm, respectively. The data for arsenic and mercury were both highly censored with 38% of the samples testing below the 0.02 ppm limit of detection for arsenic, and 97% of the samples testing below the 0.01 ppm limit of detection for mercury. Blair and Lamb (2017) estimated that the average adult U.S. female would have to consume between 0.9 and 7.2 kg of peanuts daily to exceed the provisional tolerable intake levels of heavy metals.

Peanuts are harvested in a two-step process. As growers dig the peanuts, the digger-inverter combines two adjacent rows of peanuts into a single inverted (peanuts facing upward) windrow. After partially drying in the windrow, the peanut pods are threshed and loaded into trailers and transported to a nearby buying point where they are mechanically dried, graded by an independent Federal-State Inspection Service.

During grading, a representative sample weighing between 1500 and 2200 g is extracted from each and every load delivered to the peanut buying point. The sample is sorted into foreign material, loose shelled kernels, and intact pods. A 500-g subsample of the pods is shelled; the kernels are sized and visually sorted into damaged and undamaged kernels. All peanut kernels in the sample, including loose shelled kernels (LSK), are mechanically split, and visually inspected for the presence of *Aspergillus flavus*.

After grading, the load of peanuts is emptied into a bulk warehouse and commingled with peanuts of similar quality. Warehouses range in capacity from 2,000 to 13,000 metric tons (t). The bulk inshell peanuts remain in the warehouse for one to nine months based on the capacity of the peanut shelling plant receiving the peanuts. Peanut shelling plants draw simultaneously from at least two warehouses to maintain a steady feed rate to the shelling equipment in the event of a disruption in flow from a single warehouse. This further commingles the peanuts as they are processed into 20-mt finished shelled lots of similar peanut type and size.

According to the National Peanut Buying Points Association (NPBPA, 2026), U.S. peanuts are delivered to more than 350 peanut buying points using conveyances that carry approximately 20 mt of farmers' stock peanuts each. During the 2020-2025 crop years, the Georgia Federal-State Inspection service reported that U.S. farmers delivered an average of 2.86 million t to the buying points (GAFSIS, 2026). Assuming that those deliveries are uniformly distributed across all buying points during an average 56-d harvest, an average of 7 20-t loads were delivered to each buying point per day of the harvest season.

This study is a follow-up assessment of the presence of heavy metals in U.S. peanuts for crop years 2023-2025.

Table 1. List of heavy metals, their limits of detection, method reference, and reference values in the 2023-2025 survey of peanuts.

Metal	Limit of Detection	Method Reference	Reference Value	Source
	ppm		µg/kg body weight	
Arsenic (inorganic)	0.02	AOAC 2013.06	0.060 b	EFSA CONTAM, 2020
Cadmium	0.01	AOAC 2013.06	0.357	EFSA CONTAM, 2011
Lead	0.02	AOAC 2013.06	2.20* 8.80**	FDA, 2025
Methyl Mercury	0.01	AOAC 2013.06	0.186	EFSA CONTAM, 2012
Nickel	0.1	AOAC 2011.14	13.0	EFSA CONTAM, 2020

*Young children 1-yr old, weighing an average of 11.4 kg

** Women of childbearing age, weighing an average of 60 kg

MATERIALS AND METHODS

Sample Collection.

This study was conducted using samples collected during the process of harvesting and grading the 2023-2025 peanut crops. After grading was completed, the split peanuts were emptied into a designated drum and accumulated throughout the day. At the end of the day, the split peanuts were sampled using a riffle divider, and a sample weighing approximately 1 kg was extracted. The buying point of origin was masked, then sent to an independent laboratory (Eurofins Analytical Laboratories, Inc., New Orleans, LA) and tested for the presence of the heavy metals, arsenic, cadmium, lead, mercury, and nickel. Inductively coupled plasma-mass spectrometry (ICP-MS) was used to analyse for arsenic, cadmium, lead, and mercury (AOAC, 2013). Inductively coupled plasma-optical emission spectrometry (ICP-OES) was used to analyze for the presence of nickel (AOAC, 2011). Table 1 shows the limit of detection, the method reference, and reference values associated with each heavy metal tested.

The identity of the buying point remained anonymous with only the production region of origin identified in the subsequent analyses. Table 2 shows the number of samples collected by growing region and peanut market type, each survey year, and the number of participating buying points.

Table 2. Peanut samples collected each year, 2023-2025, for a heavy metal survey.

			Number of Annual Samples			
Region	Peanut type	Number of buying points	Runner-type	Spanish-type	Virginia-type	Total
Southeast (SE)	Runner	10	28	--	--	28
Southwest (SW)	Runner, Virginia, Spanish	3	6	3	3	12
Virginia-Carolina (VC)	Runner, Virginia	3	5	--	5	10
All U.S.	All	16	39	3	8	50

In the previous study by Blair and Lamb (2017), samples were collected in the same manner and tested for pesticide residues and heavy metals. An average of 97 samples were collected each year of the three-year study. Based on annual deliveries during 2013-2015 (GAFSIS, 2026), this represented approximately 0.5% of all loads delivered to market. In this study, a total of 50 samples were collected each year at 16 buying points distributed throughout the U.S. based on the amount and type of peanuts produced in each region (Table 2). Based on the deliveries and estimated average number of loads per day delivered to a buying point, these samples represented approximately 0.26% of the loads delivered to market during the 2023-2025 harvests and is similar to the sampling rate used by Blair (2025).

Statistical Analysis.

Assessment of heavy metal exposure is critical for food safety management, and accurate estimation of concentrations is essential. Measurements below the limit of detection (LOD) are treated as non-detects, resulting in left-censored data. In this study, the choice of statistical methods depended on the censoring rate, sample size, and underlying concentration distribution.

For analytes with no censored observations (i.e., cadmium and nickel in this study), standard descriptive statistics, including the censoring rate, minimum and maximum concentrations, sample mean, 95% confidence interval (CI) for the mean, and the 95% upper confidence limit (UCL95), assuming normality are reported.

Due to testing equipment detection limits, a substantial proportion of observations for lead and arsenic are left-censored. Approaches for handling censored data generally fall into two categories. The first involves simple substitution methods (e.g., replacing non-detects with zero, ½ LOD, or LOD). Although straightforward, these methods lack a strong theoretical foundation and may introduce bias, limiting their reliability (Barringer *et al.,* 2005; EFSA, 2010; Helsel, 2006). Therefore, substitution methods were not used in this study.

The second category comprises statistically rigorous methods, including Maximum Likelihood Estimation (MLE), the Kaplan–Meier (K–M) estimator, and Regression on Order Statistics (ROS). MLE is a parametric approach that assumes a specific distribution to estimate summary statistics for both detected and censored observations (Helsel, 1990). However, its performance can be unreliable when the assumed distribution is misspecified or when sample sizes are small (typically fewer than 30–50 detected values) (Helsel, 2012). Given that the largest sample size in this study is 28 per year from the southeast region and that the data exhibit substantial censoring, MLE was not considered appropriate.

The Kaplan–Meier method (Kaplan and Meier, 1958) is a nonparametric approach that does not require distributional assumptions. It assigns cumulative probabilities to detected observations while accounting for censored values. Simulation studies have demonstrated that the K–M method performs well in estimating means and confidence intervals for left-censored environmental data when the censoring rate is below approximately 70% (Singh *et al*., 2006; Antweiler and Taylor, 2008).

ROS is a semi-parametric method that combines distributional assumptions with observed data. It involves regressing ordered detected concentrations against theoretical normal quantiles and uses the fitted relationship to impute censored values (Helsel, 2012). These imputed values are then

combined with observed data to form a complete dataset for estimation of summary statistics.

Comparative studies (e.g., Chowdhury *et al.*, 2015; Helsel, 2012; Tekindal *et al.*, 2017) indicate that both K–M and ROS perform well when censoring is below 50% and sample sizes are small. As censoring increases (50–70%), ROS is generally more stable, as K–M requires sufficient detected observations to characterize the distribution tail. When censoring exceeds 70%, no method yields reliable estimates of summary statistics (Antweiler and Taylor, 2008).

Based on these considerations and the characteristics of the data (small sample sizes and varying censoring levels), ROS was used as the primary method for inference when applicable, with K–M results reported for comparison. Confidence intervals for the mean are estimated using bootstrap methods, which do not rely on distributional assumptions and preserve the empirical structure of the data. For both K–M and ROS, the mean concentration, 95% CI, and UCL95 are reported.

In cases where censoring is extreme and neither K–M nor ROS yields reliable estimates, alternative metrics are reported, including the probability that a randomly selected sample exceeds the detection limit and its 95% CI (Blair & Lamb, 2017).

Mean concentrations were evaluated at four levels of aggregation: (1) pooled across all years and regions; (2) pooled across regions within each year; (3) pooled across years within each region; and (4) stratified by both year and region. Pairwise comparisons were conducted using confidence intervals, where non-overlapping intervals are interpreted as evidence of statistically significant differences.

All statistical analyses and graphical visualizations were performed using R (version 4.4.2). The NADA package is used to implement the K–M and ROS methods.

RESULTS AND DISCUSSION

Arsenic

Chemical analysis revealed that 123 of the 150, or 82% of peanut samples tested below the 0.02 ppm limit of detection (LOD) resulting in a highly censored dataset. The frequency distribution of the observed concentration of arsenic is shown in Figure 1.

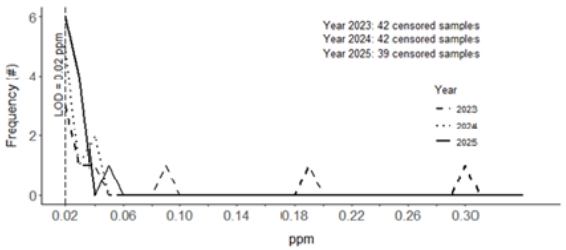

Figure 1. Frequency distribution of arsenic (EU limit = 0.20 ppm) in peanut samples collected in 2023, 2024, and 2025.

Statistical analysis showed that over the three-year period, a random sample of peanuts from any production region of the United States had an 82% likelihood of testing below the LOD for arsenic. The 95% CI ranged from 75 to 88% (Table 3). Blair and Lamb (2017) reported and overall arsenic censoring rate of 38%, which was much lower than the censoring rate of our survey. Over the course of the three-year study, the probability of a sample testing below the LOD ranged from 78 to 84% across all regions. The maximum observed concentration of arsenic in any peanuts was 0.30 ppm. The maximum arsenic concentration observed by Blair and Lamb (2017) was 0.41 ppm. Data by region and year for this study are shown in Table 3.

Table 3. Probability that a sample chosen at random will have a test result below the 0.02 ppm detection limit for arsenic.

Year	Region	Number	Censored (<0.02 ppm)	Probability Below LOD	95% CI for the Probability Below LOD
All	All	150	123	0.82	(0.7490, 0.8779)
2023	All	50	42	0.84	(0.7089, 0.9283)
2024	All	50	42	0.84	(0.7089, 0.9283)
2025	All	50	39	0.78	(0.6404, 0.8847)
All	SE	84	82	0.9762	(0.9166, 0.9971)
All	SW	36	15	0.4167	(0.2551, 0.5924)
All	VC	30	26	0.8667	(0.6928, 0.9624)
2023	SE	28	27	0.9643	(0.8165, 0.9991)
2023	SW	12	5	0.4167	(0.1517, 0.7233)
2023	VC	10	10	1	(0.6915, 1)
2024	SE	28	28	1	(0.8766, 1)
2024	SW	12	5	0.4167	(0.1517, 0.7233)
2024	VC	10	9	0.9	(0.555, 0.9975)
2025	SE	28	27	0.9643	(0.8165, 0.9991)
2025	SW	12	5	0.4167	(0.1517, 0.7233)
2025	VC	10	7	0.7	(0.3475, 0.9333)

Cadmium

There were no samples collected during the three-year study that tested below the 0.01 LOD for cadmium (Figure 2). The minimum level of cadmium detected during all three years in peanuts from all regions was 0.02 ppm while the maximum level was 0.32 ppm (Table 4). The 3-yr mean level of cadmium was 0.087 ppm. The 95% upper confidence limit (UCL95) was 0.096 ppm. Blair and Lamb (2017) reported the UCL95 for cadmium as 0.081 ppm. When looking at the yearly data, the mean cadmium concentration ranged from 0.0756 ppm in 2025 to 0.0936 ppm in 2023.

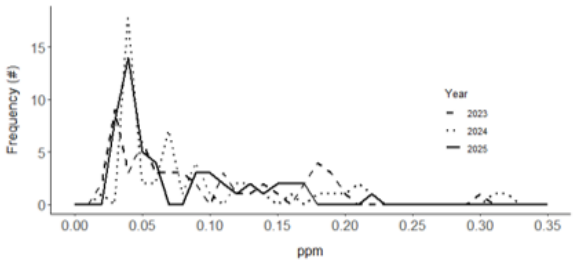

Figure 2. Frequency distribution of cadmium detected in peanut samples collected in 2023, 2024, and 2025.

Lead

During the 3-yr study, 110 out of 150 samples (73%) tested below the 0.02 ppm LOD for lead. Blair and Lamb (2017) reported that 94 out of 290 samples (32%) tested below the LOD. Of the remaining 40 samples in this study, one sample had the maximum observed concentration of lead, 1.10 ppm, which was more than 10 standard deviations of the mean for the pooled data (Figure 3). The next highest concentration observed was 0.28 ppm. Blair and Lamb (2017) reported a maximum concentration of 0.64 ppm. Data from the 2024 crop year had the lowest censoring rate (62%). When data were pooled across all locations, the mean concentration of lead and its confidence interval could only be estimated for the 2024 data due to the high level of censoring in 2023 and 2025. (Table 5).

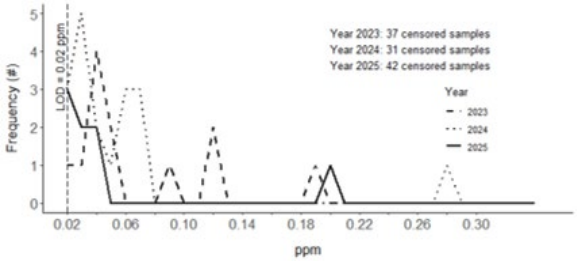

Figure 3. Frequency distribution of concentration of lead in peanut samples obtained in 2023, 2024, and 2025.

Table 4. Sample statistics and estimation results for the population mean (ppm) for cadmium 2023-2025.

Year	Region	Number	Censored	Minimum	Maximum	Mean	95% Confidence interval	UCL95
				---------- ppm ----------				
All	All	150	0	0.02	0.32	0.0873	(0.0773, 0.0972)	0.0957
2023	All	50	0	0.02	0.30	0.0936	(0.0758, 0.1114)	0.1090
2024	All	50	0	0.02	0.32	0.0926	(0.0731, 0.1121)	0.1094
2025	All	50	0	0.03	0.22	0.0756	(0.0621, 0.0891)	0.0873
All	SE	84	0	0.02	0.19	0.0525	(0.0452, 0.0598)	0.0588
	SW	36	0	0.04	0.30	0.1236	(0.1041, 0.1431)	0.1407
	VC	30	0	0.07	0.32	0.1410	(0.1183, 0.1637)	0.1610
2023	SE	28	0	0.02	0.18	0.0525	(0.0397, 0.0653)	0.0638
	SW	12	0	0.06	0.30	0.1592	(0.1249, 0.1934)	0.1919
	VC	10	0	0.07	0.19	0.1300	(0.1043, 0.1557)	0.1553
2024	SE	28	0	0.02	0.19	0.0550	(0.0410, 0.0690)	0.0674
	SW	12	0	0.07	0.22	0.1250	(0.0981, 0.1519)	0.1507
	VC	10	0	0.07	0.32	0.1590	(0.1022, 0.2158)	0.2150
2025	SE	28	0	0.03	0.15	0.0500	(0.0389, 0.0611)	0.0598
2025	SW	12	0	0.04	0.17	0.0867	(0.0605, 0.1128)	0.1117
2025	VC	10	0	0.09	0.22	0.1340	(0.1101, 0.1579)	0.1575

Table 5. Sample Statistics and Estimation Results for the Population Mean (ppm), Lead 2023-2025.

Year	Region	Number	Censoreda	Censoring rate	Maximum	Method	Mean	95% Confidence interval	UCL95
All	All	150	110	73.3	1.10 b		High censoring - CI not reported		
2023	All	50	37	74	1.10 b		High censoring - CI not reported		
2024		50	31	62	0.28	K-M	0.0344	(0.0022, 0.0578)	0.0540
						ROS	0.0269	(0.0171, 0.0409)	0.0378
2025		50	42	84	0.20		High censoring - CI not reported		
All	SE	84	75	89.3	0.04		High censoring - CI not reported		
	SW	36	16	44.4	1.10 b	K-M	0.0906	(0.0080,0.2180)	0.1996
						ROS	0.0820	(0.0387,0.1452)	0.1365
	VC	30	19	63.3	0.09	K-M	0.0267	(0.0013,0.0383)	0.0362
						ROS	0.0203	(0.0146, 0.0278)	0.0262
2023	SE	28	27	96.4	0.03		High censoring - CI not reported		
	SW	12	4	33.3	1.10b	K-M	0.1592	(0.0000, 0.4868)	0.4711
						ROS	0.1486	(0.0395, 0.3245)	0.3055
	VC	10	6	60	0.05	K-M	0.0270	(0.0000, 0.0449)	0.0433
						ROS	0.0216	(0.0133, 0.0307)	0.0295
2024	SE	28	24	85.7	0.04		High censoring - CI not reported		
	SW	12	3	25	0.28	K-M	0.0700	(0.0028, 0.1468)	0.1405
						ROS	0.0673	(0.0397, 0.1100)	0.1037
	VC	10	4	40	0.09	K-M	0.0320	(0.0014, 0.0594)	0.0566
						ROS	0.0278	(0.0156, 0.0418)	0.0394
2025	SE	28	24	85.7	0.03		High censoring - CI not reported		
	SW	12	9	75	0.20		High censoring - CI not reported		
	VC	10	9	90	0.03		High censoring - CI not reported		

Table 6. Probability that a Sample Chosen at Random Will Have a Test Result Below the Detection Limit for Lead of 0.02 ppm.

Year	Region	Number	Censored (<0.02 ppm)	Probability Below LOD	95% CI for the Probability Below LOD
All	All	150	110	0.7333	(0.6551, 0.8022)
2023	All	50	37	0.74	(0.5966, 0.8537)
2024		50	31	0.62	(0.4717, 0.7535)
2025		50	42	0.84	(0.7089, 0.9283)
All	SE	84	75	0.8929	(0.8063, 0.9498)
	SW	36	16	0.4444	(0.2794, 0.6190)
	VC	30	19	0.6333	(0.4386, 0.8007)
2023	SE	28	27	0.9643	(0.8165, 0.9991)
	SW	12	4	0.3333	(0.0992, 0.6511)
	VC	10	6	0.6	(0.2624, 0.8784)
2024	SE	28	24	0.8571	(0.6733, 0.9597)
	SW	12	3	0.25	(0.0549, 0.5719)
	VC	10	4	0.4	(0.1216, 0.7376)
2025	SE	28	24	0.8571	(0.6733, 0.9597)
	SW	12	9	0.75	(0.4281, 0.9451)
	VC	10	9	0.9	(0.5550, 0.9975)

When the lead contamination data are analyzed as highly censored data, the overall probability that a random sample of peanuts will test below the LOD was 73% (Table 6).

Mercury

There were no samples tested during the 3-yr survey that had a mercury level greater than the 0.01 ppm LOD. Blair and Lamb (2017) reported that 97% of samples collected tested below the LOD.

Nickel

All samples tested during the 3-yr survey had nickel concentrations greater than the 0.10 ppm LOD, therefore no samples were censored (Figure 4). The maximum observed concentration of nickel during the 3-yr study was 6.7 ppm (Table 7), well below the EU limit of 12 ppm. The maximum level was observed in a sample from the SE from the 2023 crop. Based these data, 1.23 ppm is the maximum likely (95% confidence) concentration of nickel to be in a random sample. Summary data by year and region are shown in Table 7.

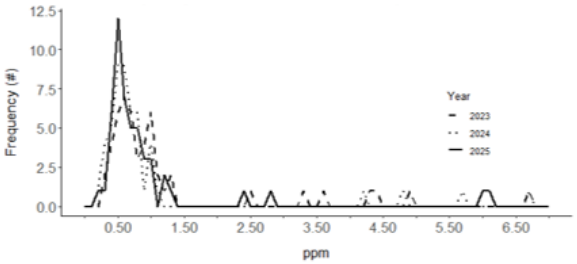

Figure 4. Frequency distribution of the concentration of nickel found in peanuts sampled in 2023, 2024, and 2025.

Table 7. Sample statistics and estimation results for the population mean (ppm), nickel 2023-2025.

Year	Region	Number	Censored	Minimum	Maximum	Mean	95% CI	UCL95
				---------- ppm ----------				
All	All	150	0	0.18	6.70	1.0593	(0.8556, 1.2630)	1.2319
2023		50	0	0.27	6.70	1.2334	(0.8670, 1.5998)	1.5500
2024	All	50	0	0.21	6.68	0.996	(0.6278, 1.3642)	1.3142
2025		50	0	0.18	6.15	0.9486	(0.6323, 1.2649)	1.2219
	SE	84	0	0.18	6.70	1.2157	(0.8754, 1.5560)	1.5063
All	SW	36	0	0.21	4.31	0.8444	(0.5762, 1.1126)	1.0789
	VC	30	0	0.48	1.34	0.8793	(0.8042, 0.9544)	0.9456
	SE	28	0	0.27	6.70	1.2800	(0.7037, 1.8563)	1.7900
2023	SW	12	0	0.39	4.31	1.3200	(0.6183, 2.0217)	1.9916
	VC	10	0	0.68	1.34	0.9990	(0.8718, 1.1262)	1.1244
	SE	28	0	0.32	6.68	1.2600	(0.6241, 1.8959)	1.8228
2024	SW	12	0	0.21	0.72	0.4967	(0.4177, 0.5756)	0.5722
	VC	10	0	0.56	1.14	0.8560	(0.7430, 0.9690)	0.9674
	SE	28	0	0.18	6.15	1.1071	(0.5563, 1.6580)	1.5947
2025	SW	12	0	0.37	1.28	0.7167	(0.5367, 0.8966)	0.8889
	VC	10	0	0.48	0.97	0.7830	(0.6709, 0.8951)	0.8935

Dietary exposure

The dietary exposure was calculated for each metal tested except mercury because there were no samples with detectable levels of mercury. The daily exposure was calculated by equation 1.

$$I_{daily} = \frac{ppm \times S}{BW} \quad (1)$$

where:

I_{daily} = *daily intake (µg/kg body weight)*

ppm= observed metal concentration (ppm = µg/kg$_{peanut}$*)*

S = serving size, 1 oz. = 28.35 g = 0.02835 kg

BW = body weight of individual

= 11.4 kg, child

= 75 kg, average adult U.S. female

The number of servings per day required to exceed the daily reference value for each metal was calculated using equation 2 assuming one serving of peanuts per day is consumed.

$$NS_{daily} = \frac{Ref}{I_d} \quad (2)$$

where:

NS_{daily} = number of servings per day required to exceed the daily reference value

Ref = the reference value (µg/kg bw)

I_{daily} = daily intake (µg/kg bw)

The reference values used were those listed in Table 1 based on recommendations by EFSA or FDA (Wong *et al.*, 2022).

The observed concentrations were derived from the summary statistics for each metal. More than 80% of samples tested below the LOD for arsenic, and no mean concentration was calculated (Table 3). Therefore, the 0.02 ppm LOD was used and represents a relatively high, but unlikely concentration of arsenic on average.

Lead concentration (Table 5) was another set that was highly censored, with 73% testing below the 0.02 ppm LOD. The UCL95 for lead was not consistent from year to year, nor by production region. Using the observed maximum concentration would represent a very conservative estimate of the risk associated with lead exposure. However, the maximum concentration of 1.1 ppm was more than 10 standard deviations above the mean concentration that tested above the LOD and may considered an outlier. The second highest observed concentration was 0.28 ppm. However, the most conservative estimate to determine exposure would be to use the observed maximum.

Cadmium (Table 4) and nickel (Table 7) concentrations had no censored data. Therefore, the UCL95 for all years across all regions were used as the observed concentration.

Based on the data collected in this three-year survey, at least 800 servings (1 oz/28 g) of peanuts would have to be consumed in a single day to exceed the daily reference values for any of the heavy metals tested for (Table 8). A child would have to consume 805 servings, or 23 kg, in a single day to exceed the reference daily intake. Similarly, an adult would have to consume 21,165 servings or 600 kg of peanuts in a single day. If the maximum observed concentration of 1.1 ppm for lead is considered an outlier and the next highest observed concentration of 0.28 ppm were used to determine dosing, the number of servings required to exceed the daily reference value a child would have to consume 3,160 servings or 90 kg of peanuts daily to exceed the current FDA recommendation for lead. An adult would have to consume 83,145 servings or 2.3 Mg (metric tons) of peanuts to exceed the recommendation for lead exposure for an adult.

Table 8. Dietary exposure to heavy metals based on observed concentrations in samples from 2023-2025.

Metal	Reference Value	Observed Concentration	Intake/serving	Daily consumption to exceed reference daily intake	
	µg/kg bw	ppm	µg/kg bw	Servings	kg
Arsenic	0.06	0.02	7.560E-06	7937	225
Cadmium	0.36	0.10	3.617E-05	9869	280
Lead					
Childa	2.20	0.28	2.736E-03	805	23
Adultb	8.80		4.158E-04	21165	600
Nickel	13.0	1.2	4.657E-04	27918	791

a Assume the child's weight = 11.4 kg
b Average U.S. adult female weight = 75 kg

SUMMARY

A survey to sample heavy metal concentration levels in peanuts was conducted during the harvest of the 2023-2025 crops. Fifty samples representing the daily deliveries of peanuts to peanut buying points in all peanut-producing regions of the U.S. were collected each year and tested for arsenic, cadmium, lead, mercury, and nickel. While the number of samples collected each year was somewhat limited, the fifty daily composite samples were conservatively estimated to represent 0.26% of the harvested crop each year. There were Runner, Spanish, and Virginia market types included in proportion to annual production. Based on the results, the likelihood of a random sample having a concentration of arsenic, lead, and mercury test below the respective limits of detection was 0.82, 0.73, and 1.00 respectively. The mean concentration of cadmium across all three years and all three production regions was 0.09 ppm. The mean concentration of nickel across all three years and production regions was 1.06 ppm. Based on a typical 28-g serving of peanuts and the observed concentration, consumers would have to consume a minimum of 3,160 servings or 90 kg daily to exceed any of the current daily reference values of any of the heavy metals.

ACKNOWLEDGMENTS

This survey was conducted with the cooperation of the Federal-State Inspection Services, throughout the peanut-producing regions of the United States. Sample collection was performed by multiple corporate members of the American Peanut Shellers Association. Funding was provided by the American Peanut Shellers Association.

LITERATURE CITED

AOAC. 2011. AOAC Official Method: AOAC 2011.14-2011 Calcium, copper, iron, magnesium, manganese, potassium, phosphorus, sodium, and zinc in fortified food products. https://www.aoacofficialmethod.org/index.php?main_page=product_info&cPath=1&products_id=2977. Accessed July 29, 2026.

AOAC. 2013. AOAC Official Method: AOAC 2013.06-2013 Arsenic, cadmium, mercury, and lead in foods. https://www.aoacofficialmethod.org/index.php?main_page=product_info&products_id=2925. Accessed July 29, 2026.

Antweiler R.C., and H.E. Taylor. 2008. Evaluation of statistical treatments of left-censored environmental data using coincident uncensored data sets: I. Summary statistics. Env. Sci. & Tech. 42(10): 3732–3738. doi:10.1021/es071301c.

Barringer J.L., Z. Szabo, Z., L.J. Kauffman, T.H. Barringer, P.E. Stackelberg, T. Ivahnenko, S. Rajagopalan, and Krabbenhoft D. P. 2005. Mercury concentrations in water from an unconfined aquifer system, New Jersey coastal plain. Sci. of the Total Env. 346(1–3): 169–183. doi: 10.1016/j.scitotenv.2004.12.017.

Blair B.F. 2025. Evaluating the presence of pesticide residues and associated health risks in US peanuts. Peanut Sci. 52(1):70-79. doi:10.3146/0095-3679-52.1-PS1614.

Blair B., and M. Lamb. 2017. Evaluating concentrations of pesticides and heavy metals in the U.S. peanut crop in the presence of detection limits. Peanut Sci. 44(1):1–9. doi: 10.3146/PS17-6.1.

Chowdhury F., J. Gulshan, and S.S. Hossain. 2015. A comparison of semi-parametric and nonparametric methods for estimating mean time to event for randomly left-censored data. J. Modern Appl. Statistical Methods. 14(1):Article 17.

EFSA - European Food Safety Authority. 2010. Management of left-censored data in dietary exposure assessment of chemical substances. EFSA J. 8(3):1557. doi: 10.2903/j.efsa.2010.1557.

EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain). 2010. Scientific opinion on lead in food. EFSA J. 8(4):1570. doi: 10.2903/j.efsa.2010.1570.

EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain). 2012. Scientific opinion on the risk for public health related to the presence of mercury and methylmercury in food. EFSA J. 10(12):2985. doi: 10.2903/j.efsa.2012.2985.

EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain). 2020. Update of the risk assessment of nickel in food and drinking water. EFSA J. 18(11):e06268. doi: 10.2903/j.efsa.2020.6268.

EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain). 2024. Update of the risk assessment of inorganic arsenic in food. EFSA J. 22(1): e8488. doi:10.2903/j.efsa.2024.8488.

FDA. 2025. Action levels for lead in processed food intended for babies and young children: Guidance for industry. U.S. Dept. Health and Human Services, Food and Drug Admin., Human Foods Program. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-action-levels-lead-processed-food-intended-babies-and-young-children. Accessed Aug 12, 2026.

GAFSIS. 2026. National Tonnage Reports. Georgia Federal State Inspection Service. https://www.gafsis.com/tonnage.php. Accessed July 29, 2026.

Helsel D. R. 1990. Less than obvious—Statistical treatment of data below the detection limit. Envi. Sc. & Tech. 24(12):1766–1774. doi: 10.1021/es00082a001.

Helsel D. R. 2006. Fabricating data: How substituting values for nondetects can ruin results, and what can be done about it. Chemosphere, 65(11):2434–2439. doi: 10.1016/j.chemosphere.2006.04.051.

Helsel D. R. 2012. Statistics for censored environmental data using Minitab and R (2nd ed.). John Wiley & Sons.

Järup L. 2003. Hazards of heavy metal contamination. British Med. Bull. 68(1): 167-182. doi: 10.1093/bmb/ldg032.

Kaplan E. L., and P. Meier. 1958. Nonparametric estimation from incomplete observations. J. Am. Statistical Assoc. 53(282):457–481. doi: 10.1080/01621459.1958.10501452.

Mahaffey K.R., P.E. Corneiussen, C.F. Jelinek, and J.A. Fiorino. 1975. Heavy metal exposure from foods. Env. Health Perspectives. 12:63-69.

Munir N., M. Jahangeer, A. Bouyahya, N. El Omari, R. Ghchime, A. Balahbib, S. Aboulaghras, Z. Mahmood, M. Akram, S.M.A. Shah, I.N. Mikolaychik, M. Derkho, M. Rebezov, B. Venkidasamy, M. Thiruvengadam, and M.A. Shariati. 2022. Heavy metal contamination of natural foods is a serious health issue: A review. Sustainability. 14(1):161-180. doi:10.3390/su14010161.

NPBPA. 2026. National Peanut Buying Points Association. https://www.peanutbuyingpoints.org. Accessed July 29, 2026.

Singh A., R. Maichle, and S.E. Lee. 2006. On the computation of a 95% upper confidence limit of the unknown population mean based upon data sets with below reporting limit observations. Lockheed Martin Environmental Services.

Tekindal M. A., B.D. Erdoğan, and Y. Yavuz. 2017. Evaluating left-censored data through substitution, parametric, semi-parametric, and nonparametric methods: A simulation study. Interdisciplinary Sci: Computational Life Sci. 9(2): 153–162. doi: 10.1007/s12539-015-0132-9.

Wani A.L., A. Ara, and J.A. Usmani. 2015. Lead toxicity: a review. Interdiscip. Toxicol. 8(2): 55-64. doi: 10.1515/intox-2015-0009.

Wong C., S.M. Roberts, and I.N. Saab. 2022. Review of regulatory reference values and the background levels for heavy metals in the human diet. Reg. Toxicol. Pharm. 130: 105122. doi: 10.1016/j.yrtph.2022.105122.