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Reductions in spice lead levels in the republic of Georgia: 2020–2022

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ABSTRACT

Spice adulteration using yellow lead chromate-based pigments has been documented as a growing global health concern. Spices from the Republic of Georgia with extremely high levels of lead, up to an order of magnitude higher than any other spices worldwide, have been implicated as sources of child lead poisoning. The objectives of this study were to 1) evaluate lead concentrations in spices sampled across the country of Georgia between 2020 and 2022, and 2) assess factors associated with spice adulteration, specifically the role of spice quality and regulatory enforcement. Spice samples were collected from 29 cities nationwide. The most populous cities were selected in each administrative region as well as those of importance to the spice supply chain. Sampling was carried out at the largest spice bazaars in each city. The regions of Adjara and Imereti were the focus of qualitative interviews conducted in 2021 with key businesspeople selling spices with very high and low levels of lead. The same cities and bazaars were visited at each of three sampling periods between 2020 and 2022. In total, 765 spice samples were collected. Lead concentrations in spices decreased over time, with a maximum of 14,233 μg/g in 2020 down to 36 μg/g in the final sampling round of 2022. A logistic regression determined that sampling round, region and spice type were associated with elevated lead in samples. Samples from Adjara and those containing marigold had the highest lead levels. Interviews with eighteen prominent spice vendors revealed difficulties sourcing sufficient quantities of high quality, brightly colored marigold, and concerns about adulteration. Interviews with two authorities from the National Food Authority highlighted the increased attention on regulating lead in spices since 2018. Continued monitoring and periodic regulatory enforcement may adequately disincentivize further adulteration with lead chromate in the spice industry in Georgia.

1. Introduction

Adulterated foods have been a source of public health concern for centuries (Wilson, 2008). Food adulteration refers to the practice of enhancing the perceived quality or quantity of a food in order to increase profits by lowering production costs or increasing sales (Moore et al., 2012). Additives to augment quality or quantity can be non-toxic, such as in the dilution of milk with water, or extremely toxic, such as adding lead chromate to spices to enhance their yellow color (Forsyth et al., 2019a,b; Spink and Moyer, 2011). Spices are one of the most commonly adulterated food types because they are expensive, often used for aesthetic purposes, such as adding color to dishes, and typically processed into a powder prior to sale (therefore easy to falsify) (Moore et al., 2012; Petrakis et al., 2017).

Spices from the Republic of Georgia have had some of the highest levels of lead among spices from all over the world, especially those containing the yellow marigold flower (*kviteli kvavli*) also known as Georgian saffron. A decade-long sampling effort in New York City linked spices, especially those hand carried from Georgia, with lead poisoning (Hore et al., 2019). Among all lead-containing spices sampled, 27% were from Georgia. More than 20 samples contained lead levels above 10,000 μg/g with a maximum of 48,000 μg/g. A lead concentration of 48,000 μg/g exceeds the Georgian national limit by nearly 10,000 times and is equivalent to 4.8% lead by weight. The extremely high lead concentrations and the yellow hue of marigold suggests adulteration with lead chromate pigments.

There is no safe level of lead exposure; lead is toxic at all levels. Exposure to lead during early childhood has a negative, irreversible, and

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long-term effect (Bellinger, 2013). Lead harms nearly every system in the body, including the circulatory, endocrine, renal, immune, reproductive, and nervous systems (Mishra, 2009; Needleman, 1991). Pooled longitudinal data from 1333 children under 10 years of age indicate that children with blood lead levels 2.4–10 μg/dL had subsequent IQ scores 3.9 points lower than children with <2.4 μg/dL (Lanphear et al., 2005). It is estimated that the IQ deficit of children from lead exposure results in economic losses totaling approximately $977 billion per year in low- and middle-income countries. In Georgia alone, the economic loss is estimated to be 2% of GDP ($427 million) (Attina and Trasande, 2013).

There has been considerable attention to the issue of lead exposure in the country of Georgia in the past 5 years. In 2018, the Georgian National Center for Disease Control and Public Health (NCDC) and UNICEF completed a nationally representative assessment of 1578 children's blood lead levels. The study found that 41% of children 2–7 years old had blood lead levels above the World Health Organization's guidance of 5 μg/dL. Children living in the Adjara region of western Georgia had the highest lead levels, with 85% of them exceeding this level (Georgia Multiple Indicator Cluster Survey, 2019). A small study of a subset of 25 of these children suggested that lead-tainted spices were a predominant source of exposure.

Despite evidence that lead exposure is high in Georgia, and that spices play a role, there have not been any nationwide assessments of spice lead levels. The objectives of this mixed-methods study, combining quantitative assessments of spices and qualitative interviews, were to i) evaluate lead concentrations in spices across Georgia between 2020 and 2022, and 2) assess factors associated with spice adulteration; specifically the role of spice quality and regulatory enforcement.

2. Materials and methods

2.1. Spice supply chain overview

In June 2020, the research team met with major spice producers and government officials to map the supply chain, including hubs of spice distribution and sale in the Republic of Georgia. The cities of Batumi (Adjara region) and Kutaisi (Imereti region) and the capital city of Tblisi were identified as hubs of spice production, packaging, and distribution. At that time, 200 spice vendors were registered with the government: two large companies (GEO and FALCON), five mid-sized companies, and the rest smaller companies and individual entrepreneurs.

Approximately 80% of spices sold in Georgia were being imported from India, Kazakhstan, Uzbekistan, Russia, and Ukraine. The rest of the spices were grown domestically, predominantly marigold as well as some coriander, blue fenugreek and pepper.

The majority of consumers purchase spices at open bazaars, where they are scooped from large 5–10 L bins or sold in small plastic packets. Fewer consumers purchase spices at major supermarkets where they are sold as packaged branded spices. At open bazaars, the focus of this study, spices and spice mixes are sold in their ground, powder form instead of as whole spices.

2.2. Quantitative assessment: spice lead levels

We used a systematic, non-probability-based sampling approach aiming to maximize geographic spread and the diversity of samples collected. Nationwide spice sampling took place in the autonomous republic of Adjara, the capital city of Tblisi, and eight of the nine administrative regions of the Republic of Georgia: Guria, Imereti, Kakheti, Kvemo Kartli, Mtskheta-Mtianeti, Samegrelo-Zemo Svaneti, Samtskhe-Javakheti, and Shida Kartli. In each region, the largest cities were identified, those with populations of at least 10,000 people for a total of 29 cities.

Sample collectors visited each of the 29 cities and identified the largest spice bazaar. At each bazaar, sample collectors visited every fifth vendor and purchased 50 g of each spice type available, including spice mixes and single spices sold loose, packaged, or branded. When multiple forms of a spice were available, all were purchased (e.g., dried marigold petals and ground marigold). The spice type, price, vendor location, and packaging information was recorded. Any additional information about spice sourcing or processing was also recorded.

Spice sampling occurred over three time periods, each separated by approximately 6–12 months: 1) June 2020–March 2021, 2) April–May 2022, and 3) November–December 2022. Repeat sampling was conducted with the same vendors.

Spice lead levels were assessed using a portable X-Ray Fluorescence (XRF) analyzer (Niton XL3t 700S GOLDD) which has previously been determined to be accurate within 5% of laboratory results for powdered spices (Lopez et al., 2022). The portable XRF has a limit of detection of approximately 2 μg/g lead. Samples were measured in triplicate and an average lead concentration was used for analyses. Any sample that was below the limit of detection for lead in any one of the triplicate measurements was deemed to have non-detectable lead levels.

Pigment vendors were visited in the cities of Tblisi and Batumi and available yellow pigments were purchased. Lead and chromium levels were measured at the Multitest Testing Laboratory in Tblisi, Georgia. Pigment powder samples were microwave digested with nitric acid and hydrogen peroxide and measured via inductively coupled plasma-optical emission spectrometry.

A logistic regression was conducted to assess the relationship between the presence of lead in spice samples (binary outcome variable) and exploratory variables like the spice type (marigold-containing spices versus other spices), region (Adjara versus other regions), round of sampling (first round versus second or third round), and spice price in Georgian Lari (GEL) per 100 g.

2.3. Qualitative interviews: practices of spice adulteration and regulatory enforcement

Qualitative semi-structured interviews were conducted in 2021 after the first spice sampling period to better understand the practices and incentives of spice adulteration. A trained social scientist and native Georgian interviewed wholesalers, retailers, grinders, packers, and distributors of spices, as well as governmental food safety inspectors and wholesale vendors selling yellow pigments. The interviews explored factors associated with spice adulteration, with questions probing perceptions of and preferences for marigold quality. The focal region was western Georgia due to the elevated spice and blood lead levels from past research, and because it is a hub of spice production. Initial interviewees were identified based on the results from the spice sampling from the first round in 2020 and included vendors selling spices with the highest and lowest lead concentrations. The interviewer was blinded to that information to avoid bias. Additional interviewees were identified using a snowball sampling approach stemming from each interview.

To understand the role of regulation, semi-structured interviews were conducted with the National Food Agency (NFA) representatives and law officers involved in monitoring and enforcing food safety rules. The interview protocol focused on daily operations, food safety priorities and frequency of monitoring activities.

Interviews were conducted in Georgian by a single trained qualitative researcher. The same researcher transcribed the audio-recorded interviews, translated them into English, and shared summaries. We coded the interview data using a priori (deductive) and emergent (inductive) coding processes guided by our interest in factors associated with spice adulteration. We obtained written informed consent from all study participants. The study protocol was reviewed and approved by the ethical review committee at the National Center for Disease Control, Georgia.

2.4. Efforts to reduce lead in spices: government training and information sharing

In November 2021, the Pure Earth team in Georgia conducted a technical training for food safety regulators, including the NFA, the City of Tbilisi's Food Safety Agency, and regional government representatives. This training provided information on lead-adulterated spices and pigments, and guidance on measuring lead in spices in a laboratory and with a portable XRF. The team produced a brochure on the health hazards of lead chromate and the relevant Georgian laws, which was distributed to regulators and spice vendors in Tblisi and Batumi. Lastly, the team shared information on the spice adulteration problem in Georgia with the public through social media. In June 2022, the Pure Earth team held a second workshop with international and local stakeholders including the NFA and the NCDC. The preliminary results of this study and recommendations were shared during the workshop.

3. Results

3.1. Quantitative assessment: spice lead levels

In total, 765 samples of spices were collected, with 255 collected at each of the three sampling periods between 2020 and 2022. A total of 15 different spices were collected from 77 vendors across 29 cities. The most sampled spices were marigold (n = 184), followed by marigold-containing spice mixes (*svaneti* salt (n = 164) and *kharchos suneli* (n = 124)), and red pepper (n = 123). Marigold was sold predominantly as a loose powder, except for four samples which were sold as dried petals. For the purposes of analysis, we categorize spice types into three categories: pure marigold, spice mixes containing marigold (*ajika*, *kharchos suneli*, *khmeli suneli*, *khortsis suneli*, *satsivi suneli*, and *svaneti* salt) and other spices (red pepper, blue fenugreek, cumin, curry, paprika, saffron, sumac, and turmeric). (Table 1).

Spice lead concentrations decreased by the last sampling round, with a maximum of 14,233 μg/g in 2020 to a maximum of 36 μg/g in the final sampling round of 2022. The percent of samples exceeding the regulatory limit of 6 μg/g ranged from 4 to 6% in the first two sampling rounds and decreased to 1% by the final sampling round. In the first and second sampling rounds, 10–14% of samples from Adjara had lead levels exceeding the regulatory limit compared to only 1–2% in other regions. By the third sampling round in 2022, 1% of samples from both Adjara and other regions had lead levels greater than 6 μg/g (Table 1).

The logistic regression determined that sampling round, region and spice type were associated with the presence of detectable lead in samples (Table 2). Although there was no statistical difference between the presence of lead in spices in the first and second sampling rounds, the odds of having lead in spices was 76% lower in the third sampling round in 2022 compared to the first sampling round in 2020 (OR: 0.24, 95% CI: 0.09–0.62, p = 0.003). Compared to the Adjara region, spices from elsewhere in Georgia had 68% lower odds of being lead-tainted (OR:0.32, 95%CI: 0.18–0.58, p < 0.001). Indeed, spices from Adjara had the highest overall lead concentrations (Figs. 1 and 2; 14,233 μg/g in Adjara versus a maximum of 2416 μg/g from other regions. Notably, the sample of marigold with 2416 μg/g from the Khaketi region was being used for display purposes but the vendor willingly sold the sample upon request.) Across all regions, spice samples without marigold had 67% lower odds of being lead-tainted than marigold-containing spices (OR: 0.33, 95%CI: 0.14–0.76, p = 0.009) (Fig. 3).

Spice samples with the highest lead concentrations, above 100 μg/g also had detectable chromium in a nearly 1:1 M ratio suggestive of lead chromate adulteration. Of the five pigment samples collected, two of the yellow powders appeared to be lead chromate-based pigments with excessively high lead and chromium concentrations up to 19.5% lead by weight.

Table 1
Summary of spice lead concentrations by spice type and region over three sampling periods from 2020 to 2022. All median values for spice lead concentrations were below the limit of detection of 2 μg/g (ND = non-detectable). Values represent averages of triplicate measures with a median RSD = 12%.

		Lead concentration (μg/g)			
Samples (n)		P90	P95	Max	%>6 μg/g [a]
1st Round - 2020					
Adjara					
Marigold	28	10	14	218	14
Marigold Spice Mixes	36	6	674	14,233	8
Other Single Spices	29	ND	11	5209	15
Other Regions					
Marigold	43	ND	ND	133	2
Marigold Spice Mixes	74	ND	3	100	1
Other Single Spices	45	ND	ND	4	0
2nd Round - 2022					
Adjara					
Marigold	29	10	25	34	14
Marigold Spice Mixes	37	12	17	35	22
Other Single Spices	27	ND	5	6	4
Other Regions					
Marigold	49	ND	ND	9	2
Marigold Spice Mixes	71	ND	4	2,416[b]	3
Other Single Spices	42	ND	ND	5	0
3rd Round - 2022					
Adjara					
Marigold	29	ND	ND	ND	0
Marigold Spice Mixes	37	ND	ND	3	0
Other Single Spices	27	ND	ND	36	4
Other Regions					
Marigold	49	ND	ND	5	0
Marigold Spice Mixes	71	ND	ND	9	1
Other Single Spices	42	ND	ND	ND	0
GRAND TOTAL	**765**	**ND**	**4**	**14,233**	**4**

[a] Threshold in Georgia was set at 6 μg/g as of 2020.
[b] The vendor reported that this sample with 2416 μg/g was an old spice mix manufactured several years prior, being used for display purposes to attract buyers.

Table 2
Logistic regression with the spice lead status (above or below the detection limit of 2 μg/g) as the outcome variable.

Variables	Adjusted Odd Ratio	95% CI	p-value
Spice Type (non-marigold)	0.33	(0.14, 0.76)	0.009
Price (GEL/100g)	0.88	(0.61, 1.27)	0.484
Region (non-Adjara)	0.32	(0.18, 0.58)	<0.0001
Round			
2nd Round 2022	1.16	(0.61, 2.23)	0.652
3rd Round 2022	0.24	(0.09, 0.62)	0.003

3.2. Qualitative interviews: spice quality and regulatory enforcement

Results from the qualitative interviews are summarized in Table 3.

3.2.1. Spice quality and quantity

Eighteen prominent spice vendors were interviewed from two regions: Adjara and Imereti. The vendors sold spices along with teas and confections. Ten of the respondents had been involved in the spice industry for more than 10 years, and the others had 1–5 years of experience. All were registered with the government either as sole entrepreneurs or limited liability corporations. Most respondents' families had been involved in the spice business for decades. Six respondents were female. The average age of respondents was 49 (s.d. ± 12.6) years old.

For the majority of respondents, marigold was the only spice that they sourced independently (in the form of dried petals) and then ground themselves and packed for sale. Other spices were predominantly sourced from intermediaries or larger companies, primarily GEO

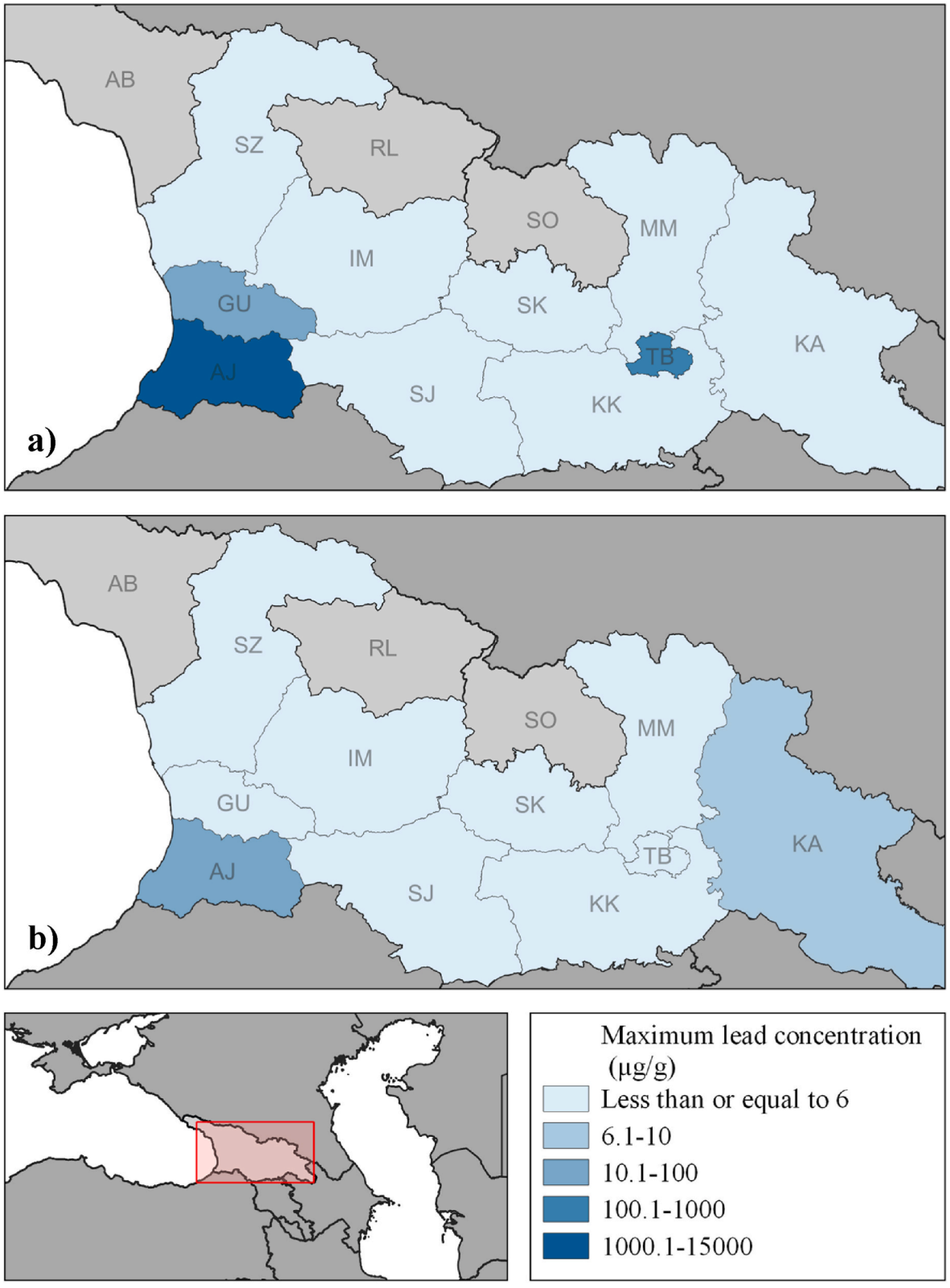

Fig. 1. Map of maximum lead concentrations in spices by region[1] in the first sampling round of 2020 (a) and the third sampling round of 2022 (b).

[1]AJ = Adjara, GU = Guria, SZ=Samagrelo-Zemo Svaneti, AB = Abkhazia (not sampled), RL = Racha Lechkhumi and Kvemo Svaneti (not sampled), IM=Imereti, SJ=Samtskhe Javakheti, SK=Shida Kartli, SO=South Ossetia (not sampled), MM = Mtskheta-Mtianeti, TB=Tblisi, KK=Kvemo Kartli, KA=Kakheti. The designations employed and the presentation of material on this map and article do not imply the expression of any opinion whatsoever on the part of the authors concerning the legal status of any country, territory, city or area or its authorities, or concerning the delimitation of its frontiers or boundaries.

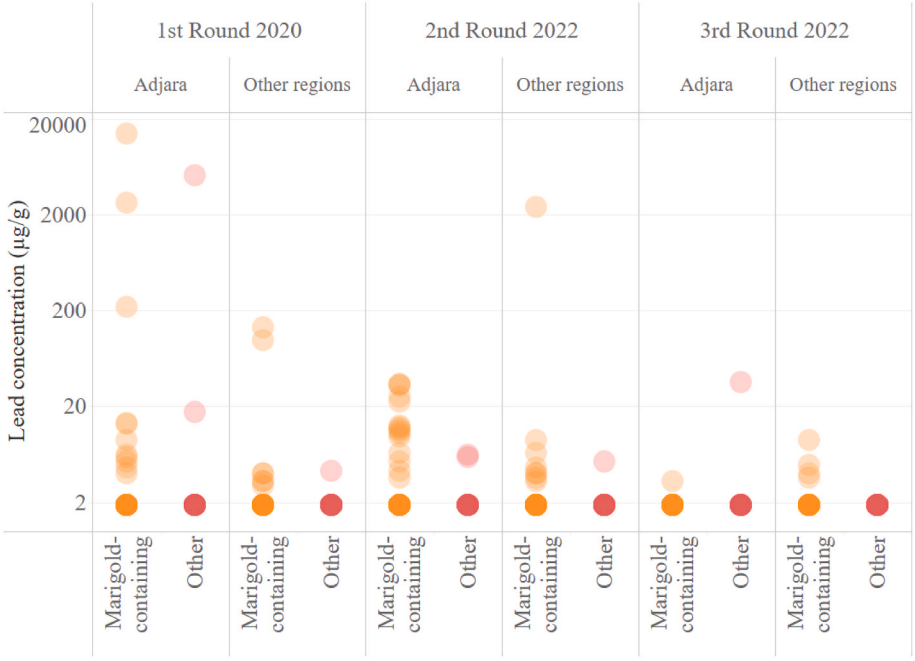

Fig. 2. Dotplot showing the distribution of lead concentrations in spices (marigold-containing or other spices) by region (Adjara vs. all other regions) over time: 2020–2022.

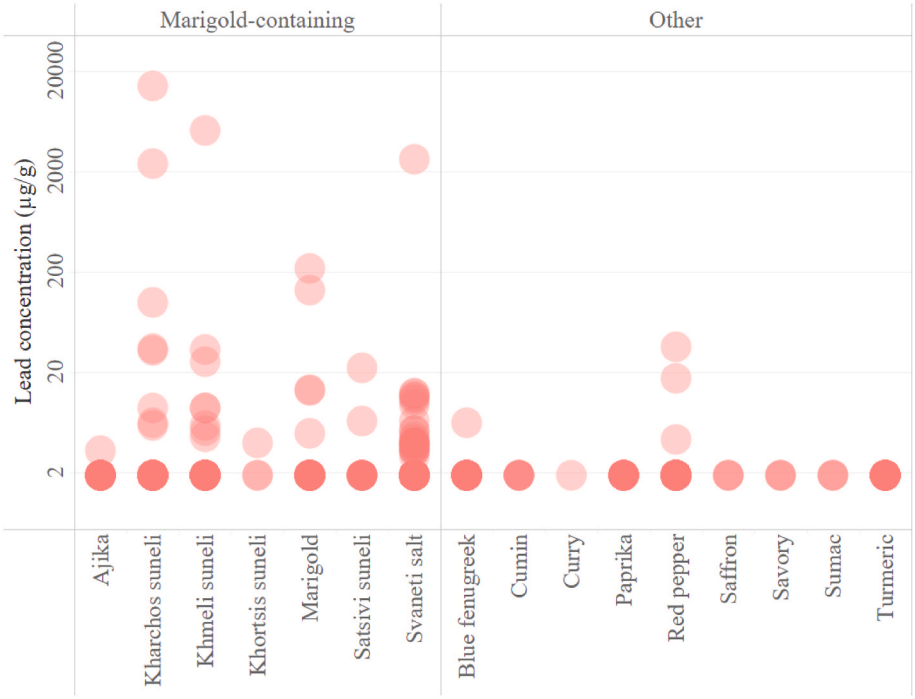

Fig. 3. Dotplot showing the distribution of lead concentrations in spices by type, combined data for all three data collection periods.

Ltd. The respondents noted that they purchased spices by weight, frequently in large quantities (tens of kilograms), but when they sold the spices, they would be pre-packed or scooped from a cup (not weighed) when sold in small quantities (50 g).

When asked about what attracts their customers, respondents mentioned ensuring that their spices have a "good" color and that their spice mixes have a unique taste according to family recipes. In Adjara there is a large tourist industry and hotel owners tell tourists which bazaars to visit and where to get spices. Vendors spoke of different types of advertising and ways to attract tourists: utilizing nice packaging, signs and displays, and one proudly spoke of a YouTube channel with videos of their spices.

A group of five spice traders based out of Adjara owned and operated the businesses selling lead-tainted spices and were responsible for more than half of all spice distribution within the Adjara region. These individuals were related and one trained the others in business practices. Although they did not admit to adding lead chromate or other additives, the quantitative sampling data indicated that the spices from these individuals contained the highest lead concentrations in 2020. All five were officially registered with the government: four as sole

Table 3
Factors affecting incentives for spice adulteration based on qualitative interviews spice vendors and government officials (n = 20).

Theme	Sub-theme	Examples and quotes
Spice quality and quantity	Color	Spice vendors mentioned that spices must have a good color to attract customers. Color is of particular importance for certain spices like marigold.
	Smell and taste	"The reason why I got involved in the spice business is that when I was buying dried coriander or any other spices, they had neither smell nor taste. That's why I decided to buy good spices for myself and sell them to customers as well." (Vendor 1)
	Form	Spice vendors noted the importance of purchasing marigold and other spices in their whole form. "Quality is very important for me. That's why I buy everything either dry flower, leaf or seed and grind them by myself, with the grinder I have here." (Vendor 2)
	Supply	Unlike other spices, marigold is completely sourced within the country. As a result, there are frequent shortages, and the price can vary by 40% or more.
Inspection and law-enforcement	Frequency	Inspections have taken place in Georgia since 1993 but intensified after 2003 and then again in 2018 due to changes in government priorities.
	Focus	During inspections it was unclear exactly what was being checked or what tests were performed on samples. Some spice vendors had heard about lead in spices but felt it was a government tactic to damage their business reputation and reduce demand.
	Follow-through	Fines varied according to the violation, from a small amount equivalent to the price of a kilogram of marigold for packaging violations, to extremely high fines, requiring up to five years to repay, for violations like lead contamination.

entrepreneurs and one as a limited liability corporation. The difference between the two registrations primarily relates to taxation. There were no specific requirements to set up spice businesses, anyone could do it so long as they paid the associated fees.

To ensure quality, respondents spoke of maintaining freshness (small supply purchased frequently), having trusted sources, and most importantly, grinding the spices themselves from their whole form. For example, one vendor remarked: "Quality is very important for me. That's why I buy everything either dry flower, leaf or seed and grind them by myself, with the grinder I have here."

Quality of spices related to the attributes like color, smell, and taste. Color was repeatedly mentioned as being of particular importance for marigold, which varied from a light yellow to dark yellow-orange hue according to breed. Respondents mentioned some difficulties finding high quality spices. One respondent said, "The reason why I got involved in the spice business is that when I was buying dried coriander or any other spices, they had neither smell nor taste. That's why I decided to buy good spices for myself and sell them to customers as well."

Several issues were mentioned related to accessing high quality marigold. First, the marigold supply struggled to meet demand in the country because it is grown on small plots of land in mountainous villages and not cultivated in large commercial farms. There is often a shortage of marigold and the price can vary by 40% or more based on supply and quality. Second, since marigold is one of the most expensive spices with high demand but limited supply, additives or substitutes may be used. Respondents did not disclose details about types of additives and none confessed to adding them themselves, however some noted the use of turmeric powder in place of marigold in spice mixes.

Several respondents mentioned a water test technique to check if marigold is falsified with additives. The respondent said that if marigold powder is mixed with water, it should not sink so any powder that sinks indicates an additive. This was in part due to the nature of the ground petals. As one respondent described: "You should observe the consistency of the powdered marigold. It should always keep the dried flower consistency. It doesn't matter how much you grind it, never becomes 100% powder."

3.2.2. *Inspection and law enforcement*

In addition to the eighteen spice vendors, two leaders from the NFA were interviewed. These two individuals had roles in overseeing the national inspection program and priorities. Inspection visits ranged in frequency from every few days to several times a year. According to the NFA respondents, inspectors generally focus on hygiene, and plant and animal protection but did not always require sampling. Inspections have taken place in Georgia since 1993 but intensified after 2003 due to changes in government priorities.

Between 2015 and 2018, the NFA reported that all lead-containing spices came from the town of Zugdidi. In 2018, they reported tested 1176 food samples (presumably from a nationwide sampling effort) and of these, 2% (23 samples) contained lead. The lead-containing foods included 15 samples of milk and 8 samples of spices. According to sampling in 2019, several types of spices contained between 5 and 7 μg/g lead (*ajika* and *khmeli suneli* which contain marigold, and red pepper).

At this time, the agency required spice vendors in open bazaars to sell their spices in a packed and labeled form. In 2020, this requirement was removed as the risk level was deemed to have decreased to an acceptable threshold. In 2018, the NFA again identified spice lead levels of concern in Adjara, prompting fines and possibly jail time for perpetrators. The details about the incident and the number of violations for elevated spice lead levels were not disclosed.

According to the eighteen spice vendors, when the NFA inspections increased in 2018, it was not clear exactly what was being checked, what tests were performed on samples, and how much follow-through there was. Vendors mentioned checks for cleanliness, labels and expiration dates on packages, as well as chemical constituents like nitrates, nitrites, and lead. Several vendors expressed skepticism about the NFA mandates and the accuracy of their tests. One respondent mentioned that the NFA fined them for elevated lead levels. To confirm the results, the vendor sent samples to another laboratory but no lead was detected. Other vendors had heard about lead in spices but felt it was a government tactic to damage their business reputation and reduce demand. Generally, fines varied according to the violation, from a small amount equivalent to the price of a kilogram of marigold for packaging violations, to extremely high fines, requiring up to five years to repay, for violations like lead contamination.

4. Discussion

Results from over 700 samples of spices collected across Georgia from 2020 to 2022 indicated that lead concentrations decreased over time. In the first and second sampling periods, 4 and 6% of samples had elevated lead concentrations and this decreased to 1% by the last sampling period in 2022. Similarly, the maximum lead level reduced from 14,233 μg/g in 2020, suggestive of adulteration with leaded pigments, to 36 μg/g in 2022. Lead levels varied by spice type and region, with spice lead levels higher among marigold-containing samples from Adjara in western Georgia. Interviews suggested that quality concerns and an emphasis on marigold color may have contributed to the practice of adulterating marigold-containing spices. The food safety authority focused on checking for lead-tainted spices since 2018 with inspections and fines.

Up until the late 1990s, gasoline was a major source of lead exposure worldwide (Lovei, 1998). Georgia successfully phased out lead in gasoline in 2000. For the past two decades, however, spices emerged as a dominant source of lead exposure both in Georgia and abroad. In

Georgia, a study of 25 children with high and low BLLs concluded that spices were the most likely source of exposure: 42% of the spice samples from the children's homes had elevated concentrations above 6 μg/g and 17% spice samples had more than 1000 μg/g (Ericson et al., 2020). In the U.S., Georgian spices purchased abroad have been linked with child lead poisoning. The earliest study in 2005 identified six lead poisoned children in Boston, Massachusetts whose parents had purchased lead-containing Georgian spice mixes containing marigold (*svaneti* salt and *kharchos suneli*) from a street vendor in Tbilisi (Woolf and Woolf, 2005). Lead levels in those spices ranged from 100 to 23,100 μg/g. In 2019, children from Los Angeles, California presented at the pediatrician with elevated blood lead levels and the source was found to be another Georgian spice mix containing marigold (*khmeli suneli*). The mix was purchased at a market in Los Angeles between 2017 and 2018 and contained 5000–21,000 μg/g lead. This was notable because it was the first time that the spice had been procured from a source in the United States instead of being hand-carried from Georgia.

There is some evidence that child blood lead levels declined across Georgia between 2018 and 2019. Median blood lead levels reduced by 29% (median of 9.6 to 6.8 μg/dL) among 423 children with elevated blood lead levels in 2018 (Ruadze et al., 2021). There was not a comprehensive sampling of spices across the Georgia in 2018–2019, but if spices were the predominant source of child lead poisoning in 2018 as they had been hypothesized, it is possible that spice lead levels may have been even higher 1–2 years prior to this study.

Awareness campaigns and regulatory actions may have led to declining lead levels in spices during the study period. Since the 2018 discovery of elevated blood lead levels among children in Georgia, the NCDC and UNICEF conducted awareness-raising campaigns and the NFA supposedly fined spice vendors with elevated lead levels. Awareness-raising efforts included press conferences, public information shared informally via Facebook and more formally via official organization websites and news channels, as well as during house-to-house visits by the NCDC. The messages have clearly stated that consumers should be wary of loose spices and lead has been found in the spices. Another aspect is the regulatory action by the NFA that ramped up around 2018 per the interviewees in this study. Given the small number of individuals and business entities linked with lead-tainted spices and the small country size of only 4 million people, it is possible that the fines and increased attention to the matter disincentivized the businesspeople from further adding lead chromate-based pigments.

An effort to reduce lead in spices in Bangladesh utilized similar tools: public information and improved regulatory enforcement, alongside the government's use of a rapid screening technology (Forsyth et al., 2023). In Bangladesh, fining the perpetrators involved a widely publicized spectacle that had been recorded and broadcasted on major news channels. In Georgia, however, there is no public proclamation or report of the penalties imposed on perpetrators. Instead, the interviews and communication with stakeholders shed light on this aspect.

Despite reductions in lead levels in spices during the study period, lead chromate pigments were available in the country. Lead chromate-based pigments are traded widely and typically used in yellow industrial paints (e.g., traffic markers) in low-, middle- and high-income countries (Saha et al., 2011). Lead chromate has been banned as a food additive in high-income countries since the early 1900s (Burrows, 2009). European countries are increasingly pressuring paint manufacturers to make yellow paints without lead chromate (Coatings World, 2012). Given the ongoing possibility of unscrupulous businesspeople using these pigments in food, a next step in Georgia could be to exercise more governmental control over lead chromate pigments, restricting their sale or banning them entirely.

There is a wide range of acceptable lead limits in spices worldwide. The NFA set a maximum allowable lead concentration for spices at 5 μg/g in 2021 and has since been developing plans to lower the limit further. In the U.S., the limit of 0.1 μg/g lead is used for spices, which is the standard set for candy (Cowell et al., 2017). Elsewhere, limits of lead in spices range from 2.5 μg/g in Bangladesh to 10 μg/g in India (Forsyth et al., 2019a,b; Cowell et al., 2017). Since lead has no physiological purpose and causes harm at any level, there is no safe level of lead in spices. Setting legal limits requires a consideration of health risks, the availability of measurement technologies and their limits of detection, and the spice industry's ability to comply. Spices may be contaminated unintentionally via ambient lead in dust and soil or from intentional adulteration with lead-containing pigments. Further investigation to understand the level of lead in spices from "natural" contamination could help establish achievable levels from the perspective of spice processors.

The primary limitation of this study was that respondents did not provide details about personal involvement in spice adulteration. Therefore, some details remain unclear despite collecting information and conducting interviews with the key informants in the country. First, interviewees never admitted to adding lead chromate-based pigments even though many of them were the sole business owners packing spices with elevated levels of lead and chromium. The interviewees only talked about additives and tests for purity in general terms. This could imply that those business owners were not the ones who added the yellow pigments or just that they were not comfortable discussing the matter. Second, it remains unclear which incentives were driving the addition of yellow lead chromate-based pigments – whether it was being added to enhance color, weight, or likely both. Given the interviewees' emphasis on the importance of marigold's color and difficulties sourcing marigold, it would make sense for the pigment to be added to enhance color. Due to the extremely elevated lead concentrations in marigold-containing samples (>10,000 μg/g), lead chromate could have also been added for weight. Spices were pre-packed or sold by the "scoop" (volume not weight) at the bazaars, though they were sold by weight to vendors from distributors. It is possible that distributors added the lead chromate and not vendors themselves. Either way, continued monitoring and periodic regulatory enforcement may adequately disincentivize further adulteration with lead chromate in the spice industry in Georgia.

5. Conclusions

We provide evidence that spices from the Republic of Georgia had extremely elevated lead concentrations, suggestive of adulteration lead chromate-based yellow pigments. The prevalence of elevated lead levels in spices decreased between 2020 and 2022. Continued periodic monitoring of spice lead levels, especially of marigold-based spice mixes from the western region of Georgia, are needed to ensure that public health and food safety are maintained.

Ethics approval and consent to participate

We obtained written informed consent from study participants. The study protocol was reviewed and approved by the ethical review committee at the Georgian National Center for Disease Control and Public Health (protocol number 2022-051).

Consent for publication

Consent for publication was obtained for data presented in this manuscript.

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Authors' contributions

All authors read and approved the final manuscript.

CRediT authorship contribution statement

Jenna E. Forsyth: Conceptualization, Data curation, Formal analysis, Methodology, Software, Visualization, Writing – original draft. **Khatuna Akhalaia:** Conceptualization, Data curation, Investigation, Project administration, Supervision, Writing – review & editing. **Mariami Jintcharadze:** Conceptualization, Investigation, Writing – review & editing. **Emily Nash:** Visualization, Writing – review & editing. **Petr Sharov:** Conceptualization, Project administration, Supervision, Writing – review & editing. **Alena Temnikova:** Project administration, Visualization. **Christlee Elmera:** Data curation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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