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Geophagic Earths Consumed by Women in Western Kenya Contain Dangerous Levels of Lead, Arsenic, and Iron

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Abstract

Objectives—Geophagy is commonly reported by pregnant women and children, yet its causes and consequences remain poorly understood. Therefore, we sought to determine if geophagy could contribute micronutrients and/or be a source of heavy metal exposure by examining the elemental composition of earths consumed in Kakamega, Kenya.

Methods—Ten samples of earths commonly consumed during pregnancy were collected by study enumerators and analyzed using inductively coupled plasma-atomic emission spectroscopy. Samples were either collected at markets or from walls of participants' homes, based on where participants reported most commonly sourcing their consumed earths.

Results—Based on estimated intakes (40 g/day), all samples had lead levels that exceeded the provisional maximum tolerable daily intake, and one sample exceeded the threshold for arsenic. Further, estimated intakes of iron for all samples were at least 8.9 times higher than the established threshold. Elemental concentrations were also compared by the site of sample collection (market vs. household wall); market samples had significantly higher iron concentrations and lower calcium concentrations than wall samples.

Conclusions—Geophagic earths in Kakamega may be harmful because of dangerously high levels of lead, arsenic, and iron. The prevalence of geophagy among vulnerable populations underscores the importance of understanding its causes and consequences for accurate public health messaging.

Keywords

pica; sub-Saharan Africa; pregnancy; geophagy; heavy metals

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Author Contributions

SLY, MO, and SLM assisted with study design. MO and SMC direted data collection. SLY and SLM had the idea to write the manuscript and outlined its various sections. JDM analyzed the data and wrote the manuscript, with the assistance of SMC. SMC, MO, SLM, KD, and SLY all provided critical feedback on the manuscript and suggested edits. JDM made those edits. All authors approved the final draft.

INTRODUCTION

Geophagy, the craving and purposive consumption of earth substances, is pervasive across human cultures and the broader animal kingdom (Young, 2010b; Krishnamani & Mahaney, 2000). Geophagy is most commonly, but not uniquely, reported by pregnant women and children (Fawcett, Fawcett, & Mazmanian, 2016; Young, Sherman, Lucks, & Pelto, 2011; Golden, Rasolofoniaina, Benjamin, & Young, 2012). Despite its considerable prevalence among these vulnerable populations, the causes and consequences of geophagy remain poorly understood.

Three non-exclusive etiologies have been proposed. The first is *micronutrient deficiency*. Geophagy is strongly associated with lower serum hemoglobin and zinc concentrations (Miao, Young, & Golden, 2015). It is hypothesized that in response to such deficiencies, individuals develop cravings for earth, which provides supplemental minerals not found in their diets. Although some geophagic earth contains high concentrations of essential nutrients such as iron, *in vitro* cell models suggest that their bioavailability is low, or nonexistent (Seim et al., 2013).

The second explanation pertains to *gastrointestinal distress*. Geophagic substances are often rich in clay minerals, which have been demonstrated to reduce nausea (De Jonghe, Lawler, Horn, & Tordoff, 2009; Njiru, Elchalal, & Paltiel, 2011). The alkaline pH of these substances also makes them effective antacids (Liu, Malik, Sanger, Friedman, & Andrews, 2005). In response to gastrointestinal distress, such as pregnancy-related heartburn, nausea, and vomiting, individuals may crave and consume earth substances to quell upset.

The third explanation is *increased susceptibility to toxins and pathogens*. Clay-rich geophagic earths have the capacity to adsorb toxic secondary plant metabolites and pathogens, as well as reinforce the intestinal mucosa, which acts as a biological barrier between ingested materials and the internal milieu (González et al., 2004; Young, Sherman, Lucks, & Pelto, 2011). During periods of impaired immune function (e.g., pregnancy, childhood), individuals may consume geophagic earths as an adaptive response to protect against infection.

There is also evidence that geophagy can be an aberrant and even harmful behavior. Geophagic materials can limit essential nutrient absorption and impair uptake of beneficial pharmaceuticals (Hooda, Henry, Seyoum, Armstrong, & Fowler, 2004; Gomes, 2017). Further, some geophagic samples have high concentrations of pathogenic bacteria, parasites, and/or heavy metals (Geissler, Mwaniki, Thiong'o, & Friis, 1998a; Marschner, Welge, Hack, Wittsiepe, & Wilhelm, 2006; Odongo, Moturi, & Mbuthia, 2015; Reeuwijk et al., 2013; Kutalek et al., 2010).

Results from composition analyses of geophagic substances vary considerably between and within studies. This suggests that local geology strongly influences the elemental composition of geophagic earths, prohibiting generalizations (e.g., "all samples are high in iron") about the content of such substances. However, site-specific findings are imperative for assessing potential health risks (or benefits) associated with geophagy in a particular region.

Geophagy is most prevalent in sub-Saharan Africa (Njiru, Elchalal, & Paltiel, 2011; Young, Sherman, Lucks, & Pelto, 2011). It has been reported in a number of regions of Kenya, mostly among pregnant women (Table 1). However, there are few data on the elemental compositions of consumed earths (Odongo, Moturi, & Mbuthia, 2015).

Therefore, in an effort to generate an evidence base for recommendations about geophagy, we sought to determine the elemental composition of earth consumed in Kakamega, Kenya. More specifically, we aimed to determine if geophagy could contribute micronutrients and/or be a source of heavy metal exposure. Further, we sought to investigate whether particular earths presented greater risks than others.

MATERIALS & METHODS

Study population

This study was conducted in the context of a larger project, the Micronutrient Initiative-Cornell University Calcium study (NCT02238704), which has been described elsewhere (Omotayo et al., 2015). As formative work for this iron, folic acid, and calcium supplementation trial, pregnant women in Kakamega County, Kenya, were asked to participate in focus group discussions and evaluate key nutrition messages that would be disseminated to other mothers (Martin et al., 2017). During these discussions, several women described craving “stones” and eating them as a strategy for improving iron status. Through additional formative work for the trial (Omotayo et al., 2017), all pregnant women who reported geophagic behavior (n=10) were asked to provide details on where and how they collected earth intended for consumption. Ultimately, six of these women provided follow-up information.

Data collection

Ten earth samples were collected in 2014 by study enumerators. Samples were collected from the sites where each participant reported acquiring geophagic earth, which included markets and the walls of participants’ homes. At least 30 g of each sample were collected to allow for triplicate analyses. Samples were stored in plastic bags and shipped to the United States.

ICP analysis

Samples were sent to Dr. Ray Glahn’s laboratory at Cornell University in 2014 for inductively coupled plasma-atomic emission spectroscopy (ICP-AES) elemental analysis. Samples weighing 0.5 g were ground into a powder, treated with nitric and perchloric acids to remove organic materials, and mixed with 0.25 mL of 40 ppm yttrium solution to correct for drift in ICP-AES. After digestion, samples were diluted with deionized water to create a 20 mL dilution. Samples were then analyzed for concentrations of lead (Pb), arsenic (As), cadmium (Cd), iron (Fe), and calcium (Ca).

Intake estimation

Mean daily consumption (MDC) of geophagic substances was estimated to be 40 g, based conservatively on reports from elsewhere in East Africa (Geissler et al., 1998; Nyanza, Joseph, Premji, Thomas, & Mannion, 2014, Young et al., 2010a). This assumption is appropriate considering the similarity of populations studied and anecdotal evidence about intake in the study area. Probable daily intake (PDI) of each element was calculated by multiplying the mean measured concentration (μ) by the mean daily consumption.

$$PDI = [\mu \times MDC]$$

For nutritive substances (Fe, Ca), PDI was compared against daily dietary reference intakes set forth by the Food and Nutrition Board of the Institute of Medicine (Institute of Medicine, 2011; Institute of Medicine, 2001). For potentially toxic metals (As, Cd, Fe), PDI was compared against standards established by the Joint FAO/WHO Committee on Food Additives (JECFA) (Joint FAO/WHO Food Standards Programme Codex Committee on Contaminants in Foods, 2017). JECFA considers each metal's metabolism by the body and effect on human health; metals that have the potential to accumulate in the body are reported as provisional tolerable weekly (PTWI) or monthly intakes (PTMI).

JECFA withdrew its provisional tolerable weekly intake level for lead in 2011 in response to new evidence on the neurotoxic effects of low-level lead exposure. Therefore, lead standards established by the Food and Drug Administration (FDA) were used (Schmidt & Rodrick, 2005).

Thus, different toxicological thresholds were used for each metal. PDI was scaled for measures of weekly and monthly intake (a month was operationalized as 30 days). Because body weight is a part of each equation, we used 60 kg as an average adult body weight.

Data analysis

All statistical analyses were performed using Stata 14 (College Station, TX: StataCorp LP). T-tests were used to examine differences in elemental composition by sample source. A significance level of $P < 0.05$ was used in all tests.

RESULTS

There were two main sources of geophagic earths that participants reported using: the walls of their homes and markets (OSM1). Participants who primarily got their earth samples from markets did so from one of three locations: Matete Market, Kuvasali Market, or Shiandiche Market. Samples were labeled to indicate those purchased at markets (M1-M6) and those scraped from the walls of participants' homes (W1-W4). Amount of sample collected ranged from 37.2-241.9 g.

Micronutrient concentrations

In terms of micronutrient content, all samples had large quantities of iron but minimal calcium (Figures 1A–B). In fact, estimated intake of iron was above the threshold for provisional maximum tolerable daily intake (PMTDI) for all samples (Figure 1A). Intakes of iron were at least 8.9 times higher than the PMTDI. Estimated calcium intakes were well below both the established recommended daily amount and upper limit (Figure 1B).

Heavy metal concentrations

In terms of heavy metals, lead was high in all samples. Estimated intakes were at least 4 times higher than the provisional tolerable total intake level. Arsenic was relatively high for sample M5, which was 1.65 times higher than the benchmark dose lower limit (Fig 2A). For cadmium, all estimated intakes were below the PTMI.

Elemental concentrations by sample source

Heavy metal (As, Cd, Pb) concentrations did not differ significantly by site (Table 2). Market samples had significantly lower concentrations (mg/g) of calcium [mean (sd), 0.69 (0.62) vs. 2.31 (1.51); p=0.04]. They also had higher concentrations of iron [14.2 (1.80) vs. 11.5 (0.58); p=0.02] compared to those retrieved from the walls of participants' homes.

DISCUSSION

We examined the elemental composition of geophagic soils from rural western Kenya and found many of them to be high in two toxic heavy metals: lead and arsenic. The samples were also dangerously high in iron.

Geophagic earths with dangerous heavy metal (Pb, As, Hg, Cd) concentrations have been identified in other studies in sub-Saharan Africa (Bonglaisin, Mbofung, & Lantum, 2011; Mathee et al., 2014; Nyanza, Joseph, Premji, Thomas, & Mannion, 2014; Owumi & Oyelere, 2015; Kutalek et al., 2010). The high concentration of lead (>4 times higher than the cutoff established by the FDA) consistently measured across all of our samples is particularly alarming. Indeed, Bonglaisin et al. (2011) have reported lead levels in Cameroonian geophagic earths that were 100 times higher than previous standards set by JECFA, suggesting that lead contamination of geophagic substances may be widespread.

Lead, like other heavy metals, is a cumulative toxin associated with kidney damage and cognitive impairment. For pregnant women, prolonged exposure may lead to miscarriage, stillbirth, and low birth weight. Maternal lead exposure is also dangerous for infants; lead can be transported both across the placenta and transferred to infants through breastmilk (Chen et al., 2014; Ettinger et al., 2013; Nsawir, 2015). Further, lead exposure directly impairs heme synthesis and causes anemia, and iron deficiency increases the absorption of lead (Hegazy, Zaher, Abd el-hafez, Morsy, & Saleh, 2010). Therefore, lead in geophagic material may be especially deleterious for women in western Kenya, where more than one-quarter of women of child bearing age have iron-deficiency anemia (Kenya National Micronutrient Survey 2011, 2014).

High arsenic levels have been reported in geophagic samples from both Bangladesh and Dutch markets (Al-Rmalli, Jenkins, Watts, & Haris, 2010; Nyanza, Joseph, Premji, Thomas, & Mannion, 2014; Reeuwijk et al., 2013). In contrast, studies of geophagic earths from other sites have detected arsenic at low or nonexistent levels, with no significant impact on blood arsenic levels (Mathee et al., 2014; Tayie, Koduah, & Mork, 2013). A systematic review of environmental exposure to arsenic during pregnancy found a strong association between arsenic and adverse pregnancy outcomes (e.g., stillbirth) (Quansah et al., 2015). Given these serious health consequences for both mother and child, geophagic substances rich in arsenic should be avoided.

Many of the samples we analyzed had extremely high levels of iron. Indeed, a previous study examining geophagic earths from Bangladesh reported that the concentration of iron was much higher than other measured elements (Al-Rmalli et al., 2010). Similarly, a number of other studies have reported that geophagic substances consumed by humans and other primates contain iron (Lar, Agene, & Umar, 2014; Mahaney et al., 2000; Mahaney et al., 1997; Nyanza et al., 2014); however, this is the first study to report concentrations of iron sufficiently high to be deleterious to health. In fact, all samples were well above the PMTDI. Intakes of elemental iron between 10-20 mg/kg body weight are associated with gastrointestinal upset and constipation, and several of our estimated intakes fell within this range (Institute of Medicine, 2001). Additional dietary iron may exacerbate these health outcomes and potentially impair zinc and calcium absorption (Solomons, 1986). Despite evidence that the bioavailability of iron in geophagic substances is low (Seim et al., 2013; Pebsworth et al., 2013), precautions should be taken before using earth as a micronutrient supplement since unabsorbed iron can irritate the lining of the gastrointestinal tract.

All analyzed samples were low in calcium. This is consistent with prior findings. For example, an examination of antiemetic Nigerian clays similarly found calcium concentrations to be low, while a study of Ghanaian geophagic substances found that calcium minimally contributed to the overall clay content (Arhin & Zango, 2016; Owumi & Oyelere, 2015). An *in vitro* study of geophagy found that the calcium in these substances may be bioavailable (Hooda et al., 2004), although their low concentrations would not be enough to confer a significant nutritional benefit. However, despite having low calcium concentrations, clay-rich geophagic earths have the potential to increase calcium bioavailability from other sources by slowing the passage of food through the gastrointestinal tract, thereby allowing for greater calcium uptake (Wiley & Katz, 1998).

In terms of differences in elemental composition by source (wall vs. market), there was significantly greater calcium and lower iron in wall samples than market samples. Concentrations of heavy metals did not differ between samples from different sources. Interestingly, an examination of Cameroonian soil samples found the opposite; samples from mines were lower in heavy metals than those purchased at markets (Bonglai, Mbofu, & Lantum, 2015).

When we examine these data in light of the three non-exclusive hypotheses about the drivers of geophagy (micronutrient deficiency, gastrointestinal distress, and increased susceptibility to toxins and pathogens), the finding of high iron across all samples is consistent with the deficiency hypothesis. However, caution should be taken before considering geophagic earths as a safe and appropriate supplement given the dangerously high concentrations of both iron and lead. Such high intakes of these metals could have negative health repercussions, especially for vulnerable populations (e.g., pregnant women), who are the most common geophagists (Young, Sherman, Lucks, & Pelto, 2011).

In order to more rigorously test the other two hypotheses, more data are needed on the proportion and type of clay in the samples, the binding capacity of the clays, and the reproductive and immunological status of the consumer. Therefore, we propose that future studies apply a more systematic method of collection and analysis of geophagic substances, as outlined by Young, Wilson, Miller, & Hillier (2008).

Although this study provides useful data on the health risks of geophagy, there is more work to do. First, we assumed daily ingestion of geophagic substances, which may have led to an over- or under-estimation of intake. Collecting information on each geophagist's consumption patterns, including quantity consumed, would provide more accurate estimates of intake. Further, a convenience sampling strategy was used, limiting generalizability. A more comprehensive study is required to determine the most common sources of geophagic substances within the region. Finally, future studies should also examine the reasons *why* lead levels were so high in this region. Knowing this could help prevent further contamination. We expect that a more comprehensive investigation of these substances will improve our understanding of their potential health consequences.

Conclusion

In summary, geophagic earths collected in Kakamega, Kenya were dangerously high in lead, arsenic, and iron. Although it is appealing to think of geophagy as a naturally available remedy for micronutrient deficiencies, the risk of exposure to dangerous heavy metals suggests that the consumption of earth from Kakamega County should be discouraged. Healthcare providers should develop public health messaging that accurately conveys the dangers of consuming these geophagic earths, taking into account women's motivations and suggesting alternatives. Given the potential for heavy metal exposure and the associated public health risks, the composition of geophagic substances from other sites should also be tested. The development of a field-friendly test would allow for more widespread analysis and faster reporting of results to protect the wellbeing of women and their infants.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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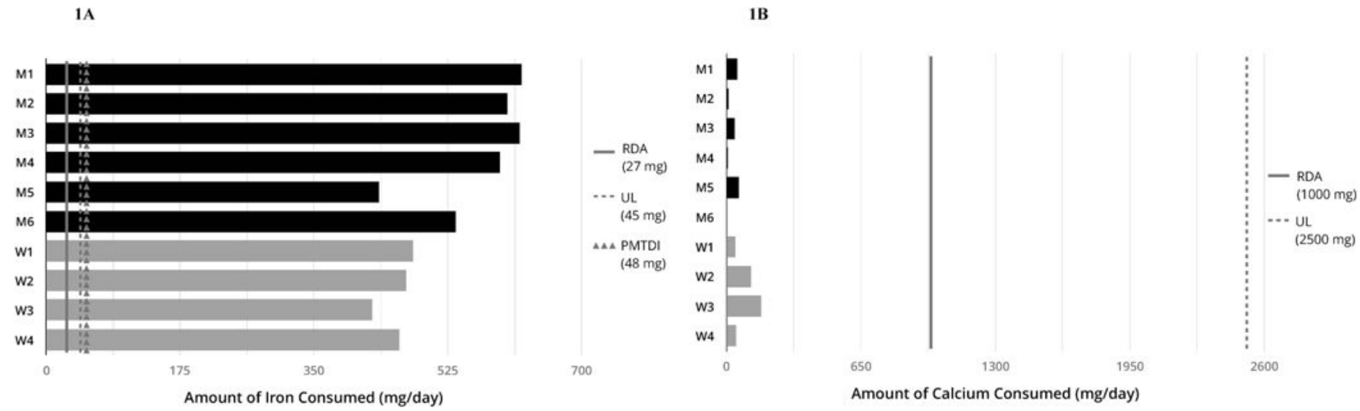

FIGURE 1.

Estimated intakes of iron (1A) and calcium (1B) from geophagic samples collected in Kakamega, Kenya, assuming 40g consumed/day and 60kg body weight. Estimated iron intakes are well above safe thresholds.

M = market sample; W = wall sample; RDA = recommended daily amount; UL = upper limit; PMTDI = provisional maximum tolerable daily intake

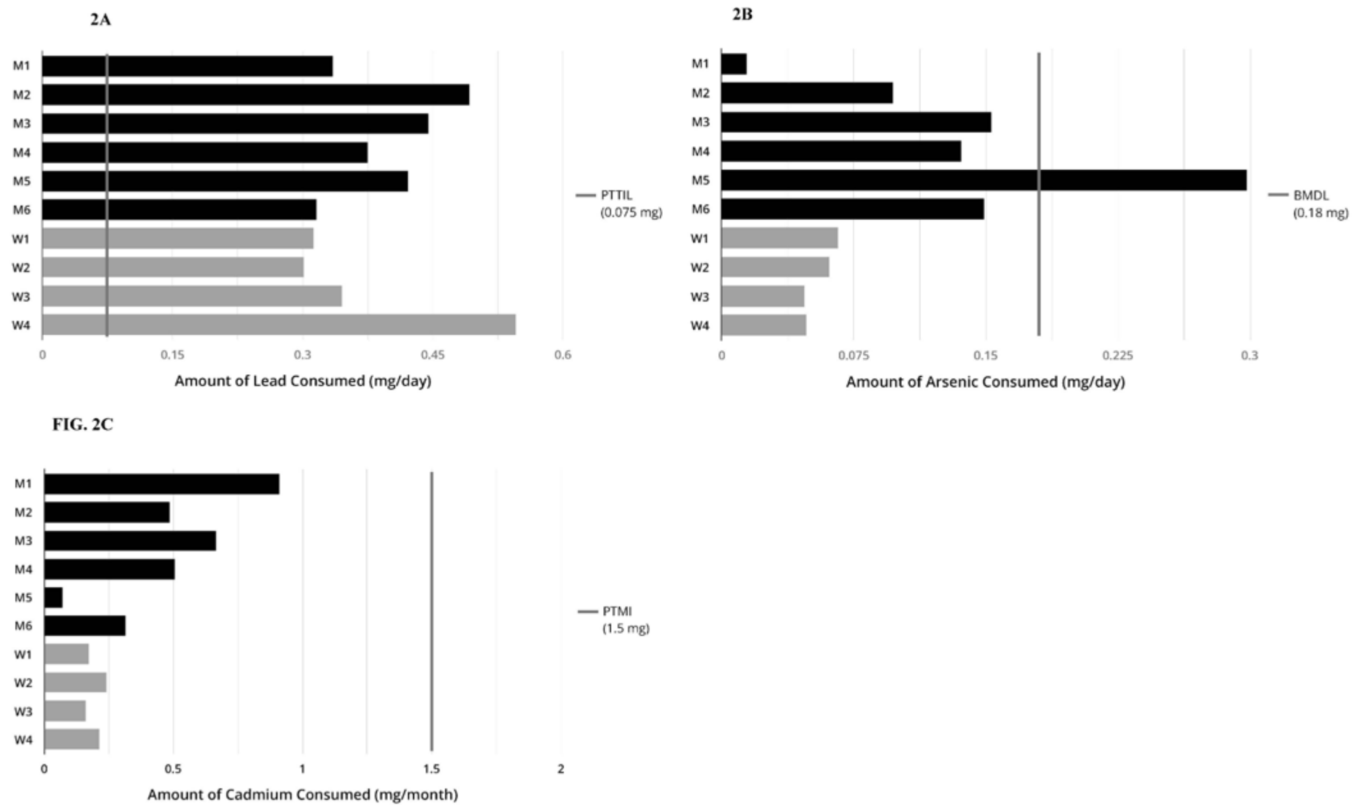

FIGURE 2.

Estimated intake of lead (2A), arsenic (2B), and cadmium (2C) from geophagic samples collected in Kakamega, Kenya, assuming 40g consumed/day and 60kg body weight. Intakes of lead were above the safety threshold for all samples; one sample exceeded the threshold for arsenic.

M = market sample; W = wall sample; PTTIL = provisional tolerable total intake level; BMDL = benchmark dose lower limit; PTMI = provisional tolerable monthly intake

TABLE 1

Reported prevalence of geophagy by region in Kenya and population of study.

Region	Population (n=)	Prevalence	References
Coastal Kenya	Pregnant women (275)	56%	Geissler et al, 1988b
	Pregnant women (52)	73%	Geissler et al., 1999
Nairobi	Pregnant women (1071)	74%	Ngozi, 2008
Rift Valley	Children (350)	49%	Moturi & Shivoga, 2009
Western Kenya	Pregnant women (202)	27.4%	Kariuki, Lambert, Purwestri, & Biesalski, 2016
	Pregnant women (827)	65%	Luoba et al., 2014
	Schoolchildren (285)	73%	Geissler, Mwaniki, Thiong'o, & Friis, 1997
	Pregnant women (79)	75%	Prince, Luoba, Ng'uono, & Geissler, 1999
	Schoolchildren (204)	77%	Geissler, Mwaniki, Thiong'o, & Friis, 1998a

TABLE 2

Mean elemental concentrations of geophagic soil samples collected in Kakamega, Kenya, by source of sample.

	Market Samples (n=6)		Wall Samples (n=4)		
	mean (mg/g)	**sd**	**mean (mg/g)**	**sd**	***P***
Arsenic	0.004	0.002	0.001	0.0002	0.11
Cadmium	0.0004	0.0002	0.0002	0.00003	0.08
Lead	0.01	0.002	0.009	0.003	0.72
Calcium	0.69	0.62	2.31	1.51	0.04*
Iron	14.2	1.80	11.5	0.58	0.02*

‡T-test;

*p<0.05