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Iron nutrition and possible lead toxicity: An appraisal of geophagy undertaken by pregnant women of UK Asian communities

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Abstract

A cultural transfer of geophagy is evident in the UK, with soils imported from Bengal being deliberately consumed mainly by pregnant Asian women. Two samples purchased from ethnic shops were subjected to a 2-part acid–alkaline in vitro physiologically based extraction test (PBET) procedure, representing the stomach and small intestine of the human digestive system respectively, to determine the bioaccessibility of elements. Despite the low bioaccessibility of Fe, with the quantity of soil consumed one sample can provide 41–54% of this mineral nutrient required by a 15–18 year old female, with the other sample providing 90–119%. Significant amounts of Ca, Cu and Mn are also supplied to the consumer, whilst further research investigating the possible effects of Pb toxicity on the geophagist would seem to be justified.

1. Introduction

Geophagy, the habit of eating clay or earth (Weller, 1989), has been practiced by humans for a long period of time, with the suggested earliest evidence being found at the prehistoric site in the local basin in the Kalambo River valley above the famous Falls on the border between Tanzania and Zambia (Clark, 2001). From its origins in Africa, geophagy undertaken by humans spread across the globe, although apparently there are regions such as Japan, Korea, Madagascar and the south of South America where the practice is limited or has not been recorded (Laufer, 1930). Recent reports indicate the continuing high prevalence of geophagy among certain human groups (Geissler et al., 1997, 1998; Thomson, 1997), although during the middle of the 20th century the practice was described as rare in Europeanised society (Gelfand, 1945). Even earlier, Foster (1927) recorded pica (of

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which geophagy is a form) in the United Kingdom as being very uncommon, confined to the cravings of pregnant women and the soil eating propensities of children. Thus, very occasional reports of geophagy in the United Kingdom are presented in the literature (Dukes, 1884; Shuttleworth et al., 1961), although a high prevalence of soil-eating by children aged 2–3 years was found by Barltrop et al. (1974).

Whilst geophagy is not limited to certain geographical areas or human societies, the practice can be recognised to be more common among some groups of people (Abrahams, 2005). These include societies of low economic status living within the tropics (Abrahams and Parsons, 1996). Immigration of people from such societies into the UK allows for the possibility of a cultural transfer of the practice (Hunter, 1973). Investigations by one of us (PWA) quickly led to the discovery of soils, variously known as sikor, mithi, patri, khuri, kattha, poorcha, or slatti, that are deliberately consumed by members of Asian communities within the UK. Whilst this practice of geophagy appears to be previously unknown to soil scientists, in the late 1980s various Environmental Health and Food Safety Officers in the country were well aware of this soil consumption. Middleton (1989) reports that these soils are traditionally consumed by Asian ethnic groups, particularly pregnant women, as a remedy for indigestion and as a 'tonic' during times of pregnancy. Bradford Metropolitan Council produced an excellent, eye-catching leaflet on the subject, with information stating that sikor may be consumed as a mineral nutrient supplement. School children of Asian descent also eat these soils, although it is unclear as to why they should do so. The soil may also be ground to a paste and used for make-up, though it should be distinguished from surma, the more widely known lead-based cosmetic used by Asians (Middleton, 1989).

These soils, referred to as sikor in this paper, are imported from the Bengal area of south Asia and are purchased from ethnic shops, being sold by weight in unnamed paper or plastic bags. For this study, two 1 kg bags of sikor were obtained for analytical purposes. One sample was purchased from Birmingham, the other from the East End of London. This paper reports on some of the physical, chemical and mineralogical properties of sikor, and considers the nutritional implications to human health. Ingested soils are a potential source of essential mineral nutrients (as well as harmful elements such as Pb), and the bioaccessible fraction of elements (defined as the fraction of a substance that is soluble in the gastrointestinal environment and is available for absorption; Paustenbach, 2000) from ingested soils are evaluated through the use of an established in vitro laboratory procedure that incorporates gastrointestinal tract parameters representative of a human.

2. Materials and methods

Some rudimentary manufacturing of sikor is evident, since the soils are shaped into approximate square shaped tablets presumably whilst moist (Fig. 1). The tablets obtained from Birmingham (median mass = 16.16 g, $n = 30$; range 10.87–22.21 g) appear to have been baked and have a distinct smell of smoke. When broken to expose a fresh surface, the soil is predominantly pale yellow in colour (Munsell colour notation 5Y 7/3). In contrast, the pale red (10R 6/4) tablets purchased in London had a median mass equal to 145.97 g ($n = 7$), with a range from 61.66 to 155.62 g.

In the laboratory, the soils were disaggregated in a porcelain mortar with a pestle, sieved through a 2 mm nylon mesh, and the <2 mm fine earth fraction retained. This portion was analysed for pH, organic C, electrical conductivity and cation exchange capacity (CEC) using standard methodologies (MAFF, 1986; Rowell, 1994). The concentrations of 11 elements were determined by atomic absorption spectrometry (AAS) and flame emission spectrometry (FES) following a HNO_3–$HClO_4$ digestion (Thompson and Wood, 1982). Such a procedure determines what may be called 'pseudo total' concentrations, since it is likely that some soil constituents are not completely attacked by the acid mixture. This may explain the low recoveries of some elements determined from a Soil Reference Material (National Council for Certified Reference Materials (China), GSS-7: laterite) that was included in this analysis (Table 1). In contrast, the extraction of total Pb appears to be overestimated by a factor of 2.6. Repeat analysis of the Soil Reference Material confirmed this result, which is ascribed to analytical noise at the relatively low concentrations of Pb in the sample solution. This problem of accurately detecting low total soil Pb concentrations by AAS however has no significant implications in the study, with the amounts determined from the two samples of sikor confirming that these soils are not Pb-enriched (see Sections 3 and 4).

Fig. 1. Sikor collected from Birmingham and London (small and large tablets, respectively).

Table 1
Selected certified values for the soil reference material, and the median concentrations determined from this sample following a HNO_3–$HClO_4$ digestion

	Elements										
	Ca	Co	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Zn
Certified values of soil reference material	1144	97	97	13.13	1660	1568	1780	549	276	13.6	142
Median concentration determined ($n = 5$)	756	100	88	9.6	920	882	1480	224	256	36	116
% Recovery	66.1	103.1	90.7	73.1	55.4	56.3	83.1	40.8	92.7	264.7	81.7

Concentrations are mg kg^{-1} except Fe (%).

A physiologically based extraction test (PBET) founded on that developed by Ruby et al. (1996) was used as an in vitro digestion procedure to determine the bioaccessibility of elements to humans. The test methodology and development is described by Cave et al. (2003). Each soil sample (1.00 g) was mixed with 100 mL of simulated gastric solution (1.25 g pepsin (activity of 800–2500 units/mg), 0.5 g sodium malate, 0.5 g sodium citrate, 420 μL lactic acid and 500 μL of acetic acid to 1 L of de-ionized water, adjusted to pH 2.5 with concentrated HCl) in a HDPE (wide-mouthed high density polyethylene) bottle, placed in a rotary water bath maintained at a constant 37 °C. After 1 h a 5.0 mL aliquot, representing the stomach phase of extraction, was removed and filtered through a Gelman 0.45 μm cellulose filter. Five millilitres of the original gastric solution was then back-flushed through the filter into the HDPE bottle to retain the original solid/solution ratio. The conditions of the bottle were then altered to represent the small intestine by titration to pH 7.0 with saturated $NaHCO_3$ (used to minimise volumetric changes and the solid/solution ratio. The amount of volume added to achieve neutralisation is typically <5 mL, representing a total volume change of <5% (Cave et al., 2003)) and the addition of 175 mg bile salts and 50 mg pancreatin. The samples were then incubated in the water bath for 2 h, the temperature and presence of labile organic matter recreating the characteristic reducing conditions of the small intestine, when an aliquot representing the small intestine phase was removed and filtered. Two hours later a further 5 mL aliquot was taken

and filtered to check that the equilibrium of the small intestinal phase had been established (determined by comparison of the elemental concentrations of the two intestinal samples. The similar results found in this work confirmed that equilibrium had been attained, and a mean value of elemental concentrations was calculated for representation of the intestinal phase of extraction). Following this extraction procedure, the samples representing the stomach and small intestine phases of the human digestion system were subjected to multi-element analysis by ICP-MS; K concentrations were determined by FES.

The amount of fluid in the human gastrointestinal tract (intra-gastric volume) varies markedly between fasting conditions in which it can reach equilibrium volumes as low as 20 mL (depending upon age and body mass) and postprandial (following a meal) volumes in excess of 1000 mL. Similarly, the amount of sikor ingested can vary widely between individuals depending if it is gnawed or crushed, ingested as a powder with water or prior/post meal. In such situations, the solid/solution ratio following sikor ingestion varies significantly. It was therefore decided in undertaking this work to take a precautionary route and assume a relatively large solid/solution ratio (1:100), more commensurate with soil ingestion with water, as this would result in expressing the maximum bioaccessibility thereby indicating the maximum exposure to potentially harmful soil constituents such as Pb. Clearly a detailed understanding of actual use of sikor would enable a more accurate calculation of appropriate solid/solution ratios. This information was not available at the date the work was undertaken, and it is hoped that this publication will stimulate the collection of such data.

Another criticism of the PBET methodology employed can be directed at the pH of the stomach phase of extraction which is unlikely to remain at 2.5 when the simulated gastric solution is mixed with the soil. The effect of soil buffering on the phase one pH was considered whilst undertaking these tests. The sikor is moderately or strongly acidic (pH 4.4 and 4.2 for the Birmingham and London samples, respectively), and the high solid/solution ratio used on these samples would result in minimising any soil buffering. Furthermore, extensive experience gained by measuring the pH before and after the stomach phase of extraction on non-carbonate soils (similar to sikor) have indicated a pH change of <0.5 pH units (BGS, unpublished data).

Appropriate quality control procedures were employed during the geochemical analysis. Duplicate analysis of soils subjected to the PBET confirmed similar results, whilst replicate analysis of a single tablet of sikor demonstrated a good precision of analysis for the pseudo total concentrations; for almost all of the 11 elements, the coefficient of variation (CV) was $<5\%$ ($n = 3$). Whilst it is clear that the 2 samples of sikor come from different sources, the tablets within each purchased bag of soil have a similar origin. For example, 5 tablets of the sikor from Birmingham were analysed individually to assess their homogeneity. For the pseudo total concentrations, the median CV (3.1%) demonstrates a low variability between the tablets.

The mineralogy of samples of sikor was determined by X-ray diffraction. In this analysis, a semi-quantitative assessment of the whole-soil mineralogy was undertaken on the fine earth fraction, and a quantitative assessment was completed on the <2-μm (clay) fraction (the latter obtained by ultrasound, shaking and centrifugation). Results were then combined to give an overall assessment of the soil mineralogy. The degree of clay mineral development (e.g. well or poorly crystallised) was evaluated, and the percentage of clay content by weight of the fine earth fraction was also determined by removing a 20 ml aliquot of the final clay suspension and evaporating to dryness at 80 °C.

Various exposure scenarios were simulated to investigate the impact of the soil ingestion on blood Pb (PbB) concentrations. This approach used an Excel implementation of the International Commission on Radiological Protection (ICRP) Pb model as described by Leggett (1993) and Pounds and Leggett (1998). This is a multi-compartmental pharmacokinetic model of Pb uptake and deposition in humans that includes a central plasma compartment, 15 peripheral body compartments, and 3 elimination pools. This systemic model can be used with any absorption fraction quantifying the transfer of Pb from the gastrointestinal tract into blood. In the authors' simulations, changes in the PbB concentrations of females aged 18 years were predicted based on various dosing regimens (1, 2, 3 or 4 doses of soil per day) undertaken over varying timescales (7, 30 or 90 days of ingestion) for both the Birmingham and London samples. For these simulations, all ICRP model default parameters (e.g. transfers of Pb to soft tissues and bone) were used excepting the absorption fraction. Further details are given in Section 4.

3. Results

The sikor purchased from Birmingham is a moderately acidic soil (pH measured in a 1:2.5 w/v water suspension = 4.4), very low in organic C (0.8%) and is salt free (electrical conductivity = 0.4 dS m^{-1}). The CEC (23.2 $cmol_c\ kg^{-1}$) is rated as medium. Many geophagical samples are described as clays, typically ferruginous and kaolinite enriched. Certainly this sample of sikor, containing 54% by weight of clay-sized particles is predominantly comprised of fine constituents, but the clay mineralogy is dominated by 2:1-type silicates most notably poorly crystallised illite. Quartz is also a major mineral constituent of this soil (Table 2).

The sikor from London has some similarity to the Birmingham sample, being clay enriched (43%), strongly acidic (pH 4.2) and having a medium CEC (22.8 $cmol_c\ kg^{-1}$). However, the soil also has a very high organic C content (27.6%) and is moderately saline (electrical conductivity = 8.6 dS m^{-1}). Poorly crystallised illite and moderately crystallised kaolinite constitute the main clay-sized minerals, with quartz also being an important component of the <2 mm fine earth fraction.

Table 2 records the pseudo total concentrations of the 11 selected elements determined from the soil tablets. The sikor obtained from Birmingham contains high concentrations of K, Mg, Na and Ni (Fe is also elevated bearing in mind the recovery of this element following the acid digestion procedure; Table 1), and low amounts of Mn and especially Ca. High concentrations of Ca, K and Na, and low amounts of Fe, Mn and Pb, are associated with the tablets purchased from London. Table 3 shows the concentrations of elements extracted from the 2-part, acid–alkaline PBET system that represents the stomach and small intestine of the human digestion system, respectively. In many cases the concentrations extracted from the intestinal phase (pH 7) are similar or greater than those associated with the acidic stomach phase (pH 2.5). This has been noted in many other studies (Wragg and Cave, 2003), being ascribed to a variety of reasons (Ruby et al., 1996; Smith et al., 2000) including the effect of complexing by pancreatin/bile salts, particle size/mineralogy and dissolution kinetics, the latter being one of the key reasons for trying to mimic both the chemical composition and kinetics of the human gut in the PBET test.

Absorption of elements mainly occurs in the intestines (Daugherty and Mrsny, 1999; Plumlee

Table 2
Mineralogy and geochemistry of sikor

Birmingham												
Mineralogy[a]	Haematite	Illite	Kaolinite	Quartz	Chlorite	Goethite	Plagioclase	Pyrite	Smectite	Total		
	2.9	28.4	9.2	36.1	5.3	7.5	2.0	1.9	6.7	100		
Geochemistry[b]	Ca	Co	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Zn	
Pseudo total	80	22	30	5.88	1.81	0.40	69	0.18	81	38	80	
	(50–110)	(21–23)	(29–31)	(5.50–5.92)	(1.70–1.85)	(0.39–0.40)	(63–76)	(0.18)	(79–84)	(34–39)	(77–82)	
London												
Mineralogy	Haematite	Illite	Kaolinite	Quartz	Dolomite	Gypsum	Siderite	Total				
	Trace	14.1	43.4	26.2	2.6	8.9	4.8	100				
Geochemistry	Ca	Co	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Zn	
Pseudo total	1.62	6	16	0.66	0.80	0.30	64	0.12	34	20	48	
	(0.58–1.66)	(6–8)	(14–16)	(0.63–0.70)	(0.40–0.86)	(0.20–0.32)	(44–69)	(0.12–0.18)	(24–36)	(18–30)	(34–54)	

[a] XRD methodology does not take into account any amorphous content and the results are normalised to 100% based on the assumption that the complete mineral content of the sample is accounted for in the diffractogram.
[b] Element concentrations are in mg kg^{-1} except the total concentrations of Ca (London), Fe, K, Mg and Na (%). The median and (in parenthesis) minimum and maximum concentrations are determined from 5 tablets (Birmingham) and 3 tablets (London) of sikor, respectively.

Table 3
Mean[a] concentrations (mg kg^{-1}) of elements extracted from the 2 phases of the PBET system

	Elements									
	Ca	Co	Cu	Fe	K	Mg	Mn	Ni	Pb	Zn
Birmingham										
Stomach phase	nd	1.6	2.5	44	39	237	4.7	4.5	4.1	12.9
Intestine phase	nd	1.5	5.9	124	45	221	8.3	4.2	1.2	7.8
	–	(6.8)	(19.7)	(0.2)	(0.2)	(5.5)	(12)	(5.2)	(3.4)	(9.8)
London										
Stomach phase	7274	0.6	7.7	542	537	1652	49	7.1	0.5	55
Intestine phase	6503	0.5	8.7	271	462	1551	37	4.4	0.6	16
	(40.1)	(8.3)	(54.4)	(4.1)	(5.8)	(51.7)	(57.8)	(12.9)	(3.0)	(33.3)

The percentage bioaccessibility of elements in the intestinal phase is shown in parentheses.
[a] $n = 2$ and 4 for stomach and intestine phases of each duplicated sample, respectively; nd = not determined.

and Ziegler, 2003), and Table 3 details the percentage bioaccessibility associated with the intestinal phase of the PBET system. Compared to the Birmingham sample of sikor, the soil purchased in London is associated with a greater percentage bioaccessibility of all the elements except Pb. For both samples of sikor, Cu and Mn have the greatest percentage bioaccessibility, and Fe, K and Pb display the lowest percentage bioaccessibility. The low bioaccessibility of Fe (0.2% and 4.1% for the Birmingham and London samples, respectively) is of interest since this mineral nutrient is frequently implicated in a physiological explanation for geophagy. Despite the low bioaccessibility of Fe indicated in Table 3, sikor has the potential to supply a significant amount of this element to the geophagist following ingestion. Table 4 shows the intake of elements supplied in a bioaccessible form via the consumption of 16.2 g (i.e. the median mass of the Birmingham soil tablets) of soil. These data are compared against Reference Nutrient Intake (RNI) values, the latter being the daily dietary values of nutrients above which the amounts will almost certainly be adequate for everybody (actually about 97% of people in a group; Department of Health, 1991). Table 4 presents the RNI values

Table 4
The intake[a] of elements following the consumption of 16.2 g of sikor, and a comparison with the Reference Nutrient Intake (RNI) values for 15–18 year olds, and Safe Upper Levels (SULs)/Guidance Levels for a 60 kg adult

	Elements									
	Ca	Co	Cu	Fe	K	Mg	Mn	Ni	Pb	Zn
Element intake (mg) per 16.2 g soil										
Birmingham	–	0.02	0.10	2.01	0.73	3.58	0.13	0.07	0.02	0.13
London	105.3	0.01	0.14	4.39	7.48	25.12	0.60	0.07	0.01	0.26
RNI[b] for 15–18 years										
Males	1000	No RNI[c]	1.2	11.3	3500	300	No RNI	No RNI[d]	No RNI[e]	9.5
Females	800	No RNI[c]	1.2	14.8	3500	300	No RNI	No RNI[d]	No RNI[e]	7.0
SUL/Guidance Level[f]	1500[g]	1.4[h]	10[i]	17[g]	3700[g]	400[g]	4[g]	0.26[h]	No SUL[j]	42[i]

[a] Intake calculated by assuming that all the quantity of elements released in the intestinal phase of the PBET is absorbed by the geophagist.
[b] RNI values (mg d^{-1}) from UK Department of Health (1991).
[c] No RNI in this form can be given since although an essential element, Co is utilised by humans only in the form of vitamin B_{12}.
[d] No RNI available. The human requirement for Ni is unknown, and could be as low as 5 μg d^{-1} (Nielsen, 1984).
[e] No RNI because of the lack of evidence that Pb is essential for humans.
[f] Values (mg d^{-1}) from Expert Group on Vitamins and Minerals (2003).
[g] Guidance level for supplemental intake.
[h] Guidance level for total intake.
[i] SUL.
[j] Reference does not consider Pb.

for the 15–18 years age group (i.e. those humans who generally have the highest requirements for mineral nutrients). The comparison shown in Table 4 demonstrates the potential importance of sikor in supplying significant amounts (i.e. 10% or greater of the RNI) of Ca, Cu, Fe and Mn to the geophagist (note: the Department of Health, 1991, set no RNI for Mn, but a safe intake is believed to be greater than 1.4 mg d^{-1} for adults). Indeed, bearing in mind that the majority of people will have nutrient requirements lower than the RNI values presented in Table 4, the amounts of these elements supplied to geophagists relative to their nutritional need is greater than this table indicates. Furthermore, the authors have been informed by Asian geophagists that soil equivalent to 3–4 tablets of the Birmingham sample (i.e. ca. 48.6–64.8 g) can be consumed per day by the pregnant women of the Bengali community (such rates of ingestion should be of no surprise, bearing in mind that Geissler et al. (1998) recorded a median daily intake of 41.5 g from a sample of pregnant Kenyan women). Ingestion of 48.6–64.8 g of Birmingham soil would contribute 40.7–54.3% of the Fe required by a 15–18 year female. Following the ingestion of a similar amount of the London soil sample, 90–118.6% of the 15–18 year female requirement for this mineral nutrient is supplied to the geophagist.

4. Discussion

The research described in this report indicates the potential of sikor in supplying significant amounts of Fe, as well as Ca, Cu and Mn, to the geophagist. In coming to this conclusion, it is appreciated that the use of the PBET extraction system only estimates bioaccessibility, and it is not known if this fraction is actually absorbed by the geophagist. Furthermore, investigations have shown that it is possible that soil ingestion can lead to a deficiency of Fe (Minnich et al., 1968), and other in vitro equilibrium studies with mineral nutrient concentrations and conditions similar to the gastrointestinal tract have shown the potential of ingested soils to sorb large amounts of this element (Hooda et al., 2002). The limited and conflicting literature on this subject means that the extent to which soils can provide Fe to the geophagous person remains to be fully evaluated. Bearing in mind the importance of geophagy in some societies and the fact that Fe deficiency is one of the world's most widespread nutritional problems (UNICEF/Micronutrient Initiative, 2004), the role of soil ingestion in Fe nutrition needs urgent further investigation.

Whilst the ingestion of sikor may provide benefits to the geophagist, there are some potential hazards that need to be evaluated. For example, geophagy is associated with helminthiasis caused by the ingestion of parasitic worms (Luoba et al., 2005), although in the case of sikor the baking to which the soil tablets appear to have been subjected may be effective in destroying any deleterious organisms. Any supplementation of mineral nutrients to geophagists may also lead to excessive absorption and toxic symptoms if sufficiently large amounts of sikor are consumed. The Expert Group on Vitamins and Minerals (2003) has recommended Safe Upper Levels (SULs), or Guidance Levels for nutrients with limited data, of mineral nutrients. Such levels allow the determination of doses of mineral nutrients that potentially susceptible individuals could take daily on a life-long basis, without medical supervision in reasonable safety. The SULs/Guidance Levels for the mineral nutrients considered in this study are presented in Table 4. Should the geophagists be consuming some 65 g of soil (equivalent to 4 Birmingham soil tablets of average mass) per day, then the Guidance Levels for Fe and Ni can be exceeded provided all the bioaccessible fractions are absorbed in the body. However, in reaching this conclusion, it needs to be remembered that the SUL/Guidance Levels are conservative, and it is possible that for some mineral nutrients larger amounts can be consumed for shorter periods without risk to health. The latter point is important, bearing in mind the often sporadic high dose nature of geophagical practices.

Middleton (1989) records that sikor may contain elevated concentrations of potentially harmful elements. With a total concentration of 38 and 20 mg Pb kg^{-1}, the 2 samples investigated in the present study can hardly be described as being enriched in this element when compared to typical soil Pb concentrations. However, Middleton (1989) considers that sikor is consumed in quantities that justify the use of food quality standards in evaluating the soil as a potential health hazard, an opinion that is shared with the UK Food Standards Agency (FSA, 2002a). In this respect the UK permitted level for Pb in unspecified foods was only 1 mg kg^{-1} (Jukes, 1997), though this figure is derived from food regulations established in the late 1970s. Today this general limit can be regarded as very high (FSA, 2002b), and recent European Union regulations

have established maximum Pb concentrations in foodstuffs that are significantly lower than 1 mg kg^{-1} in order to provide consumer protection (Byrne, 2001). The average dietary exposure of the UK population to Pb is 0.026 mg d^{-1} (FSA, 2002b), well within recommended safe levels. These are the Provisional Tolerable Weekly Intakes (PTWIs), defined as an estimate of the amount of a substance that can be ingested over a lifetime without appreciable risk to health, set by the Joint Expert Committee on Food Additives (JECFA) of the Food and Agriculture Organisation, United Nations and the World Health Organisation. The JECFA has set PTWIs for Pb of 0.025 mg kg^{-1} bodyweight, equivalent to 0.21 mg d^{-1} for a 60 kg person. Reference to Table 4 suggests that anyone ingesting sikor would significantly increase their Pb intake. For pregnant women this is particularly relevant because the risks from exposure to Pb are greatest for the unborn and developing child.

As mentioned previously in Section 2, the ICRP Pb model was used to investigate the impact of the ingestion of sikor on PbB concentrations. In the simulations, changes in the PbB concentrations of females aged 18 years were predicted based on various dosing regimens (1, 2, 3 or 4 doses per day of 16.2 g soil) undertaken over varying timescales (7, 30 or 90 days of ingestion) for both the Birmingham and London samples. For the simulations, all ICRP model default parameters were used except the absorption fraction. The in vitro PBET assay undertaken on the Birmingham soil tablets indicated a mean bioaccessible concentration of 5.3 mg Pb kg^{-1} (stomach and intestinal phases combined, Table 3), with replication of the analysis determining a minimum of 4.8 mg Pb kg^{-1} and maximum of 5.7 mg Pb kg^{-1}. For the London sample, a mean of 1.1 mg Pb kg^{-1} is bioaccessible (minimum 0.53 mg Pb kg^{-1} and maximum 2.50 mg Pb kg^{-1}). These bioaccessible concentrations were expressed as percent of total dose and used in

Table 5
ICRP model simulation conditions and summary results for various daily consumption patterns of Birmingham and London soil tablets (assumed mass of each dose consumed = 16.2 g) by an 18 year old woman for one week (7 days), one month (30 days), or three months (90 days) consecutively, using PBET bioaccessible concentrations that are assumed to be wholly absorbable

Simulation number	Dose scenario for Birmingham and London tablets	Peak GM PbB[a] (μg dL^{-1}) (min.–max.)	Peak P10 (%)[b] (min.–max.)
Birmingham			
1	1 dose per day for 7 days	3.57 (3.37–3.67)	1.42 (1.03–1.64)
2	2 doses per day for 7 days	5.82 (5.42–6.01)	12.46 (9.55–13.93)
3	3 doses per day for 7 days	8.07 (7.45–8.35)	32.36 (26.57–35.09)
4	4 doses per day for 7 days	10.31 (9.50–10.70)	52.59 (45.61–55.72)
5	1 dose per day for 30 days	7.89 (7.29–8.17)	30.70 (25.02–33.39)
6	2 doses per day for 30 days	14.53 (13.33–15.10)	78.67 (72.96–80.97)
7	3 doses per day for 30 days	21.18 (19.37–22.03)	94.48 (92.02–95.36)
8	4 doses per day for 30 days	27.68 (25.41–28.69)	98.49 (97.64–98.57)
9	1 dose per day for 90 days	11.46 (10.51–11.90)	61.41 (54.21–64.43)
10	2 doses per day for 90 days	21.82 (19.93–22.70)	95.16 (92.89–95.94)
11	3 doses per day for 90 days	30.48 (28.54–31.35)	99.11 (98.72–99.25)
12	4 doses per day for 90 days	36.76 (34.61–37.73)	99.72 (99.59–99.76)
London			
13	1 dose per day for 7 days	1.35 (1.33–1.47)	0.00 (0.00–0.00)
14	2 doses per day for 7 days	1.59 (1.54–1.83)	0.00 (0.00–0.01)
15	3 doses per day for 7 days	1.83 (1.76–2.18)	0.01 (0.01–0.03)
16	4 doses per day for 7 days	2.06 (1.97–2.54)	0.04 (0.03–0.18)
17	1 dose per day for 30 days	1.69 (1.63–2.03)	0.01 (0.01–0.03)
18	2 doses per day for 30 days	2.36 (2.23–3.03)	0.11 (0.07–0.55)
19	3 doses per day for 30 days	3.03 (2.83–4.03)	0.55 (0.36–2.66)
20	4 doses per day for 30 days	3.70 (3.43–5.03)	1.71 (1.14–7.20)
21	1 dose per day for 90 days	1.90 (1.79–2.41)	0.02 (0.01–0.12)
22	2 doses per day for 90 days	2.93 (2.72–3.96)	0.45 (0.28–2.42)
23	3 doses per day for 90 days	3.96 (3.65–5.50)	2.42 (1.60–10.16)
24	4 doses per day for 90 days	4.98 (4.58–7.04)	6.92 (4.81–22.79)

[a] Peak (min.–max.) maternal geometric mean blood lead concentration in μg dL^{-1} for 18th–19th year.
[b] Peak (min.–max.) risk (or probability) of exceeding 10 μg dL^{-1} (P10) for 18th–19th year.

place of the ICRP default bioavailability value for the 18 year old to predict PbB and to bound the results (Table 5). A criticism that may be directed at the procedure here is that the use of the sum of the two-phase bioaccessible fractions, i.e. stomach and intestine, is unreasonable, given the fact that no significant absorption occurs in the stomach, particularly from solid foods. Whilst this observation is correct, the net in vitro solubility or bioaccessibility (stomach phase plus intestinal phase) was used as a reasonable maximum exposure surrogate for bioavailability estimates (bioavailability being the fraction of a substance that reaches the central blood compartment from the gastrointestinal tract; Paustenbach, 2000).

The US EPA Adult Lead Methodology (US EPA, 1996) assumes a baseline PbB concentration of approximately 2 μg dL^{-1} for an adult female (US EPA, 2002). As shown in Table 5, consumption of the soil tablets results in an elevation in predicted maternal PbB. This is particularly evident for the Birmingham soil tablets, where under the proposed bioaccessibility conditions, various exposure scenarios for ingestion of these tablets result in short-term maximum maternal PbB increasing over 10 μg dL^{-1}. Relating maternal consumption of the soil tablets to foetal PbB can be accomplished by employing the maternal–foetal PbB relationship as described in the US EPA Adult Lead Methodology (US EPA, 1996). This uses a maternal-foetal ratio of 0.9 to predict foetal PbB. Table 6 shows these predicted PbB concentrations alongside the risk estimates based on the results of the various maternal exposure scenarios. This prediction of foetal PbB based on maternal exposure and maternal PbB does not resolve the issue of interpreting toxicological significance of short-term (acute) elevations in foetal PbB.

Table 6
Predicted foetal PbB and risk estimates for 5% probability of exceeding 10 μg dL^{-1} (P10) or 20 μg dL^{-1} (P20)

Sample and simulation number[a]	Foetal peak GM[b] PbB (μg dL^{-1}) (min.–max.)	Foetal peak P10 (%)[c], (min.–max.)	Foetal peak P20 (%)[d], (min.–max.)
Birmingham			
1	3.21 (3.03–3.30)	0.79 (0.56–0.92)	0.01 (0.00–0.01)
2	5.24 (4.87–5.41)	8.44 (6.29–9.55)	0.22 (0.13–0.27)
3	7.26 (6.71–7.52)	24.81 (19.75–27.16)	1.56 (1.00–1.86)
4	9.28 (8.55–9.63)	43.67 (36.95–46.80)	5.11 (3.53–6.00)
5	7.10 (6.56–7.35)	23.32 (18.49–25.65)	1.38 (0.89–1.66)
6	13.08 (12.00–13.59)	71.59 (65.08–74.30)	18.30 (13.84–20.55)
7	19.06 (17.43–19.83)	91.51 (88.15–92.73)	45.93 (38.50–49.26)
8	24.91 (22.87–25.82)	97.39 (96.08–97.82)	67.98 (61.23–70.66)
9	10.31 (9.46–10.71)	52.62 (45.29–55.80)	7.94 (5.56–9.20)
10	19.64 (17.94–20.43)	92.45 (89.31–93.57)	48.45 (40.84–51.80)
11	27.43 (25.69–28.22)	98.41 (97.76–98.63)	74.93 (70.28–76.80)
12	33.08 (31.15–33.96)	99.45 (99.22–99.54)	85.79 (82.71–87.00)
London			
13	1.22 (1.20–1.32)	0.00 (0.00–0.00)	0.00 (0.00–0.00)
14	1.43 (1.39–1.65)	0.00 (0.00–0.01)	0.00 (0.00–0.00)
15	1.65 (1.58–1.96)	0.01 (0.00–0.03)	0.00 (0.00–0.00)
16	1.85 (1.77–2.29)	0.02 (0.01–0.08)	0.00 (0.00–0.00)
17	1.52 (1.47–1.83)	0.00 (0.00–0.01)	0.00 (0.00–0.00)
18	2.12 (2.01–2.73)	0.05 (0.03–0.28)	0.00 (0.00–0.00)
19	2.73 (2.55–3.63)	0.28 (0.18–1.55)	0.00 (0.00–0.01)
20	3.33 (3.09–4.53)	0.97 (0.62–4.59)	0.01 (0.00–0.08)
21	1.71 (1.61–2.17)	0.01 (0.01–0.06)	0.00 (0.00–0.00)
22	2.64 (2.45–3.56)	0.23 (0.14–1.41)	0.00 (0.00–0.01)
23	3.56 (3.29–4.95)	1.41 (0.89–6.73)	0.01 (0.01–0.15)
24	4.48 (4.12–6.34)	4.39 (2.97–16.58)	0.07 (0.04–0.72)

[a] Simulation number equals simulation dosing regime outlined in Table 5.
[b] Geometric mean. Foetal PbB calculated using the maternal–foetal ratio: $PbB_{foetal} = 0.9 \times PbB_{maternal}$ (US EPA, 1996) and the maternal PbB (Table 5).
[c] Risk (or probability) of foetal PbB exceeding 10 μg dL^{-1} calculated according to Hastings (1955, cited in Abramowitz and Stegun (1969)).
[d] Risk (or probability) of foetal PbB exceeding 20 μg dL^{-1} calculated according to Hastings (1955, cited in Abramowitz and Stegun (1969)).

One option is to rely on existing risk levels for children as guidelines for understanding the relative risk associated with these excursions (Khoury and Diamond, 2003). For example, in older children it would be undesirable to have an exposure that poses a significant risk of a PbB concentration that exceeds the Centres for Disease Control and Prevention (CDC) trigger level for medical evaluation of 20 μg dL^{-1} (CDC, 1991). It is likely that this level of concern for older children can be applied to determine relative risk associated with short-term elevations in PbB for the foetus (whilst 20 μg dL^{-1} can be regarded as a high value for a long-term (chronic) PbB concentration, in the absence of consensus about health risks that might be associated with acute elevations in PbB concentration, it is reasonable to think that concentrations >20 μg dL^{-1} should be avoided even when they may persist only for a few days). Therefore, for the authors' analysis, short-term or acute risk to the foetus was defined as a greater than 5% probability of a child having a PbB concentration on any given day that exceeded 20 μg dL^{-1} (i.e. the CDC trigger level for medical evaluation in children). Using this definition, for many of the scenarios involving the maternal ingestion of the Birmingham soil tablets, the value of peak foetal PbB has more than a 5% probability of exceeding 20 μg dL^{-1} (Table 6). For none of the scenarios for the London soil does the value of predicted peak foetal PbB have more than a 5% probability of exceeding this value.

The UK FSA is concerned about this source of soil-Pb, having previously warned of the dangers of ingested soils (so-called Calabash chalk, samples of which have been found to contain 8.2–16.1 mg Pb kg^{-1}) that were being consumed by pregnant women of the UKs ethnic West African community (FSA, 2002a). Consequently, the importation of Calabash chalk is now banned (FSA, 2004). Clearly, bearing in mind the results of the present study, similar warnings (and import controls) need to be expressed about the consumption of sikor.

5. Conclusions

Immigration has led to a cultural transfer of geophagy, with imported soils being deliberately consumed by members of the UKs Asian community. During times of pregnancy, significant quantities of soil (>60 g) may be consumed. Such rates of soil ingestion are comparable to contemporary studies undertaken in developing countries. Despite the fact that geophagy has been recognised since the beginning of recorded history, a physiological explanation for the practice undertaken by humans remains to be confirmed. However, the use of an in vitro PBET procedure representing the human gastrointestinal tract indicates the potential importance of ingested soils in supplying significant amounts of several mineral nutrients, especially Fe, to the geophagist. At high rates of soil ingestion potentially deleterious amounts of this element may be consumed, and there is also a risk of Pb toxicity affecting the unborn child. More research is needed to determine the prevalence of geophagy within the ethnic groups of the UK, and provide an understanding of the actual use of ingested soils. Furthermore, bearing in mind the continuing importance of this practice in a number of societies throughout the world, further geochemical and nutritional investigations into the supply of beneficial and potentially harmful elements to the geophagist would seem to be justified.

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