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Soil Ingestion and Associated Health Implications: A Physicochemical and Mineralogical Appraisal of Geophagic Soils from Moko, Cameroon

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ABSTRACT Geophagia, the deliberate ingestion of soil has both beneficial and detrimental health effects. The positive and negative effects of geophagia may vary depending on the physico-chemistry, mineralogy and geochemistry of the soil. In this study, geophagic soils from Moko, Cameroon were physico-chemically and mineralogically characterised in order to ascertain their health implications. Colour, particle size distribution (PSD), consistency limits, pH, electrical conductivity (EC) and mineralogy of the soils were determined.. The soils were predominantly yellowish in colour, silty in texture, with high plascticity. Soil pH ranged from 4.8 – 5 whereas EC was low (£ 12 µS/cm). Kaolinite + quartz + mica + microcline + goethite + anatase ± smectite ± hematite ± gibbsite were the identified mineral phases. Samples exhibited OH stretching and bending vibrations similar to that of theoretical kaolinite. Kaolinite enrichment in the soils, may positively influence the release of essential nutrients to the geophagic individuals through isomorphic substitution. Observed high plasticity and acidic pH, rendered the soils suitable for use as remedy for nausea associated with pregnancy. However, the gritty texture of the soil may present significant health concerns for the geophagic individuals.

INTRODUCTION

Geophagia, the deliberate consumption of earth or soil has been practised for many centuries in a range of ethnic, religious, and social groups of the world (Abrahams et al. 2013). Though commonly practiced among pregnant women (Ngole and Ekosse 2012), women of all ages, educational level, and social status equally engage in the practice of geophagia (Songca et al. 2010). Some of the reasons advanced by geophagic individuals include; nutrient supplementation, detoxification, alleviation of gastrointestinal disorders such as diarrhoea, craving and relief from morning sickness (Gomes and Silva 2007) or as part of cultural belief system (Ngole and Ekosse 2012). Despite these beneficial aspects of geophagia, several studies have associated the practice with detrimental effects such as; iron deficiency anaemia (Mogongoa et al. 2010), hypokalaemia (Bisi-Johnson et al. 2010), excessive tooth wear, enamel damage and erosion of the mucosal surface of the stomach, perforation of the colon (Barker 2005; Ekosse and Anyangwe 2012), parasitic infections resulting from transmission of Ascaris lumbricoides, and other highly toxigenic bacteria, causative agents of gas gangrene, tetanus and boitulism (Saathof et al. 2002; Bisi-Johnson et al. 2010).

According to Ngole and Ekosse (2012) the positive and negative effects of geophagia may vary depending on the physico-chemistry, mineralogy and geochemistry of the ingested soils. The aforementioned soil properties are in turn influenced by; the soils pedogenetic development, type, amount and degree of crystallinity of clay minerals as well as the associated non-clay minerals.

Objectives

Studies on soils ingested by humans could provide clues on the relationship between health of geophagic individuals and soil physico-chemical, mineralogical and geochemical properties. On the basis of this premise, the objectives of this study are to physico-chemically and mineralogically characterise geophagic soils from the locality of Moko, South West Region of Cameroon,

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and to ascertain possible health implications on the geophagic individuals.

METHODS

Soil samples were obtained in situ from geophagic mining sites in Moko for laboratory analyses. Colour was determined using Munsell Soil Colour chart following procedures discussed in Diko et al. (2011). Particle size distribution (PSD) was determined using a Malvern Mastersizer Hydro 2000 Mu laser particle size analyser, following methods discussed in Fitzsimmons et al. (2009). Liquid limit (LL) and plastic limit (PL) tests were determined for the fine mortar fraction (< 63 µm) with a Cassagrande apparatus (Diko et al. 2012), whereas plasticity index (PI) was obtained from the arithmetic difference between LL and PL. Hydrogen ion concentration was determined with a pH meter (Hi 9321 Micro Processor) whereas electrical conductivity (EC) was determined with a Metler Tolledo EC meter (Tan 1996). X–ray Powder diffraction (XRD) for bulk kaolin was carried out using a Philips PW 1710 XRD unit operated at 40 Kv and 30 mA, with a Cu-Ka radiation. A graphite monochromator with a PW 1877 Automated Power Diffraction, X'PERT Data Collector software package was employed for qualitative identification of the minerals. The IR spectra for bulk kaolin were acquired using a Perkin Elmer system 2000 FTIR spectrophotometer at a resolution of 4 cm^{-1} (Ekosse 2005).

RESULTS

Soil Physico-chemistry

Table 1 summarizes the physico-chemical properties of the analyzed geophagic soils. Colour ranged from yellowish through brownish yellow to pinkish grey. The greyish colour may be attributed to the presence of finely disseminated organic matter whereas, the yellowish to brownish colour was attributed to the presence of iron oxides or from mixing of green clay minerals and organic matter. Sand sized fractions ranged from 4.8 mass % (MK 6) to 43.2 mass % (MK 1) with a mean of 22.7 mass %. Silt varied from 48.7 mass % (MK 1) to 75.7 mass % (MK 6) whereas clay fraction was between 8.1 mass % (MK 1) and 19.5 mass % (MK 6 and 7). The samples were generally silty in texture. Two size distribution were revealed; Group 1 (comprising MK 1 – Mk 3) enriched in coarser fractions and Group 2 (MK 5 – MK 7), slightly skewed towards medium to fine-grained. Liquid limit ranged from 50 mass % (MK 3) to 60 mass % (MK 7) with a mean value of 55.7 mass % whereas PL ranged from 36 mass % (MK 3) to 45 mass % (MK 1) with a mean of 41.8 mass %. Plasticity index (PI) was between 9 mass % (MK 1) and 17 mass % (MK 5 and 7). Three samples, MK 1, 2 and 3 had plasticity indices less than the mean of 13.8 mass %. Soil pH was in the range of 4.8 to 5 with an average of 4.9. Compared to all seven samples, MK 3 registered the highest pH. Electrical conductivity values ranged from 5.3 µS/cm to 12.4 µS/cm with a mean of 8.7 µS/cm.

Mineralogy of Geophagic Soils

Bulk rock mineralogy of representative samples are given on Table 2. Kaolinite + quartz + mica + microcline + goethite + anatase ± smectite ± hematite ± gibbsite were the identified mineral phases. Based on their relative intensities, the constituent minerals have been described as major, minor or trace phases. The XRD patterns

Table 1: Physico-chemical properties of eophagic soils

Sample (<2 µm)	*Hue/ value/ chroma*	*Colour*	*Sand mass % (> 63 µm)*	*Silt mass % (63 µm – 2 µm)*	*Clay mass %*	*Atterberg limits (mass %)*			*pH*	*EC (µS/cm)*
						LL	*PL*	*PI*		
MK 1	10YR/6/6	Yellowish	43.2	48.7	8.1	54	45	9	4.8	6.4
MK 2	10YR/6/6	Yellowish	38.0	52.2	9.8	55	44	11	4.9	5.3
MK 3	10YR/6/8	Brownish yellow	14.1	67.8	18.1	50	36	14	5	5.4
MK 5	10YR/6/8	Brownish yellow	27.9	55.9	16.2	57	40	17	4.8	12.1
MK 6	7.5YR/6/2	Pinkish grey	8.1	72.4	19.5	58	43	15	4.8	10.4
MK 7	7.5YR/6/2	Pinkish grey	4.8	75.7	19.5	60	43	17	4.8	12.4
Mean	–	–	22.7	62.1	15.2	55.7	41.8	13.8	4.9	8.7

(Fig. 1) were characterized by weak first order kaolinite peaks and the absence of the second order and 110 kaolinite peaks in all samples. The IR spectra of the samples (Fig. 2) revealed the following characteristic peaks; Al—O-H stretching doublet between 3620 – 3700 cm^{-1}, H-O-H bending (1633 – 1636 cm^{-1}), H-O-H stretching (1417 cm^{-1}, 1428 cm^{-1}, 1434 cm^{-1}, 3359 cm^{-1}, 3385 cm^{-1} and 3411 cm^{-1}), Si-O stretching (982 – 1116 cm^{-1}) and Al—O-H deformation (907 – 909 cm^{-1}). Si-O corresponding to quartz was ascribed to 749 cm^{-1}, 778 cm^{-1}, 794 cm^{-1} and 797 cm^{-1} transmittance bands. Si-O-Si stretching occurred at 677 cm^{-1}, 682 cm^{-1} and 691 cm^{-1} whereas Fe-O, Fe$_2$O$_3$, Al-O-Si, Si-O-Si and Si-O deformations were observed between 390 cm^{-1} and 523 cm^{-1}.

DISCUSSION

Characteristics of Geophagic Soils and Their Health Implications

Implications of Soil Colour

Colour could be indicative of mineralogy or presence of organic matter in the geophagic material. The most common shades employed to infer kaolin mineralogy are; white – cream, red, yellow – brown, and grey – green suggesting the presence of kaolinite, hematite, goethite and chlorite respectively (Frenandez-Caliani and Cantano 2010). Most of the samples were yellowish in colour (10YR), suggesting the presence goethite FeO(OH). Ngole et al. (2010) asserted that preference for reddish or brownish soils is based on the assumption that these materials are rich in iron. In general, iron in heam form (Fe^{2+}) is easily absorbed by the body unlike the non heam form (Fe^{3+}), with optimal uptake occurring in the duodenum (Bain et al. 2011). Given that colour of the geophagic samples from Moko suggest enrichment in goethite; their ingestion for iron supplementation may be justified to some extent. However, Fontes et al. (2005) and Ngole et al. (2010) cautioned that, the reddish or yellowish tint of soils could be used to infer the presence of Fe but not its quantity or bioavailability.

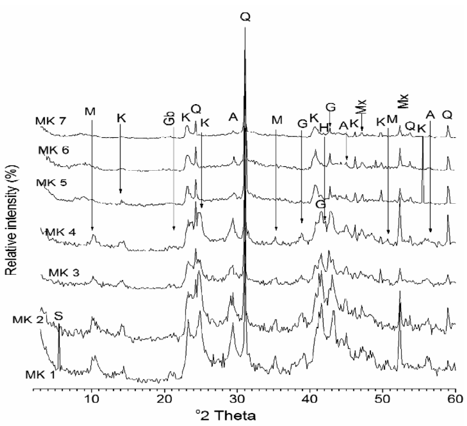

Fig. 1. X-ray diffractogram of analysed geophagic soils

Soil Textural Implications

Geophagic individuals are influenced by the texture of geophagic materials, with a preference for soil that is soft, silky or powdery. The studied samples were predominantly silty, and imparted a gritty feel to the materials. Geophagic soils that are gritty contain fine sand particles of quartz and feldspars which may negatively affect dental enamel of geophagic individuals. Quartz for example, with a higher degree of hardness of 7 on Mohr scale compared to dental enamel (5 on Mohr scale), can grind, crack and break dental enamel during mastication. (Ekosse and Anyangwe 2012). In addition, quartz particles in

Table 2: Bulk rock mineralogy of geophagic samples

Samples	K	Q	M	Mx	S	G	H	A	Gb
MK 1	+++	+++	++	+++	++	+++	+++	+++	+
MK 2	+++	+++	++	+++	++	+++	+++	+++	+
MK 3	+++	+++	+	++	–	+++	+++	++	+
MK 4	+++	+++	++	+	–	+++	+++	++	+
MK 5	+++	+++	+	++	–	++	–	+	–
MK 6	++	+++	+	++	–	++	–	+	–
MK 7	++	+++	+	++	–	++	–	+	–

(+++*)* Major, (++) minor, (+) trace, (–) not detected: k-kaolinite; Q-quartz; M-mica; Mx-microcline; S-smectite; G-goethite; H-hematite; A-anatase; Gb-gibbsite.

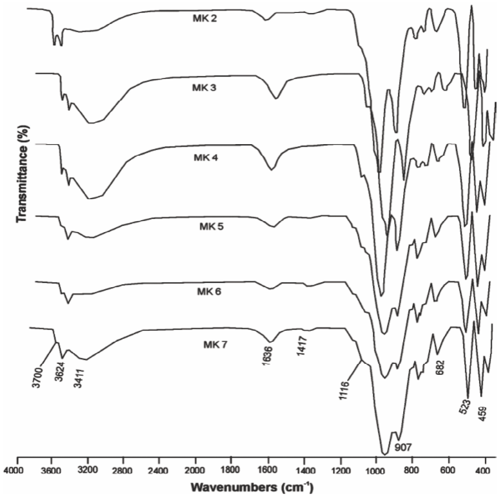

Fig. 2. Infra-red spectra of geophagic soils

geophagic soils can erode gastro-intestinal (GI) lining of geophagic individuals with the possibility of perforating the sigmoid colon (Barker 2005).

Implications of Soil Consistency Limits

Relief from nausea has been advanced as one of the reasons for ingesting soil especially by pregnant and lactating women (Mahaney et al. 2000). For these individuals, geophagic materials that tend to be slightly sticky during mastication are most effective in reducing salivation. This property of the geophagic material is based primarily on its consistency which in turn depends on the PSD and type of clay mineral present (Diko et al. 2011). The use of soil to reduce salivation is defined by its ability to absorb moisture during mastication. When soil comes in contact with moisture, it would exist in any of the four states; solid, semi-solid, plastic and liquid. For each state, the consistency and behaviour of the materials are different and so are their ability to reduce salivation and ultimately nausea. By ingesting dry soil and increasing its resident time in the mouth, the state changes from solid, through semi-plastic to plastic depending on how much moisture it can retain – thereby leaving the mouth dry, reducing salivation and ultimately curbing nausea (Ngole et al. 2010; Diko and Siewe 2014). Generally, soil with a plastic consistency is most effective in this regard. From Figure 3, the samples plot within the high plasticity field on the consistency diagram, and are thus considered suitable for use in relief of nausea associated with pregnancy.

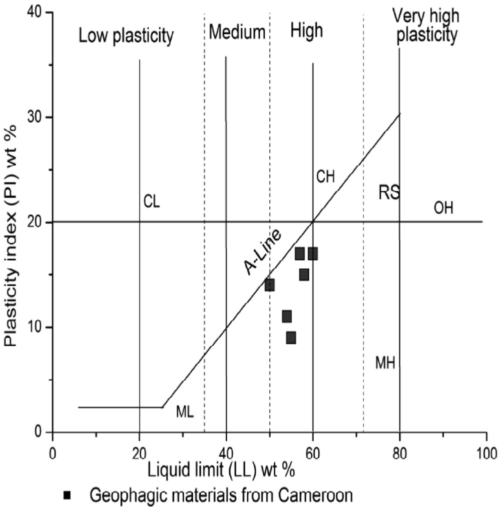

Fig. 3. Consistency limits of geophagic soils

Soil pH and EC Considerations

The pH and dissolved salt content of geophagic soils influences their taste. Generally, the more acidic soils tend to impart a sour taste. Ibeanu et al. (1997) reported the consumption of clay to control excessive secretion of saliva during pregnancy among women in Kenya and Nigeria. The use of soil to control secretion of saliva during pregnancy as reported by some women could be linked to the sour taste of the soil (Diko and Siewe 2014). The pH values of all the samples analysed from Moko, were in the acidic range and thus would impart a sour taste. The sour taste may be beneficial during pregnancy to prevent excessive secretion of saliva and reduce nausea. Electrical conductivity could be used to indicate the amount of dissolved salts in soils (Ngole et al. 2006). The geophagic soils all exhibited very low EC, indicating that the amount of dissolved salts contained in them were low. The taste of these samples is therefore not likely to have been influenced by the salt content.

Soil Mineralogical Considerations

Geophagic soils are mostly characterized by the presence of clay minerals. Clay minerals are secondary minerals derived from chemical alteration of mostly feldspars and micas. These minerals are dominantly alumino silicates made up of tetrahedron and octahedron sheets constituting a unit cell. The unit cell is characterized by layering yielding 1:1 and 2:1 classes of clay comprising kaolinite–serpentinite and smectites group respectively (Ekosse et al. 2010). The versatility displayed by the clay mineral structures allows for differential cationic substitution within the octahedral sites of the clay minerals, thereby influencing its mineralogy and physico-chemistry (Souza et al. 2002). The ability of geophagic soils to fulfil their desired objectives in humans is controlled in part by the type, amount and degree of crystallinity of clay mineral(s). Different clay minerals (such as kaolin and smectites) have variable properties (physical, chemical and mineralogical) that they may impart on soils. The inherent characteristic of soils is generally reflective of the predominant clay mineral present. However, crystallization of the predominant clay mineral(s) in soils is commonly associated with other clay and non-clay minerals in varying proportions (Souza et al. 2002). Interactions between these associated minerals and the structure of the predominant clay mineral (say kaolin for example), may reduce its degree of crystallinity and surface area (Oliveira et al. 2013). A decrease in surface area implies restriction in structural channels available for reactions such as adsorption and isomorphic substitution. As such, the ability of geophagic soils with poorly crystallized clay mineral constituents to be used for nutrient supplementation, detoxification or as antidiarrheal remedy will be significantly compromised.

The studied geophagic materials are enriched in kaolinite with minor amounts of smectite. The samples exhibited OH stretching and bending vibrations similar to that of theoretical kaolinite (Vaculikova et al. 2011). Results from IR spectrometry were well correlated with XRD data and equally inferred low to moderate kaolinite crystallinities associated with quartz and iron oxide contamination. Health impacts of quartz (that is, as free silica) have been discussed under textural implications above.

The small size of the clay minerals ($< 2\ \mu m$) accords them large surface areas over which adsorption of cations and micro-organisms could occur (Ekosse and Anyangwe 2012). This property enables clay minerals to create a surficial coating on the stomach with inferred pharmacological implications. Reactions such as isomorphic substitution occurring in the octahedral sheet of kaolinite is usually 67% filled, providing vacant sites for other ionic reactions. Isomorphic substitution is the process whereby one atom is replaced by another (for example, Al^{3+} for Si^{4+} in the tetrahedral and $Mg^{2+,}$ Fe^{2+} and Fe^{3+} for Al^{3+} in octahedral sheet) within the clay mineral structure, leading to a permanent negative charge (Ekosse et al. 2010). This reaction is particularly important in geophagic soils given that, the net negative charge readily accommodates cations that may be subsequently available for nutrient supplementation or assist with detoxification by forming complexes with toxins. With respect to the studied samples, iron from goethite and hematite could be supplied from the geophagic soils and absorbed as possible nutritional supplements (Abrahams et al. 2013). However due to contentious scientific debates with regards to soil ingestion and Fe deficiency anaemia in geophagic individuals (Brand et al. 2009) more in-depth studies with the soils from Moko are required.

CONCLUSION

The physico-chemistry and mineralogy of geophagic soils from Moko, Cameroon have been appraised and their possible health implications ascertained. Yellowish colour of the soils inferred significant amount of goethite. The presence of quartz and feldspar grains impart a gritty texture that may be detrimental to the health of the geophagic individuals. The soils had high plasticity and acidic pH rendering them suitable for use as remedy for relief of nausea and to curb salivation associated with pregnancy. The predominance of kaolinite in the materials was considered to play a significant role in ionic reactions such as isomorphous substitution and release of nutrients to the geophagic individuals.

RECOMMENDATIONS

Although the soils displayed very good geophagic properties, there are significant health concerns associated with high quartz content. Beneficiation to reduce/eliminate quartz content and detailed studies on the bioavailability of Fe from these soils is thus recommended.

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