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Full Length Research Paper

Physicochemical characteristics of geophagic clayey soils from South Africa and Swaziland

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Physicochemical properties of geophagic clayey soils from South Africa and Swaziland were determined in order to appreciate their capability to perform the functions for which they are consumed and possible consequences of the practice in humans. Tests conducted included colour, texture, pH, electrical conductivity (EC), water retention capacity (WRC), organic matter (OM) content and cation exchange capacity (CEC). The colour of the clayey soils ranged from grey to red. The soils varied texturally from loam to clay and had pH values of between 5.0 and 7.4. Values obtained for EC and OM content were generally low but those for WRC of the clayey soils were above 50% for all samples. These clayey soils, due to their colour are inferred to contain different forms of iron oxide minerals including haematite and goethite, which may help alleviate symptoms of iron deficiency anaemia. Their relatively high WRC may increase their effectiveness in the absorption of moisture in the gastrointestinal tract and therefore confirms the possibility of using these clays in the treatment of diarrhoea.

Key words: Soil pH, texture, cation exchange capacity, diarrhoea, water retention capacity.

INTRODUCTION

The contamination of food with soil and clay materials may not be regarded as a threat to human health but direct consumption of these materials may present a significant health threat (Committee on Research Priorities for Earth Science and Public Health, National Research Council, 2007). Soils/clays harbour billions of microbes some of which may be pathogenic and could cause disease if ingested. In addition, they may also contain toxic chemical substances which if ingested could pose a threat to human health. Deliberate ingestion of soil by human beings is referred to as geophagia (Diamond, 1999; Dominy et al., 2004; Johns and Duquette, 1991; Woywodt and Kiss 2002; Young et al., 2008). The practise of geophagia has, been reported in several countries across continents including Africa (South Africa, Cameroon, Democratic Republic of Congo, Nigeria, Swaziland, Tanzania and Uganda), Asia (China, India, Guatemala, New Guinea, Philippines, and Thailand) and the Americas (Abrahams and Parsons, 1997; Aufreiter et al., 1997; Callahan, 2003; Hunter and de Kleine, 1984; Hunter, 1973; Halsted, 1968; Johns and Duquette, 1991; Reid, 1992; Vermeer, 1966; Woywodt and Kiss, 2002).

Interactions between the ingested soil and the gastrointestinal fluids may result in the liberation of some of the toxic chemicals contained in the soils. Several studies have highlighted the role of soil physicochemical properties on the chemical processes that may take place in soil. Though this role has been established in soils in their natural environment, no such studies have been made on soils in the gastrointestinal tract and yet they could have some of the answers to the reasons behind the consumption of soils/clays and the likely consequences of the practice. A survey by Mahaney and Krishnamani (2003) revealed that most geophagic materials are not properly characterized in terms of their

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Table 1. Source, of geophagic clayey soil samples from South Africa and Swaziland.

Country	Sample number	Area from where sample was collected	Geographic coordinates
South Africa	SA1	Qwa Qwa	26°42'0''S, 28°13'0''E
	SA2	Qwa Qwa Market	26°42'15''S, 28°13'8''E
	SA3	Lusaka1, Qwa Qwa	28°24'14''S, 28°28'16''E
	SA4	Lusaka2, Qwa Qwa	28°24'14''S, 28°28'16''E
	SA5	Harrismith	28°16'0''S, 29°07'0''E
	SA6	Harrismith	28°16'0''S, 29°07'0''E
	SA7	Bloemfintein1	29°07'0''S, 26°11'0''E
	SA8	Bloemfiontein2	29°07'0''S, 26°11'0''E
	SA9	Bloemfontein3	29°07'0''S, 26°11'0''E
Swaziland	SZ1	Mahlanya	26°30'0''S, 31°17'0''E
	SZ2	Ezulwini	26°24'0''S, 31°10'0''E
	SZ3	Mbekelweni	26°26'25''S, 31°19'27'E
	SZ4	Nsingweni	28°56'60''S, 31°37'60''E
	SZ5a	Mphembekati (powder)	26°26'53''S, 31°23'43''E
	SZ5b	Mphembekati (Ball)	26°26'53''S, 31°23'43''E
	SZ6	Nsingweni	28°56'60''S, 31°37'60''E
	SZ7	Mbekelweni	26°26'25''S, 31°19'27'E

texture, pH, EC and CEC. Aufreita et al. (2000) and Mahaney et al. (2000) have reported on geophagic soils that have a pale yellow colour while Abraham (1997) identified dark grey red geophagic clays. Abraham and Parsons (1997) reported wt % clay of 28, 16 and 15 in geophagic soils from Thailand, Uganda and Zaire, respectively. Aufreiter et al. (1997) reported > 40 wt % clay in geophagic material from China. A range of 52 - 88 wt % clay has also been reported in geophagic samples from Indonesia (Mahaney et al., 2000) and 40% from Ivory Coast (Kikouama et al., 2009).

According to Wilson (2003) and Young et al. (2008), these physicochemical properties may aid in the interpretation of physiological and nutritional reasons for the practice. Iron supplementation for example has been the most popular reason to justify geophagia among humans (Dominy et al., 2004; Hooda, 2003; Jones and Hanson, 1985) but Reid (1992) and Severance et al. (1988) have shown that geophagia has in some cases resulted in rather than correct iron (Fe), zinc (Zn), or potassium (K) deficiencies. Brouillard and Rateau (1989) have attributed this occurrence to the cation exchange capacity (CEC) of the ingested soils, which is a physicochemical property. The use of geophagic material for the control of diarrhoea (Mahaney et al., 1996) is attributed to the surface area and water retention capacity of the soils/clays which are also physicochemical properties. These properties may dictate the inter-reactions between the ingested soil and other enzymes in the gastro-intestinal tract (GI) and consequently the ability of the soils to perform the very function for which they have been consumed (Hooda, 2003). This study thus aimed at characterizing the physicochemical properties of geophagic clayey soils from South Africa and Swaziland with a view of understanding whether they are capable of carrying out the functions that have been used to justify the practice of geophagia in humans.

MATERIALS AND METHODS

Samples of geophagic clayey soils commonly ingested by individuals in Free State Province of South Africa and the middle veldt region of Swaziland were obtained from different areas as indicated in Table 1. The collected clayey soil samples were air-dried and their physicochemical properties including texture, pH, EC, OM content, WRC and CEC determined. These properties were chosen because they have been reported to affect cation absorption reactions, water retention capacity and flocculation of soil particles which are some of the reasons that have been advanced to justify the practice of geophagia. The texture of the geophagic soils was determined by the hydrometer method after dispersing with sodium hexametaphosphate (Na_6PO_4) (van Reeuwijk, 2002). With the aid of a texture auto lookup Software Package (TAL Version 4.2), the results obtained from the PSA were used to determine the texture of each sample. The pH of the clayey soil samples was determined both in a 1:2.5 (soil: water) and soil: 1 M KCl suspension according to the methods advanced by van Reeuwijk (2002) and Palumbo et al. (2000). Electrical conductivity of samples was measured in the saturation paste extract of each sample as described in the United States of Soil Survey Laboratory Manual (1996).

The WRC of the soils was determined by percolating an excess amount of water through a known amount of each sample and determining the weight of the percolate after letting the soil stand

Table 2. Colour of analysed geophagic samples from some regions in South Africa and Swaziland.

Country	Sample number	Hue value and chroma of samples	Color of samples based on Munsell soil color charts
South Africa	SA1	7.5YR6/3	Dull brown
	SA2	5Y8/2	Light grey
	SA3	10YR7/4	Dull yellow orange
	SA4	5Y7/3	Light yellow
	SA5	10R5/8	Red
	SA6	2.5YR7/3	Light yellow
	SA7	7.5Y7/2	Light grey
	SA8	7.5Y7/2	Light grey
	SA9	7.5YR7/2	Light brownish grey
Swaziland	SZ1	10R5/6	Red
	SZ2	7.5R4/6	Red
	SZ3	10YR6/8	Bright yellowish brown
	SZ4	10YR8/3	Light yellow orange
	SZ5a	2.5YR5/8	Bright reddish brown
	SZ5b	7.5R3/6	Dark red
	SZ6	10Y8/1	Light grey
	SZ7	7.5Y7/1	Light grey

overnight weight of the percolate after the soil stood overnight was determined (Forster, 1995). Organic matter content of the clayey soil samples was analysed using the modified Walkley-Black wet combustion method as described by van Reeuwijk (2002). The barium chloride compulsive exchange method of CEC determination as described by Gilman and Sumpter (1986) was employed in the determination of the CEC of all samples. The significance of the differences observed between the means of physicochemical properties of geophagic clayey soils from South Africa and those from Swaziland were determined using the student's *t*-test.

RESULTS

Soil colour of samples, determined using the Munsell soil colour chart, showed that samples from South Africa were greyish to yellowish and those from Swaziland were mainly greyish to reddish (Table 2).

Texture of geophagic clayey soils

Samples from Swaziland had a significantly higher weight percent (wt %) sand (15 – 55 wt %) than those from South Africa (0 – 20 wt %) ($P < 0.05$). There was no significant difference in the wt % of silt in geophagic clayey soils from Swaziland (20 – 58) and South Africa (18 – 57) ($P > 0.05$). The clay content in the samples from South Africa (30 – 70 wt %) were however higher than that of samples from Swaziland (25 – 50 wt %) ($P < 0.05$). The textures of the samples from South Africa were clay, silty clay or silty clay loam whereas those from Swaziland were mainly clay, clay loam or loam (Figure 1).

pH of geophagic clayey soils

The $pH_{(H_2O)}$ of most samples were below 7 with geophagic soils from South Africa generally having lower pH values (5.69) than those from Swaziland (6.33) (Figure 2).This difference was however not significant ($P = 0.05$). Values for $pH_{(KCl)}$ of all samples were significantly lower than those of $pH_{(H_2O)}$ ($P < 0.05$) indicating that the samples were all negatively charged.

Electrical conductivity of geophagic clayey soils

All samples had very low EC values which indicated a low amount of dissolved salts in the soils/clays. Though the samples from South Africa had higher values for EC (mean EC = 59.99 μS/cm) compared to those from Swaziland (mean EC = 54.93 99 μS/cm) (Figure 3), these differences were not significant ($P > 0.05$).

Organic matter content of geophagic clayey soil

The OM content of the samples was generally very low

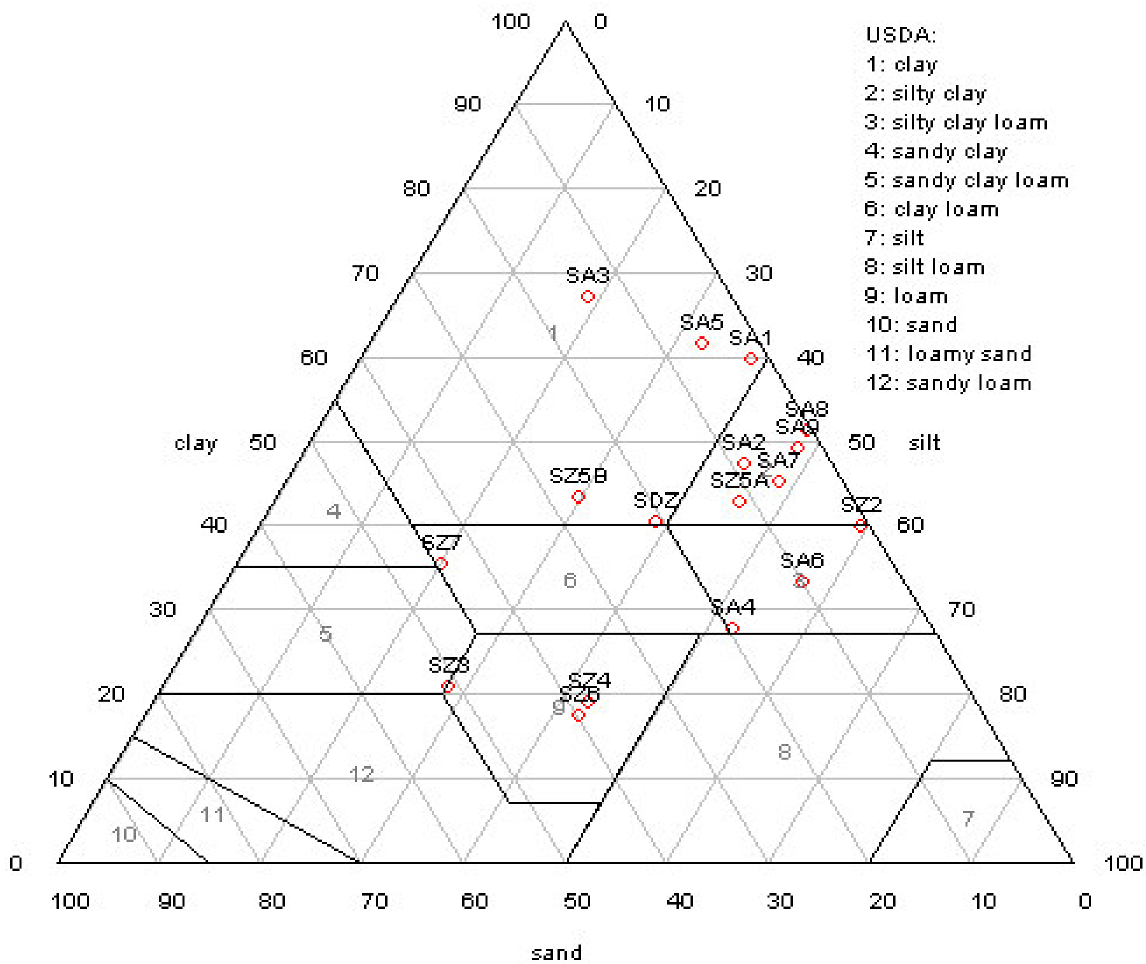

Figure 1. Textural triangle showing the textures of clayey soil samples from South Africa and Swaziland.

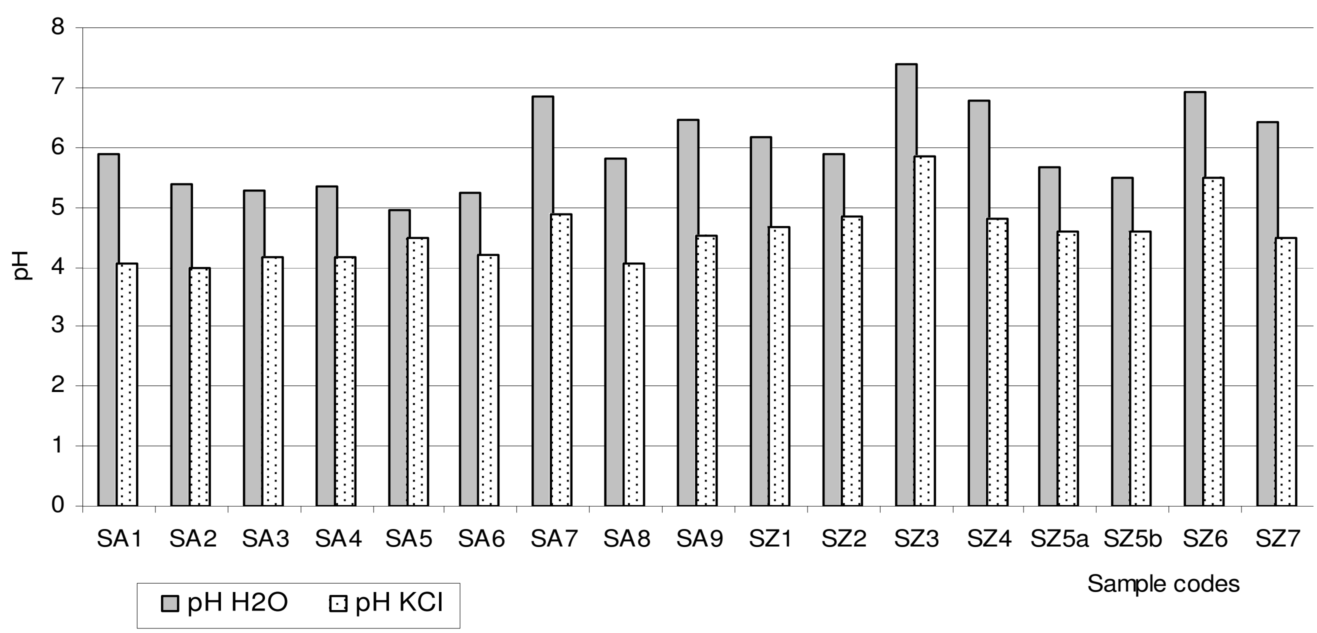

Figure 2. pH of geophagic clayey soil samples from South Africa and Swaziland.

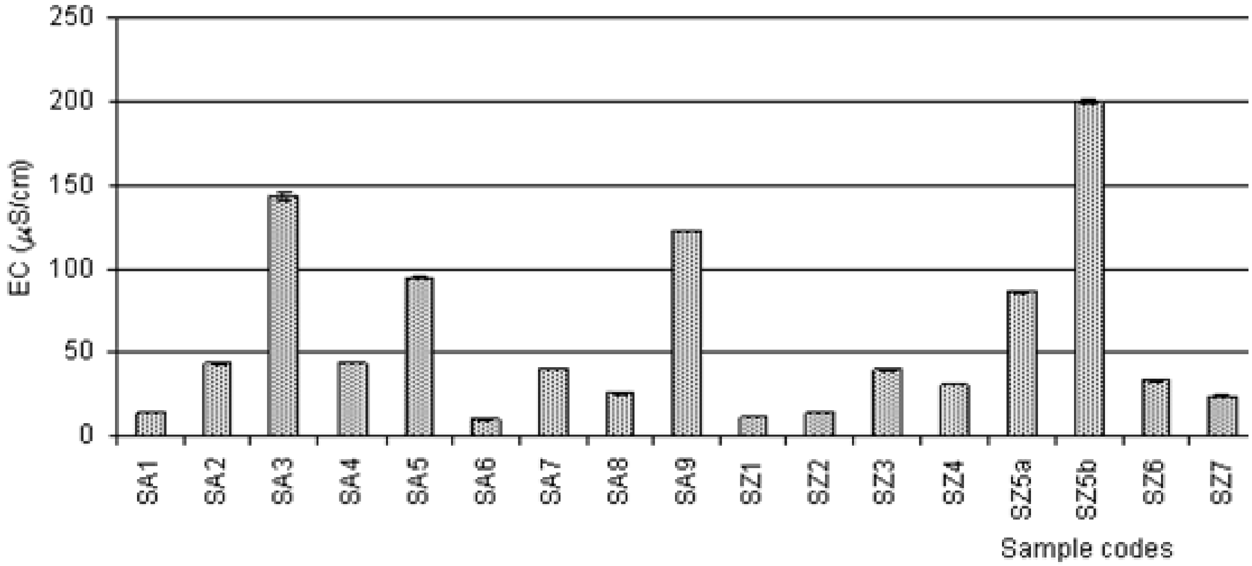

Figure 3. Electrical conductivity of geophagic clayey soil samples from South Africa and Swaziland.

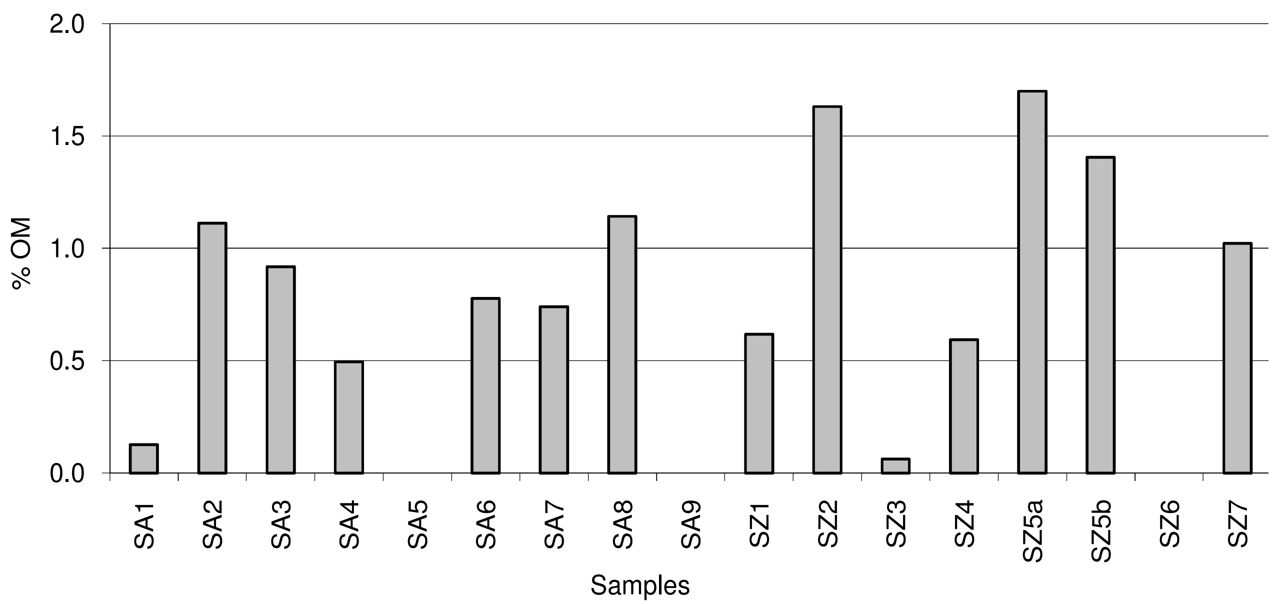

Figure 4. Organic matter content of geophagic clayey soil samples from South Africa and Swaziland.

ranging from 0-1.7% (Figure 4). Geophagic clayey samples from Swaziland generally had higher OM content than those from South Africa (Figure 4). These differences were however not significant ($P > 0.05$).

Water retention capacity (WRC) of geophagic clayey soils

The values of WRC of all samples ranged from 60% to 90% (Figure 5). Samples from Swaziland had a higher mean value for water retention (78.74 %) than those from South Africa (73.64 %). These differences were also insignificant ($P > 0.05$).

Cation exchange capacity of geophagic clayey soils

Geophagic clayey soil samples from Swaziland had significantly higher values for CEC compared to those from South Africa ($P < 0.05$), with mean CEC values of 9.60 and 7.28 Meq/100 g soil respectively for samples

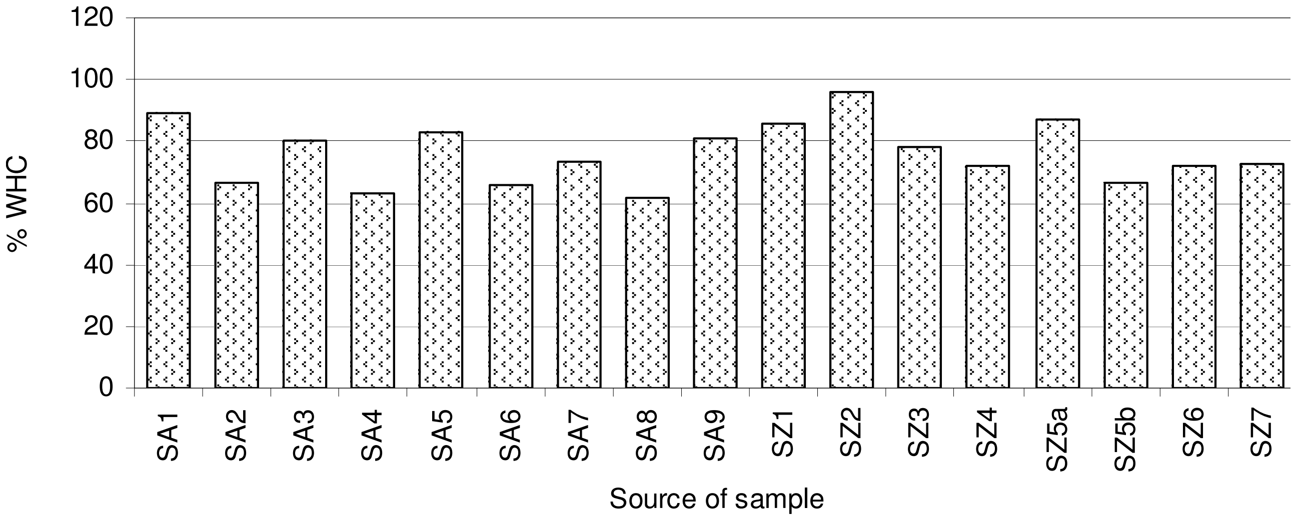

Figure 5. Water retention capacity of geophagic clayey soil samples from South Africa and Swaziland.

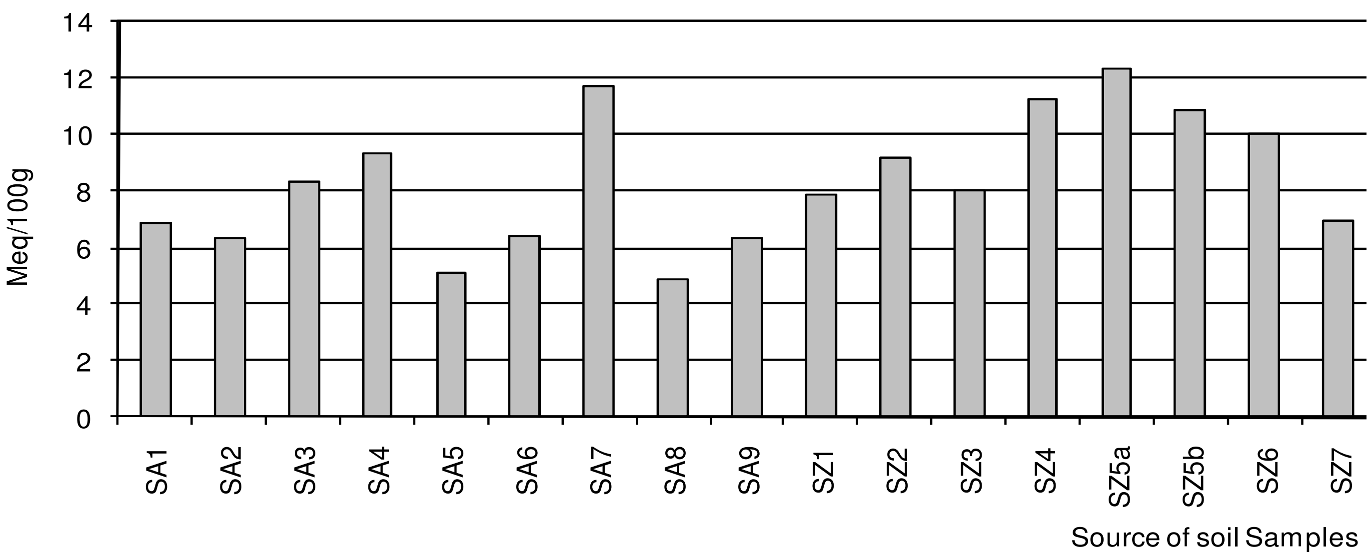

Figure 6. Cation exchange capacity of geophagic clayey soils samples.

from Swaziland and South Africa. The trends of CEC in both set of samples are indicated in Figure 6.

DISCUSSION

The amount of soil/clay that is consumed and the frequency of consumption vary from one person to the other. The health consequences of the practice may therefore vary from individual to individual depending on the amount, type and frequency of soil/clay ingestion. Most of the studied geophagic clayey soils had a hue of 2.5YR to 10YR corresponding to the colour of hematite (Fe_2O_3) and goethite FeO(OH). These hue values may therefore infer the occurrence of goethite and hematite in the samples. Both hematite and goethite are oxides of Fe in which the presence of one could depend on the reduction or oxidation of the other as illustrated in equations 1 and 2.

$$Fe^{2+} + O_2 + 4H^{3+} \rightleftharpoons 4Fe^{3+} + 2H_2O \quad \text{(Eqn 1)}$$

$$4Fe^{3+} + O_2 + 6H_2O \rightleftharpoons 4FeOOH + 8H^+ \quad \text{(Eqn 2)}$$

It is a general belief among geophagic individuals that reddish soils are rich in Fe and could be used to supplement Fe in humans. This belief is responsible for the association of red soil ingestion with Fe deficiency among humans. Geophagic individuals in Swaziland and South Africa also seem to prefer consuming clays that have yellowish to reddish tint. Preference for these clayey soil types could be attributed to their inferred Fe content. Fontes et al. (2005) has however cautioned that the reddish tint of soils could be used to infer the presence of Fe but not its quantities or availability.

Texture of geophagic clayey soil

Although the studied geophagic clayey soils were texturally dominated by silty clay, there was a considerable amount of sand present in the samples which may present some health risks. Sand particles are dominated by quartz (SiO_2), a very hard mineral measuring seven (7) on the Mohr hardness scale. Dental enamel which is the main inorganic component of the human tooth, is dominated by hydroxylapatite ($Ca_5(PO_4)_3(OH)$, (a calcium phosphate mineral), which is relatively softer than quartz. It has a hardness of five (5) on the Mohr hardness scale. Due to its relative hardness compared to teeth, sand particles in geophagic clayey soils could cause damage to dental enamel through grinding, cracking, splitting and breakage during mastication. Studies carried out by King et al. (1999) indicated that medium sized sand (250 - 500µm) caused severe dental damage in hominid species. Continuous ingestion of the geophagic clayey soils from Swaziland, being more sandy, would pose a greater risk of dental damage compared to those from South Africa. Perforation of the sigmoid colon has been reported in some geophagic individuals (Woywodt and Kiss, 1999). According to Lohn et al. (2000) foreign bodies in the small intestines can cause perforation and the most important considerations of these bodies are the size, shape and nature of the object. Individuals ingesting the geophagic soils from Swaziland are more at risk of intestinal perforations due to accumulation of quartz particles than those ingesting soils from South Africa.

pH of geophagic clayey samples

The pH of the studied geophagic samples ranged between 5 and 7. The pH value of human saliva varies between 5 and 8 according to Omen et al. (2000). The pH value of the geophagic clayey soils and human saliva are thus similar; no significant chemical reactions should occur in the clayey material in the mouth. The pH of the geophagic soil could also affect its taste. Acidic soils are reported to have a sour taste (Abrahams and Parsons, 1997). 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 taste of the soil which in turn is related to soil pH and dissolved salts content. The pH values of all the samples analyzed were in the acidic range which would impart a sour taste to the soils. The sour taste may be beneficial during pregnancy to prevent excessive secretion of saliva and reduce nausea.

Possible reactions involving clay minerals and organic matter in the geophagic soil could occur in the stomach because of the acidity (pH = 2) (Omen et al., 2000) of its gastric juice. However, residence time of ingested material in the stomach, being approximately 2 h, is inadequate for any significant reaction to occur. The low pH of the intestines would result in the release of cations that may have been adsorbed on the exchange sites of the ingested soil. In the duodenal and intestinal section of the GI where the pH is about 8 (Omen et al., 2000), some of the clay sized particles may undergo chemical reactions but the silt and sand-sized particles dominated mostly by silica may not be altered. The unaltered particles would pass through the GI and most likely be lodged in the diverticuli of the sigmoid colon. Similar observations have been reported by Jahanshahee et al. (2004) in a boy after prolonged consumption of sandy material. Due to the abrasive nature of these silica rich particles, possible lacerations, and eventual rupturing of the colon may ensure; a condition referred to as perforation of the sigmoid colon.

The studied geophagic clayey samples have reasonable pH buffering capacity as indicated by the values of $pH_{(KCl)}$. When ingested, the pH of these soils is not likely to drop to the pH of the stomach because of this buffering capacity. According to Young et al. (2008), solubility of Fe and other cations in the GI increases with a decrease in pH. Ingestion of any of these soils may prevent the stomach pH from dropping to levels that are favourable for Fe dissolution thereby reducing their bioavailability to the geophagic individual even where the Fe concentration in the ingested soil is high.

Electrical conductivity of geophagic clayey samples

Electrical conductivity could be used to indicate the amount of dissolved salts in clays and soils (Ekosse, 2000; Ngole et al., 2006). The geophagic clayey soils all exhibited a low EC, indicating that the amount of dissolved salts contained in them were low. The taste of these geophagic soils from both South Africa and Swaziland is not therefore likely to have been influenced by the salt content of the soils. The relationship between flocculation, soil pH and salt content has been reported by Goldberg and Foster (1990) and Kotlyar et al. (1998). Flocculation in geophagic clayey soils may influence their ability to coat the intestinal mucosa. The coating creates a shield that protects the intestines from the acidic gastric juice. The low salt content of these geophagic samples is not likely to have any influence on the degree of flocculation that may occur.

Organic matter content of geophagic clayey soils

The range of values obtained for OM content of the geophagic clayey soils (0.2 – 1.5%) are similar to those in geophagic material from Zaire, Thailand and Uganda (Abraham and Parsons, 1997). Organic matter in soils is a source of nitrogen (N) from which soil microbes could synthesise their proteins and DNA. Soils which are rich in OM are therefore likely to harbour more bacteria some of which may be pathogenic. Considering that the geophagic soils from both Swaziland and South Africa had low levels of OM, it is assumed that the pathogen load would also be low. The risk of bacterial infection including those of *E. coli*, *E. histolytica S. typhi* and helminth infection such as those of *A. lumbricoides*, *T. trichiura* and *S. stercoralis* as a consequence of consuming these soils would be low. The tendency of geophagic clayey materials harbouring these pathogens, though substantiated, was not verified in this study although an assumption is projected from the low OM content in the samples.

Water retention capacity (WRC) of geophagic clayey samples

Water retention is the ability of soils to process and hold large amounts of water (Brady and Weil, 1999). Geophagic clayey soils differ in terms of their WRC. Those with high clay content tend to have higher WRC compared to those with high sand content (Brady and Weil, 1999). The geophagic clayey soils from Swaziland and South Africa were silty to clayey in nature and would thus have considerable WRC. This property has been gainfully exploited in medicinal and pharmaceutical sciences where clays such as kaolin have been used to prepare formulations used in the treatment of diarrhoea and other GI related ailments (Murdoch, 1985).

One health reason advanced by geophagic practitioners for the ingestion of clayey soils is to curb diarrhoea. Diarrhoea could be caused by several factors including bacteria, viruses, stress and food poisoning. Geophagic clayey soils such as those studied, with high clay content are likely to have numerous micro pores in which bacteria some of which may be pathogenic, could be lodged. The survival rate of these pathogens in these geophagic soils would however be low because of low amounts of nutrients as indicated by the low levels of OM. These clayey soils also have considerable WRC and therefore have the ability to absorb water from the GI should in case it is infected with diarrhoea causing pathogens. An inferred role of these clayey soils in the control of diarrhoea is thus suggested.

Cation exchange capacity of geophagic clayey soils

For soils to serve as supplements for any one nutrient, the nutrient must be sufficiently present in the available form in the soil. Availability of the nutrient in the soil and eventually in the stomach is influenced by the soil texture and mineralogy; OM and pH which also influence soil CEC (Brady and Weil, 1999; Ngole et al., 2006). The CEC values were low compared to those reported by Abrahams and Parsons (1997), but they compare well with those from Turkey and lie within the range of 1:1 clay minerals CEC values (3 – 15 Meq/100g soil) (Brady and Weil, 1999). The adsorption capacity of these soils could be classified as low and their ingestion is not likely to result in adsorption of cations from the GI. Though not substantiated, the ability of these soils to supply cations including Fe to the geophagic individual will depend on the concentration of Fe in the soil ingested.

Clays with high CEC have been reported to absorb diarrhoea-causing enterotoxins (Brouillard and Rateau, 1989). Rateau et al. (1982) have also reported that the clay fraction of ingested soil protects the gastrointestinal epithelium because it forms cross linkages with glycoprotein in the intestinal mucosa. Because of their high clay content, the geophagic soils from South Africa could also form a coating along the digestive tract mucosa, shielding the GI from diarrhoea causing toxins and other toxic substances. This capability is enhanced by their acidic pH values, which according to Young et al. (2008) encourages clay flocculation. These impacts of geophagic practices on the geophagic individual would be less obvious when the geophagic soils/clays from Swaziland are consumed because of their lower clay content and circumneutral pH values.

Conclusions

This paper has examined the physico-chemical properties of geophagic clayey soils from South Africa and Swaziland. It has attempted to elucidate on reasons advanced by geophagic individuals engaged in the practice. Based on results obtained, the colour of the studied soils infers the presence of Fe which could be useful as a source of Fe supplement. Due to their low CEC, exchangeable Fe and other related cations may not be adsorbed but can be released and absorbed in the GI tract. The slightly acidic nature of the soils gives a sour taste which is mostly coveted by pregnant women in overcoming nausea and excess salivation. Absorption of water from the GI is a possibility, considering their high WRC. Possible human health shortcoming in the ingestion of the geophagic clayey soils would include dental enamel damage and perforation of the sigmoid colon.

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