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Soil type influences crop mineral composition in Malawi

Edward J.M. Joy [a,b], Martin R. Broadley [a], Scott D. Young [a], Colin R. Black [a], Allan D.C. Chilimba [c], E. Louise Ander [b], Thomas S. Barlow [b], Michael J. Watts [b,1]

[a] School of Biosciences, University of Nottingham, Sutton Bonington Campus, Loughborough, LE12 5RD, UK
[b] Centre for Environmental Geochemistry, Inorganic Chemistry, British Geological Survey, Keyworth, Nottingham NG12 5GG, UK
[c] Ministry of Agriculture and Food Security, Lunyangwa Research Station, P.O. Box 59, Mzuzu, Malawi

HIGHLIGHTS

- Plant samples collected across Malawi and analysed for elemental composition.
- Higher concentrations of Ca, Se and Zn in cereal grains from calcareous soils.
- Soil dust contributed 77% and 34% of Fe in leaf and grain samples, respectively.
- Nationally, average dietary supplies of Ca, Se and Zn are inadequate; Cu, Fe, Mg adequate.
- Estimated risks of Ca, Se and Zn deficiency lower in areas of calcareous soils.

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ABSTRACT

Food supply and composition data can be combined to estimate micronutrient intakes and deficiency risks among populations. These estimates can be improved by using local crop composition data that can capture environmental influences including soil type. This study aimed to provide spatially resolved crop composition data for Malawi, where information is currently limited.

Six hundred and fifty-two plant samples, representing 97 edible food items, were sampled from >150 sites in Malawi between 2011 and 2013. Samples were analysed by ICP-MS for up to 58 elements, including the essential minerals calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), selenium (Se) and zinc (Zn).

Maize grain Ca, Cu, Fe, Mg, Se and Zn concentrations were greater from plants grown on calcareous soils than those from the more widespread low-pH soils. Leafy vegetables from calcareous soils had elevated leaf Ca, Cu, Fe and Se concentrations, but lower Zn concentrations. Several foods were found to accumulate high levels of Se, including the leaves of *Moringa*, a crop not previously been reported in East African food composition data sets.

New estimates of national dietary mineral supplies were obtained for non-calcareous and calcareous soils. High risks of Ca (100%), Se (100%) and Zn (57%) dietary deficiencies are likely on non-calcareous soils. Deficiency risks on calcareous soils are high for Ca (97%), but lower for Se (34%) and Zn (31%). Risks of Cu, Fe and Mg deficiencies appear to be low on the basis of dietary supply levels.

1. Introduction

Mineral micronutrient deficiencies (MNDs) are an important global health problem, affecting up to two billion people worldwide (WHO, 2002, 2004, 2008, 2009; Muthayya et al., 2013). Estimates of deficiency for some minerals can be based on direct measurement of mineral concentrations or indicators in blood and other tissues or in urine (e.g., Gibson, 2005; Zimmermann, 2008; Fairweather-Tait et al., 2011). Alternatively, food consumption or supply data can be used to calculate dietary mineral intakes and infer deficiency risks. These methods include direct intake assessments from duplicate dietary analyses (e.g., Hurst et al., 2013) or, in conjunction with food composition tables (FCTs), individual recall-based dietary surveys (e.g., Gibson and Huddle, 1998; Department of Health/Food Standards Agency, 2011), household consumption data (e.g., Ecker and Qaim, 2011) and national Food Balance Sheets (FBSs) available from the United Nations Food and Agriculture Organization (FAO, 2014) (e.g., Broadley et al., 2012; Joy et al., 2014).

Previous studies to estimate mineral deficiency risks in Malawi using dietary recall or food records in combination with local or regional composition data have reported a high risk of zinc (Zn) deficiency in children (Ferguson et al., 1989), calcium (Ca) and Zn in pregnant women

E-mail address: mwatts@bgs.ac.uk (M.J. Watts).
[1] Tel.: +44 115 936 3042.

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Table 1
Summary of published estimates of dietary nutrient supplies in Malawi.

Nutrient	Supply (mg *capita*$^{-1}$ d^{-1})	Population (n)	Region	Methodology	Reference
Ca Zn Phytate	410, 335, 350 6.8, 6.2, 6.4 1621, 1667, 1729	Females 4–6 years: harvest season (60), post-harvest (60), pre-harvest (62)	Rural area, southern Malawi	Mean from three-day food records and local/published composition data	Ferguson et al. (1989)
Ca Zn Phytate	473, 342, 379 7.8, 7.0, 8.0 1921, 1857, 2161	Males 4–6 years: at harvest (60), post-harvest (60), pre-harvest (62)			
Ca Cu Fe Zn	415 1.0 14.8 9.0	Pregnant women (141)	Rural area, Mangochi	Median from 24 h recall and local food composition data	Gibson and Huddle (1998)
Se	0.044, 0.046	TB patients (40) and controls (40)	Rural area, Mangochi	Median from 24 h recall and local composition data	Eick et al. (2009)
Fe Zn	19.0 10.2	11,280 nationally representative households	National	Mean from HH survey and regional composition data	Ecker and Qaim (2011)
Ca Mg	306 789	National	National	Mean from FBSs and local/ regional composition data	Broadley et al. (2012)
Fe Se Zn	16.6 0.0066 4.8	Adult women (55)	Rural area, soil pH <4.5	Median from one-day-weighed duplicate diet composites	Hurst et al. (2013); Siyame et al. (2013)
Fe Se Zn	29.6 0.0553 6.4	Adult women (58)	Rural area, soil pH >6.5		
Ca Cu Fe Mg Se Zn	592 2.95 29.1 760 0.0336 11.8	National	National	Mean from FBSs and regional composition data	Joy et al. (2014)

(Gibson and Huddle, 1998) and selenium (Se) in adults (Eick et al., 2009; Table 1). Local food composition data are likely to improve estimates of mineral deficiency risks in Malawi and a strong influence of soil type on the concentration of Se in maize grain and dietary composites has been identified. Chilimba et al. (2011) observed mean and median concentrations of Se in maize grain of 0.022 and 0.016 mg kg^{-1} on low pH soils ($n = 72$), but 0.298 and 0.342 mg kg^{-1} on Eutric Vertisols (pH >6.9, $n = 16$). Such variation is consistent with earlier findings as Donovan et al. (1991) reported a mean Se concentration in refined maize flour in Zomba District of 0.029 mg kg^{-1} ($n = 10$), while Eick et al. (2009) reported a mean concentration in Mangochi District of 0.078 mg kg^{-1} (n > 20; Supplementary Table 1). Analyses of composite diets showed that the median Se intake of women from villages with predominantly non-calcareous soils (pH <4,5) in Zombwe Extension Planning Area (EPA) was 6.6 μg d^{-1} (range 1.1-62.3, $n = 55$) but was eight-fold greater in villages with predominantly calcareous soils in Mikalango EPA (median 55.3 μg d^{-1}, range 5.8-192, $n = 58$); the estimated average requirement (EAR) for adult females is 45 μg d^{-1} (IOM, 2000a). Women in Mikalango EPA had greater median concentration of Se in blood plasma (117 μg L^{-1}, range 82.6-204, $n = 60$) compared to subjects from Zombwe EPA (53.7 μg L^{-1}, range 32.4-78.4, $n = 60$; Hurst et al., 2013).

There is evidence of spatial variation in dietary supplies of other elements, with median intakes of iron (Fe) and Zn of 29.6 and 6.4 mg d^{-1} diets, respectively, among Mikalango subjects compared to 16.6 and 4.8 mg d^{-1} for subjects from Zombwe EPA (Siyame et al., 2013); for diets low in animal products, the adult female EARs of Fe and Zn are 13.4 mg d^{-1} and 8.2 mg d^{-1}, respectively (WHO and FAO, 2004). Low Zn intakes and high phytate:Zn ratios are likely to be the cause of low plasma Zn status, with 92 and 95% of plasma Zn concentrations <10.7 μmol L^{-1} in Zombwe and Mikalango EPAs, respectively. In contrast, the majority of subjects in Zombwe (70%) and Mikalango (78%) EPAs were Fe-sufficient (body Fe >0 mg kg^{-1} and haemoglobin >120 g L^{-1}). Despite greater intakes of Fe on high-pH soils, body Fe and haemoglobin (Hb) concentrations were greater on low pH soils. Consistent with these findings, Dickinson et al. (2009, 2014) reported greater blood Fe and Hb, but lower Se, concentrations among pregnant women living in villages on low- compared to high-pH soils in southern Malawi. Zinc deficiency was also apparent in the low- and high-pH soil groups, with mean concentrations in the plasma of 9.8 and 10.3 μmol L^{-1}, respectively.

At a national level, Ecker and Qaim (2011) estimated dietary Fe and Zn supplies to be adequate although intakes are highly dependent on income, using food supply data from the Malawi Second Integrated Household Survey (NSO, 2005) combined with regional food composition data (Table 1). Broadley et al. (2012) found that risks of deficiency are likely to be high for Ca but low for Mg in Malawi based on FBS supply data and national maize composition data. Overall, published sources suggest that risks of dietary mineral deficiencies of calcium (Ca), selenium (Se) and zinc (Zn) are likely to be high in Malawi, as for many other countries in sub-Saharan Africa (Joy et al., 2014), and that environmental factors such as soil type are an important consideration.

Risk estimates are sensitive to the quality of composition data, especially for elements required in trace quantities (sub-milligram *per capita per* day). The FCTs of greatest potential relevance to Malawi, and which have been used previously (Joy et al., 2014), are those for Tanzania (Lukmanji et al., 2008), Mozambique (Korkalo et al., 2011) and South Africa (Wolmarans et al., 2010). Further, Malawian food composition data for commonly consumed items were reported by Ferguson et al. (1988, 1989, 1993), Donovan et al. (1991), Eick et al. (2009) and Dickinson et al. (2014). However, some elements and foodstuffs are not adequately represented in these data sets; for example, Gibson et al. (2011) were not able to assess dietary Se intakes because of limited data on the Se concentration of local foodstuffs.

This study aimed to provide crop composition data for a wide range of food items and investigate the influence of soil type on national-level dietary mineral supplies. As maize grain is commonly processed into flour in Malawi during preparation of the staple dish, *nsima*, flour samples were taken to test the effect of household processing on elemental composition. Composition data were obtained for up to 58 elements in 652 plant samples, representing 97 edible food items collected from >150 different locations in Malawi, including grains, roots, tubers, fruits and leaves. Coupled soil samples were also taken where possible and