Original Communication

Dietary Requirements for Magnesium, but not Calcium, are Likely to be met in Malawi Based on National Food Supply Data

Martin R. Broadley[1], Allan D.C. Chilimba[1,2], Edward J. M. Joy[1,3], Scott D. Young[1], Colin R. Black[1], E. Louise Ander[3], Michael J. Watts[3], Rachel Hurst[4], Susan J. Fairweather-Tait[4], Philip J. White[5], and Rosalind S. Gibson[6]

[1]School of Biosciences, University of Nottingham, Sutton Bonington Campus, Loughborough, United Kingdom
[2]Ministry of Agriculture and Food Security, Department of Agricultural Research Services, Lunyangwa Research Station, Mzuzu, Malawi
[3]British Geological Survey, Keyworth, Nottingham, United Kingdom
[4]Department of Nutrition, Norwich Medical School, University of East Anglia, Norwich, United Kingdom
[5]The James Hutton Institute, Invergowrie, Dundee, United Kingdom
[6]University of Otago, Dunedin, New Zealand

Abstract: Mineral malnutrition is widespread in sub-Saharan Africa but its extent is difficult to quantify. Using Malawi as a case study, the aim of this work was to investigate the adequacy of calcium (Ca) and magnesium (Mg) nutrition by combining national food supply and food composition data with a new spatial survey of maize grain. Non-maize dietary sources of Ca and Mg were estimated using existing food supply and composition data. Calcium and Mg concentrations in maize grain were determined at 88 field sites, representing > 75 % of Malawi's land area in terms of soil classification. Median maize grain concentrations from the survey were 34 and 845 mg kg^{-1}, representing a *per capita* supply of 12 and 299 mg d^{-1} of Ca and Mg, respectively. Combining these data with food supply and composition data reveals that average Ca nutrition is likely to be inadequate for many individuals, whereas average Mg nutrition appears adequate. Optimal supply of Ca *per capita* depends critically on balanced food availability and choice. Since maize grain sourced from highly calcareous soils is still unlikely to deliver > 5 % of estimated average requirements, agronomic solutions to rectify Ca malnutrition *via* maize are limited, in comparison with strategies for dietary diversification.

Key words: biofortification, calcium, fertilizers, GIS, magnesium, maize, micronutrients, soil

Introduction

Calcium (Ca) and magnesium (Mg) are among the most abundant mineral components of the human body. There are many physiological disorders associated with Ca and Mg deficiency [1–3]. Calcium deficiency is linked to bone-related disorders; for example, rickets and osteomalacia are associated with inadequate Ca intake and poor absorption. Magnesium deficiency affects energy metabolism and electrolyte balance, and is linked to cardiovascular, neuromuscular, and personality disorders. However, identifying Ca and Mg deficiency in human populations is difficult because there are no reliable biomarkers of Ca and Mg status due to their tight homeostatic regulation. Hence, data on the global extent of Ca and Mg deficiencies in humans are limited [4].

The prevalence of inadequate intakes of Ca and Mg is typically used to identify population groups most at risk of deficiency [1–4]. Unfortunately, few low-income countries have conducted national food consumption surveys, so the global extent of inadequate intakes of Ca and Mg is unknown. However, alternative sources of information such as data from Food Balance Sheets (FBSs) published by the Food and Agriculture Organization (FAO) for ~180 countries and territories can provide suggestive evidence of the adequacy of Ca and Mg intakes in low-income countries. National FBSs indicate the quantity produced of each foodstuff, plus imports, which is then adjusted to take account of changes of stocks in storage [5]. Subsequently, utilization quantity is obtained after adjustments for exports and non-food uses including livestock feeds and seed production. Estimates of food supply are based at a retail level; i. e. they represent the supply of a foodstuff leaving the retailer or otherwise entering the household. No account is made for losses of a foodstuff at a household level. Furthermore, FBSs do not provide information on seasonal changes in supply, or information on food supply at the household or individual level.

The aim of this work was to estimate the risk of inadequate Ca and Mg nutrition from the national food supply among a population in Sub-Saharan Africa (SSA), using Malawi as a case study. Malawi was chosen primarily because it has a large rural population engaged in subsistence agriculture, whose diets are dominated by maize [6]. Furthermore, detailed soil maps exist for Malawi (1:50,000 scale), which provide a framework for data integration if it is assumed that the transfer of mineral nutrients from soil to crops is similar within each soil type [7]. Food composition data are also available for Malawi [8, 9] and neighboring Tanzania [10]. In a previous study we used FBSs, along with new survey data for soils and maize grain and spatially informed extrapolations based on soil type, to show that ~90 % of the population of Malawi is likely to have access to $<30\ \mu g\ capita^{-1}\ d^{-1}$ of the essential micronutrient selenium (Se) [7], reflecting a suboptimal level of intake. A similar strategy was adopted in the present study.

Materials and Methods

The average *per capita* supply of Ca and Mg was estimated from food supply and food composition data. Food supply data were sourced from the most recent FAO databases [11], which provide FBSs for 2007. Food composition data for the major categories of FAO food commodities were sourced primarily from studies by Ferguson and colleagues [8, 9]. These studies are based on information collected for up to 44 foodstuffs purchased at three local markets and used at a household level within a rural village in Zomba District. Calcium concentrations were measured using flame atomic absorption spectrophotometry (AAS); Mg concentrations were measured using X-ray fluorescence (XRF). Where Ca and Mg data for the major FAO food commodities were not provided by Ferguson and colleagues [8,9], data were sourced from the *Tanzania Food Composition Tables* [10] or from the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) Nutrient Database for Standard Reference [12].

A spatially-referenced survey of soil and maize grain was conducted to improve assessments of dietary supply of Ca and Mg. Sampling procedures are described in a previous study of Se [7]. Briefly, in 2009, soil and maize grain were sampled from 73 sites, representing seven of the eight Agricultural Development Divisions (ADDs) and > 75 % of the national soil types based on primary FAO soil classifications. In 2010, a further 15 sites with high soil pH values (>6.5) were sampled at locations in the Shire Valley ADD. Each sample represents a composite pool of eight subsamples. Sample preparation and analysis are described in detail by Chilimba and colleagues [7]. Dried and sieved (<2 mm) soils (~0.2 g dry weight, DW) were digested fully in open top vessels using Trace Analysis Grade (TAG) 70 % HF, 70 % HNO_3, and 60 % $HClO_4$ (Fisher Scientific UK Ltd, Loughborough, Leicestershire, UK). Dried and finely milled samples of maize grain (~0.4 g DW) were microwave-digested in 3.0 mL of 70 % TAG HNO_3, 2.0 mL H_2O_2, and 3.0 mL milli-Q

Table I: Contribution of 26 major food commodity groups to average daily *per capita* Ca and Mg supply in Malawi. Food supply data were sourced from FAO Food Balance Sheets for 2007 [11]. Sources of food composition data are given as superscripts in the "Notes" columns: [a][8], [b][9], [c][10].

FAO supply data		Calcium			Magnesium		
Category and supply (g *capita*$^{-1}$ d^{-1})		Notes	Conc. (mg g^{-1})	Supply (mg *capita*$^{-1}$ d^{-1})	Notes	Conc. (mg g^{-1})	Supply (mg *capita*$^{-1}$ d^{-1})
Total supply (g *capita*$^{-1}$ d^{-1})				306.4			789.0
Maize	354	[a]White ufa (*nsima*)	0.03	10.6	[b]Mgayewa flour	1.52	538.5
Potatoes	275	[c]Cooked	0.05	13.7	[c]Cooked	0.25	68.7
Cassava	197	[b]Boiled	0.26	51.3	[b]Boiled	0.22	43.4
Bananas	67	[c]Ripe	0.05	3.3	[c]Ripe	0.27	18.0
Plantains	56	[a]Banana	0.09	5.1	[c]Ripe	0.27	15.2
Fruits, Other	46	[b]Raw	0.12	5.5	[c]Ripe, fresh, edible portion	0.09	4.1
Veg, other	42	[a]Chinese cabbage	0.97	40.8	[b]Chinese cabbage	0.15	6.3
Beverages, Fermented	41	[c]Beer, local, grain	0.05	2.0	[c]Beer, local, grain	0.06	2.4
Sugar (raw)	33	[c]Sugar	0.01	0.3	[c]Sugar	0.00	0.0
Pulses, other	23	[a]Pigeon pea	0.42	9.8	[b]Cow pea	0.48	11.2
Wheat	17	[c]Flour, whole grain	0.15	2.6	[c]Flour, whole grain	0.22	3.8
Beans	13	[a]Bengal beans	0.24	3.2	[b]Bengal beans	0.28	3.7
Freshwater Fish	13	[b]Catfish (dried)	9.29	119.7	[b]Catfish (dried)	1.61	20.8
Groundnuts (shelled)	13	[a]Boiled	0.41	5.3	[c]Groundnuts	1.68	21.6
Rice (milled)	12	[b]Rice	0.00	0.0	[b]Rice	1.69	20.9
Onions	10	[c]Raw	0.23	2.3	[c]Raw	0.10	1.0
Milk, excl. butter	10	[c]Whole, 3.25% fat	1.15	11.1	[c]Whole, 3.25% fat	0.11	1.1
Tomatoes	7	[c]Ripe	0.05	0.3	[c]Ripe	0.11	0.8
Sorghum	6	[a]Sorghum flour	0.07	0.4	[c]Sorghum total grain	0.34	2.0
Millet	6	[c]Finger, grain or flour	2.75	15.6	[c]Finger, grain or flour	0.27	1.5
Beer	5	[c]Commerc-ial	0.05	0.3	[c]Commercial	0.06	0.3
Bovine Meat	5	[c]Medium fat, cooked	0.04	0.2	[c]Medium fat, cooked	0.23	1.2
Pig Meat	5	[c]Medium fat, cooked	0.18	0.9	[c]Medium fat, cooked	0.17	0.8
Mutton & Goat Meat	3	[c]Goat meat	0.04	0.1	[c]Goat meat	0.23	0.8
Eggs	3	[c]Chicken	0.50	1.6	[b]Duck	0.14	0.4
Poultry Meat	3	[c]Boiled or roasted	0.13	0.4	[c]Boiled or roasted	0.20	0.6

Table II: Soil and maize grain concentration data for Ca and Mg. Samples were collected at 88 sites [7].

	Soil concentration ($g\ kg^{-1}$)		Grain concentration ($mg\ kg^{-1}$)	
	Ca	Mg	Ca	Mg
Mean	10.15	5.08	38	871
Median	5.09	2.88	34	845
n	82	82	83	86
Minimum	–[a]	0.35	15	554
Maximum	43.23	26.10	99	1388
Intake (mg *capita*$^{-1}$ d^{-1})			12	299

[a]Below limit of detection

water (18.2 MΩ cm; Fisher Scientific UK Ltd). Elemental analysis was conducted using inductively coupled plasma-mass spectrometry (ICP-MS; X-Series[II], Thermo Fisher Scientific Inc., Waltham, MA, USA), following appropriate dilutions. Internal and external quality controls were used including certified reference materials and sample blanks. Grain data were excluded from the analysis if there was evidence that >25 % of the grain Ca and Mg concentration could be attributed to soil contamination, based on soil:grain aluminum (Al) concentration ratios.

Data from soil and maize grain surveys were integrated spatially within the geographical information system (GIS) described by Chilimba and colleagues [7]. First, median grain Ca and Mg concentrations for each primary soil classification were calculated. Second, the area represented by each primary soil classification within each administrative unit (District; n = 28) was estimated using ArcGIS (v. 9.3, ESRI, Redlands, CA, USA), using the most recent cartographic data for FAO soil series [13]. Third, by extrapolation, grain Ca and Mg concentrations were predicted for crops growing on soils representing >75 % of the land area in Malawi. Dietary Ca and Mg intakes from maize were estimated assuming a homogeneous *per capita* consumption of maize derived from FBSs.

Results and Discussion

Food supply data *per capita* for 92 categories of food commodities were combined with food composition data for Malawi [8, 9], or, where these data were unavailable, for Tanzania [10] or the US [12]. Across all 92 categories of food commodities, the average daily supply of Ca and Mg is 341 and 792 mg *capita*$^{-1}$ d^{-1}, respectively. Data for the 26 dominant major food commodities, ranked in terms of their contribution to food supply in terms of grams *per capita* per day, are summarized in Table I. Taken together, these 26 food commodities accounted for 98.1 and 99.3 % of the total supply of Ca and Mg in 2007. The dominant food groups for Ca supply (mg Ca *capita*$^{-1}$ d^{-1} in parentheses) are freshwater fish (120), followed by cassava (51), other vegetables (41; N.B. these data are based on composition data for Chinese cabbage), millet (16), potato (14), and maize (11). The dominant food group for Mg supply (mg Mg *capita*$^{-1}$ d^{-1} in parentheses) by far is maize (539), with potato (69), cassava (43), groundnut (22), rice (21), and freshwater fish (21) contributing smaller amounts. Based on the World Health Organization (WHO)/FAO estimated average requirement (EAR) for Ca of 833 mg *capita*$^{-1}$ d^{-1} for adults aged 19 to 50 years [14], these data suggest the potential for dietary Ca inadequacies within the national food system in Malawi. Conversely, given an EAR of 217 mg *capita*$^{-1}$ d^{-1} of Mg for adult males, the supply of Mg is likely to be sufficient within Malawi.

To refine Ca and Mg supply data, spatially-referenced soil and maize grain data were obtained (Table II). Median maize grain concentrations were 34 mg Ca kg^{-1} and 845 mg Mg kg^{-1}. Based on a supply of 354 g maize *capita*$^{-1}$ d^{-1}, which represents ~50 % of dietary energy availability in Malawi, these grain composition data translate to a supply from maize of 12 and 299 mg *capita*$^{-1}$ d^{-1} of Ca and Mg, respectively. Published maize grain composition data for Malawi [8, 9] indicate a supply from maize of 11 and 539 mg *capita*$^{-1}$ d^{-1} of Ca and Mg, respectively (Table I). Thus, whilst the new survey data reveal lower mean Mg concentrations in maize grain, national Mg supply is still sufficient in overall terms. Risk of deficiency may still result from inequalities of food distribution, food preparation (especially grain milling), and health complications.

Table III: Median maize grain Ca and Mg concentrations according to primary FAO soil classification [13].

FAO soil classification		Grain Ca concentration				Grain Mg concentration			
Group	Area (m^2)	n	Percentiles (mg kg^{-1})			n	Percentiles (mg kg^{-1})		
			25th	50th	75th		25th	50th	75th
Haplic Lixisols	25,691	11	29.2	36.2	40.1	11	750	853	1,025
Chromic Luvisols	21,546	22	29.5	31.4	37.0	22	755	799	915
Eutric Cambisols	13,026	11	32.7	38.1	41.4	11	798	836	922
Haplic Luvisosols	4,801	3	27.3	29.3	30.5	3	790	798	816
Ferralic Cambisols	3,778	6	22.1	28.4	40.6	6	762	866	925
Rhodic Ferralsols	1,553	7	22.2	29.0	38.7	7	681	744	907
Chromic Cambisols	1,346	6	18.7	20.0	33.7	6	779	845	869
Eutric Planosols	859	2	–	33.5	–	2	–	802	–
Humic Alisols	486	2	–	19.5	–	2	–	624	–
Eutric Vertisols	473	13	58.1	65.6	75.4	16	967	1,029	1,134
Other soil types	21,821	–	–	–	–	–	–	–	–
Total area	95,380								

To explore further the dietary supply of Ca and Mg *via* maize in Malawi, the data for the nutrient status of grain were integrated spatially using the approach described previously for Se [7], in which the median grain concentration for each element was extrapolated across primary soil classifications (Table III). Grain sampled from crops growing on calcareous (pH>6.5) Eutric Vertisols, in the Shire Valley ADD, had higher levels of Ca and Mg than other soil types. This extrapolation can be visualized in graphical terms (Figure 1). Although such maps are necessarily speculative, they nevertheless reveal the extent to which common soil types could influence mineral supplies through the food chain, thereby providing a framework to identify sites for further geochemical investigation. The effect of soil type on grain Ca and Mg concentration is low compared to previous studies of Se [7]. Thus, even grain from the upper 25th percentile (75.4 mg kg^{-1}) of Ca concentrations from Eutric Vertisols would only supply 26.7 mg *capita*$^{-1}$ d^{-1} of Ca; i. e. 3.2 % of the WHO/FAO EAR for Ca. Whilst liming or fertilization strategies to improve dietary Ca intake *via* horticultural crops may be feasible [4], it seems unlikely that the application of such agronomic measures to maize would be sufficient to address the shortfall of Ca in the food supply chain.

Published national food supply and food composition data reveal a significant potential shortfall in Ca supply to the Malawi population. These data are consistent with new information from wider sampling of maize grain from soils representing >75 % of the primary soil classifications in Malawi. There is no evidence of similar national shortfalls in Mg supply. There are some caveats to this analysis. The first is that data from FBSs do not account for food supplied by non-commercial production, which will include some foods high in Ca, such as small fish eaten whole with bones, vegetables, or dairy products from domestic goats. To address this issue, estimates of food supply can be improved through the use of dietary surveys. In a recent study, Ecker and Qaim [15] estimated dietary intake of iron and zinc in Malawi using food consumption data for 11,280 households from the second Malawi Integrated Household Survey (IHS; 2004/05). We therefore tested our *per capita* estimates of Ca and Mg supply from FBSs against HIS consumption data [15]. From IHS data, dietary Ca intake estimates are 507 mg *capita*$^{-1}$ d^{-1}; i. e. approximately one third more than estimates of dietary Ca intake based on FBSs. This is due primarily to the reported consumption of 29 g *capita*$^{-1}$ d^{-1} of freshwater fish in the IHS, compared to the supply of 13 g *capita*$^{-1}$ d^{-1} reported in the FBSs (assuming that fish bones are consumed). If fish data are excluded from the comparison, dietary Ca intake estimates from the IHS are within ~5 % of those based on supply data from the FBSs. Thus, data from the IHS still shows risk of widespread dietary Ca deficiency in Malawi. Dietary Mg intake estimates from the IHS (807 mg *capita*$^{-1}$ d^{-1}) are within ~2 % of those based on supply data from the FBSs (792 mg *capita*$^{-1}$ d^{-1})

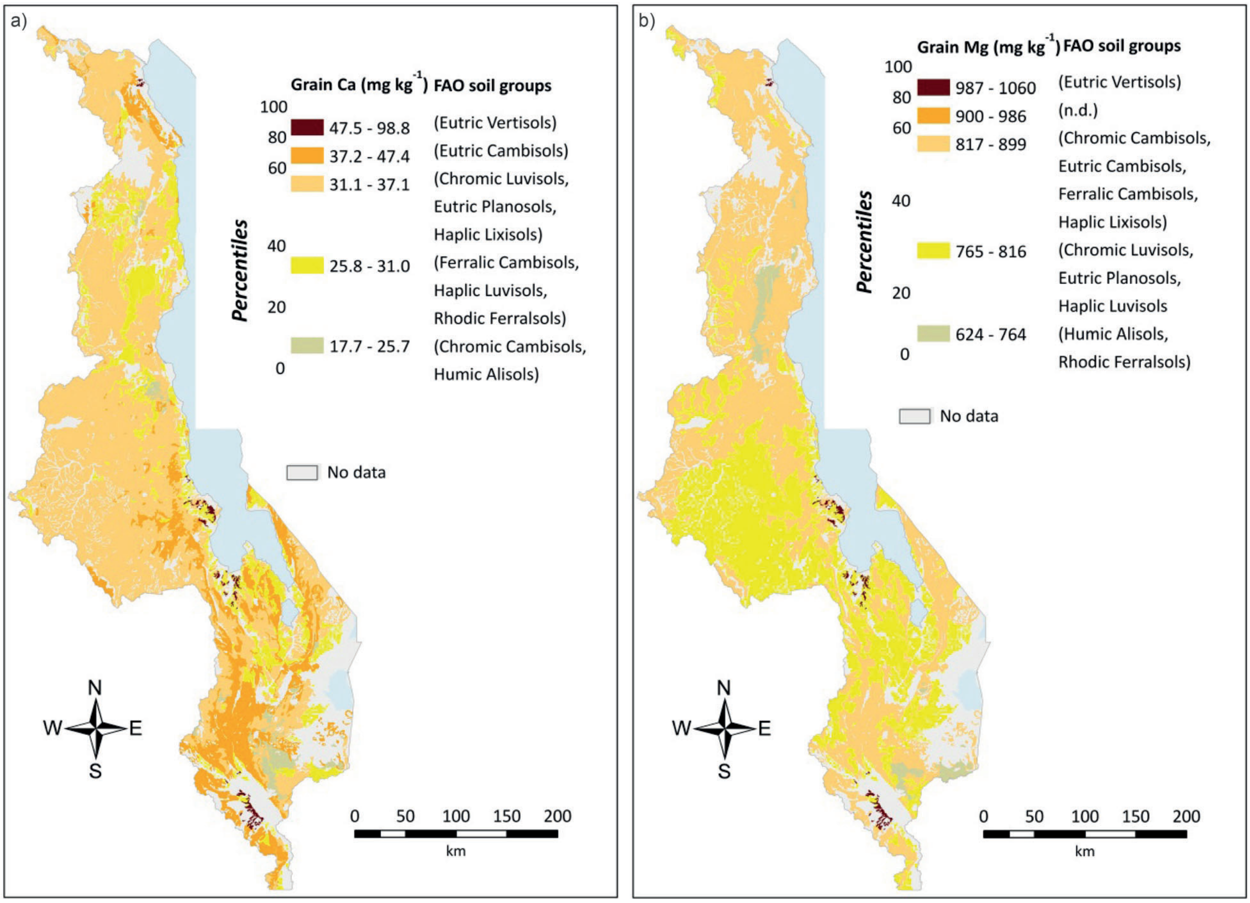

Figure 1: Extrapolated maize grain a) Ca and b) Mg concentration. Data represent the median grain Ca and Mg concentration for each soil type according to quintiles. Blue areas represent water bodies, grey areas represent soil types not included in the study. Figure produced using ArcGIS (v. 9.3).

across all data sources. Notably, 381 g *capita*$^{-1}$ d^{-1} of maize is reportedly consumed in the IHS study, compared to 354 g *capita*$^{-1}$ d^{-1} of maize in the FBSs. Thus, estimates of dietary supply based on FBSs are likely to be relatively robust in Malawi whenever maize is the dominant source of a particular nutrient.

The second caveat is that the analysis is clearly very sensitive to certain food composition data, and these are typically based on single sample-types. For example, 13 g of smoked catfish including bones is reported in FBSs and delivers 120 mg Ca to the diet (Table I). If fish meat is consumed without bones, dietary Ca intakes will be much lower. It is therefore clear that additional food composition data are needed to reduce these sources of uncertainty. There is also a need to consider dietary intakes of minerals from water, which could be significant for some minerals. Furthermore, there is also a clear need to take account of spatial variation in (1) soil geochemistry and soil to crop transfer of minerals for all crops, including vegetables; and (2) population access to rivers, lakes, and transport routes which will affect the consumption of many food groups, especially fish. Finally, for both FBSs and IHS data, there are difficulties in resolving nutrient supply at an individual level. For example, fish consumption is linked to both gender and socio-economic status and can lead to substantial differences in dietary mineral intake between and within households [16].

Despite these caveats, strategies to address a shortfall in dietary Ca supply in Malawi appear to be required. At a production level, the integration of aquaculture and agriculture strategies [17] can increase fish consumption and is a valuable strategy for increasing the dietary supply of Ca. Also at a production level, there is scope for increasing Ca intake through addition of lime or fertilizers to horticultural crops whose edible leaves can accumulate significant quantities of this element. The Ca composition of seeds, fruits, roots, and tubers is much more difficult to alter using agronomic approaches due to the relative immobility of Ca in the phloem of plants, in contrast to Mg which is highly phloem-mobile [4, 18, 19]. In addition to strategies based on production, there is also scope for educational approaches including the encouragement of increased consumption of small fish (whole with bones), milk, and milk products at the household level.

Acknowledgements

Author contributions to this study were funded by: Yara GmbH; The Malawi Government (Ministry of Agriculture & Food Security); the Biotechnology and Biological Sciences Research Council (BBSRC grant reference BB/G013969/1); a Partnership and Project Development Award (NE/I003347/1) from the UK Natural Environment Research Council (NERC), the UK Department for International Development (DFID) and the Economic and Social Research Council (ESRC) under the Ecosystems Services for Poverty Alleviation (ESPA) scheme; the Rural and Environment Science and Analytical Services Division (RESAS) of the Scottish Government; the British Geological Survey; and the University of Nottingham.

References

1. Department of Health (1991) Report on health and social subjects: 41. Dietary reference values for food energy and nutrients for the United Kingdom. Her Majesty's Stationery Office (HMSO), London.

2. Institute of Medicine (U.S.) (1997) Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride. Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board, The National Academies Press, Washington, D.C.

3. Institute of Medicine (U.S.) (2005) Dietary reference intakes for water, potassium, sodium, chloride, and sulfate. Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board, Panel on Dietary Reference Intakes for Electrolytes and Water, The National Academies Press, Washington, D.C.

4. Broadley, M.R. and White, P.J. (2010) Eats roots and leaves. Can edible horticultural crops address dietary calcium (Ca), magnesium (Mg) and potassium (K) deficiencies in humans? Proc. Nutr. Soc. 69, 601–612.

5. FAO (2001) (Food and Agriculture Organization of the United Nations). Food Balance Sheets. A Handbook. FAO, Rome.

6. Dorward, A. and Chirwa, E. (2011) The Malawi agricultural input subsidy programme: 2005–6 to 2008–9. Int. J. Agric. Sustain. 9, 232–237.

7. Chilimba, A.D.C., Young, S.D., Black, C.R., Rogerson, K.B., Ander, E.L., Watts, M, Lammel, J. and Broadley, M.R. (2011) Maize grain and soil surveys reveal suboptimal dietary selenium intake is widespread in Malawi. Scient. Rep. 1, 72.

8. Ferguson, E.L., Gibson, R.S., Thompson, L.U., Ounpuu, S. and Berry, M. (1988) Phytate, zinc, and calcium contents of 30 East African foods and their calculated phytate:Zn, Ca:phytate, and [Ca][phytate]/[Zn] molar ratios. J. Food Composit. Anal. 1, 316–325.

9. Ferguson, E.L., Gibson, R.S., Weaver, S.D., Heywood, P., Heywood, A. and Yaman, C. (1989) The mineral content of commonly consumed Malawian and Papua New Guinean foods. J. Food Composit. Anal., 2, 260–272.

10. Lukmanji, Z., Hertzmark, E., Mlingi, N., Assey, V., Ndossi, G. and Fawzi, W. (2008) Tanzania food composition tables. Muhimbili University College of Health and Allied Sciences; Tanzania Food and Nutrition Center; Harvard School of Public Health, Dar es Salaam, Tanzania.

11. FAO (2010) (Food and Agriculture Organization of the United Nations). Food Supply Statistics [online]. Available at http://faostat.fao.org/site/345/default.aspx [accessed October 2011].

12. USDA-ARS (U.S. Department of Agriculture, Agricultural Research Service) (2011). USDA National Nutrient Database for Standard Reference, Release 24. Nutrient Data Laboratory Home Page. Available at http://www.ars.usda.gov/nutrientdata [accessed November 2011].

13. Green, R. and Nanthambwe, S. (1992) Land Resources Appraisal of the Agricultural Development Divisions. Field Document No. 32. Lilongwe, Malawi: Ministry of Agriculture/United Nations Development Programme/Food and Agriculture Organization MLW/85/011.

14. World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO) (2006). Guidelines on food fortification with micronutrients. (Allen, L., de Benoist, B., Dary, O. and Hurrell, R., eds.) Geneva.

15. Ecker, O. and Qaim, M. (2011) Analyzing nutritional impacts of policies: an empirical study for Malawi. World Develop. 39, 412–428.

16. Benemariya, H., Robberecht, H. and Deelstra, H. (1993) Daily dietary intake of copper, zinc and seleni-

um by different population groups in Burundi, Africa. Sci. Total Environ. 136, 49–76.

17. Brummeitt, R.E. and Jamu, D.M. (2011) From researcher to farmer: partnerships in integrated aquaculture – agriculture systems in Malawi and Cameroon. Int. J. Agric. Sustain. 9, 282–289.

18. Karley, A.J. and White, P.J. (2009) Moving cationic minerals to edible tissues: Potassium, magnesium, calcium. Current Opinion Plant Biol. 12, 291–298.

19. White, P.J. and Broadley, M.R. (2009) Biofortification of crops with seven mineral elements often lacking in human diets – iron, zinc, copper, calcium, magnesium, selenium and iodine. New Phytol.182, 49–84.

Martin R. Broadley

School of Biosciences
University of Nottingham
Sutton Bonington Campus
Loughborough, LE12 5RD
United Kingdom
Fax: +44 115 9516334
martin.broadley@nottingham.ac.uk