Soil factors influence the geospatial variation in zinc nutritional quality of maize in Malawi

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SOILS: WHERE FOOD BEGINS

Background

The findings of our previous study…

Article

The nutritional quality of cereals varies geospatially in Ethiopia and Malawi

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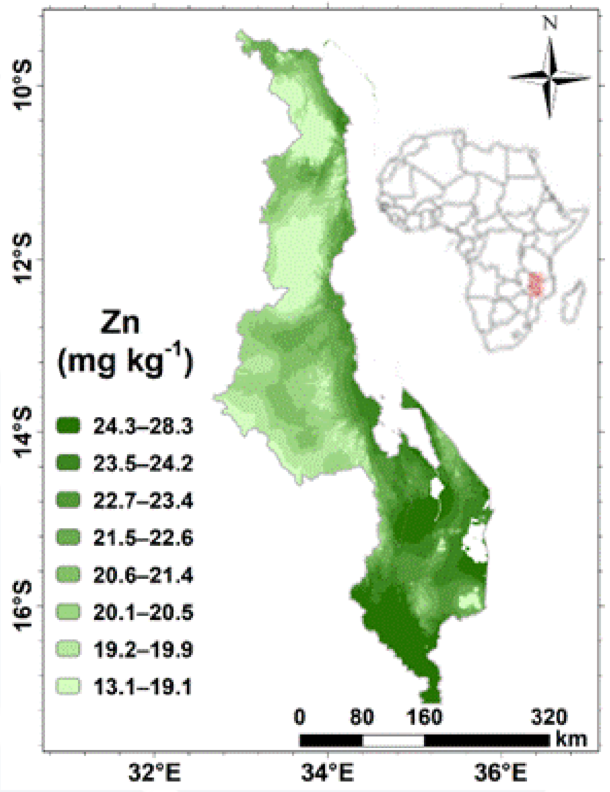
Micronutrient deficiencies (MNDs) remain widespread among people in sub-Saharan Africa[1–5], where access to sufficient food from plant and animal sources that is rich in micronutrients (vitamins and minerals) is limited due to socioeconomic and geographical reasons[4–6]. Here we report the micronutrient composition (calcium, iron, selenium and zinc) of staple cereal grains for most of the cereal production areas in Ethiopia and Malawi. We show that there is geospatial variation in the composition of micronutrients that is nutritionally important at subnational scales. Soil and environmental covariates of grain micronutrient concentrations included soil pH, soil organic matter, temperature, rainfall and topography, which were specific to micronutrient and crop type. For rural households consuming locally sourced food—including many smallholder farming communities—the location of residence can be the largest influencing factor in determining the dietary intake of micronutrients from cereals. Positive relationships between the concentration of selenium in grain and biomarkers of selenium dietary status occur in both countries. Surveillance of MNDs on the basis of biomarkers of status and dietary intakes from national- and regional-scale food-composition data[1–7] could be improved using subnational data on the composition of grain micronutrients. Beyond dietary diversification, interventions to alleviate MNDs, such as food fortification[8,9] and biofortification to increase the micronutrient concentrations in crops[10,11], should account for



- Long-range geospatial variation in maize grain Zn concentrations was observed at distances of up to 100 km

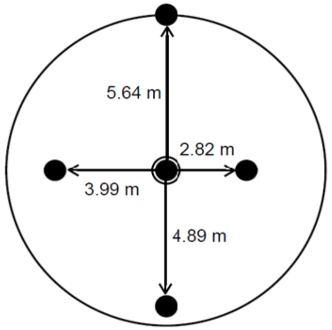
- Specifically, the aim of the present study was to identify potential soil properties which might explain this longer-range spatial variation in maize grain Zn concentration.

Gashu, Nalivata et al., 2021

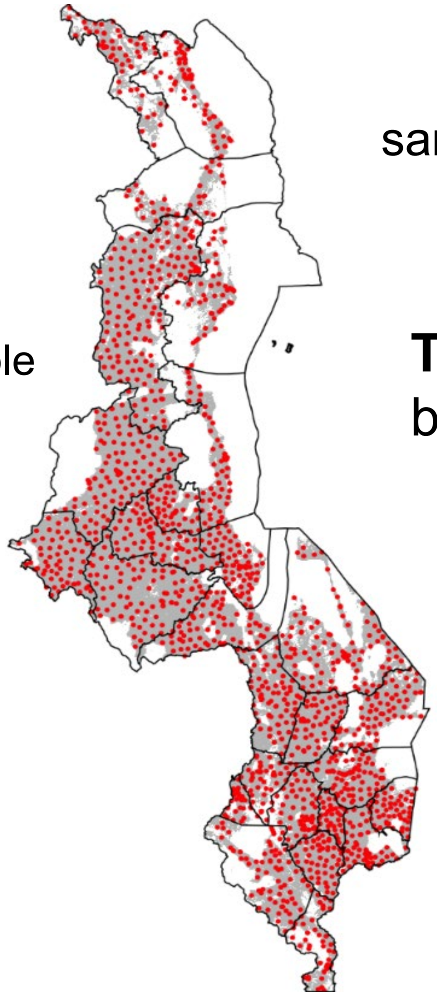
Materials and Methods

Field plant and soil sampling across the country

- The pre-determined sampling locations were randomly selected using GIS.
- The site locations were loaded on a computer tablet and were navigated using GPS
- A single plant and soil sub-sample was collected at each of the five sub-sample points
- Plant and soil analyses were done at UoN and Rothamsted Research labs



Layout of five sub-sample points for each location (black circles)



Plant and soil sampling locations (red dots)

Total sites =1812 but 1600 used

212 sites were excluded due to poor satellite accuracy, sampled crops other than maize, and low LOD

Tested soil covariates

- Soil $pH_{(water)}$
- Soil organic carbon (SOC)
- Aqua regia extractable Zn
- Effective cation exchange capacity (eCEC)- (hexaminecobalt trichloride solution)
- Ammonium oxalate extractable oxides (AlOx, FeOx, MnOx)
- Solution Zn
- DTPA-extractable Zn
- Zn solid-solution distribution coefficient (Zn-Kd)
- Isotopically exchangeable Zn (Zn_E)- equilibrating soil with 70Zn stable isotope

Sequence of soil properties using expert ranking for predicting grain Zn concentration

Order	Soil Property
1	Zn_{S*}
2	pH
3	Zn_{E}
4	Zn_{DTPA}
5	SOC
6	Zn_{AR}
7	eCEC
8	Oxalates
9	Zn_{Kd}

Data analysis and identification procedure of predictors for grain Zn conc.

- A Linear Mixed Model (LMM) framework was used in which maize grain Zn concentration was modelled

- In a LMM framework, the evidence that a fixed effect coefficient is significantly different from zero can be tested by calculating the Wald statistic

- The evidence that adding fixed effects to a simpler model achieves a significant improvement is done by computing the log-ratio statistic

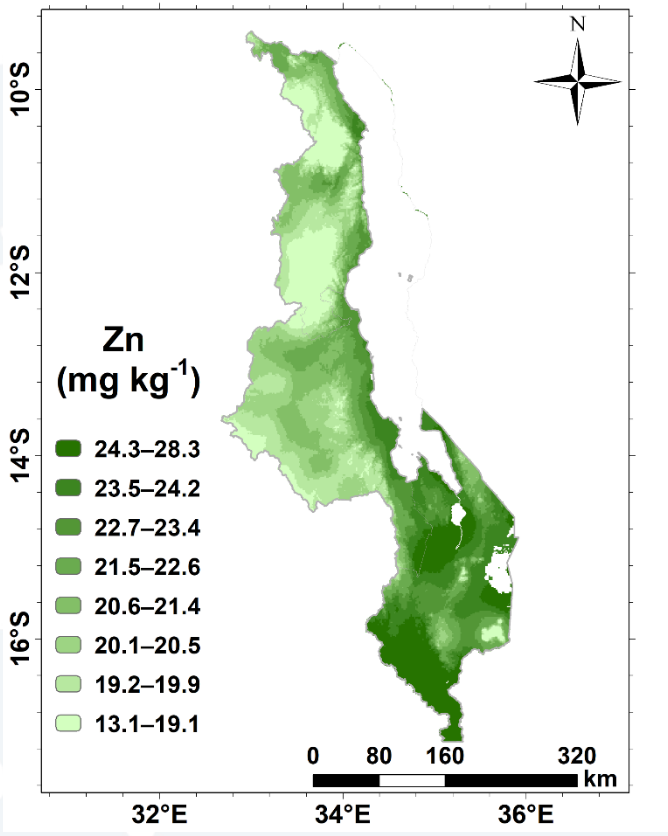
$$L = 2(\ell_1 - \ell_0)$$

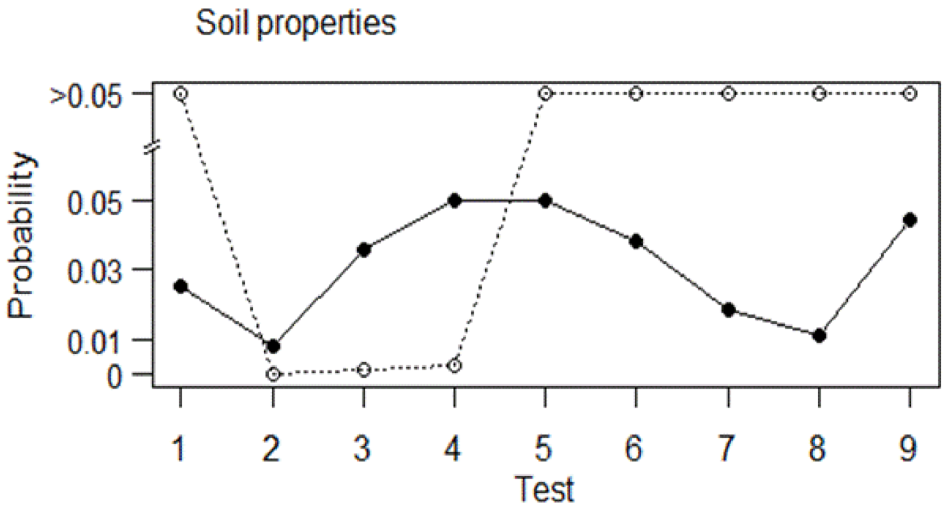
Where ℓ_1 and ℓ_0 denote, respectively the maximized log-likelihoods from fitting the model with the additional fixed effects, and the simpler model without them

- This approach was used to hypothesis testing for the identification of independent variables (covariates) to include as fixed effects in models for target properties of interest

Key findings…

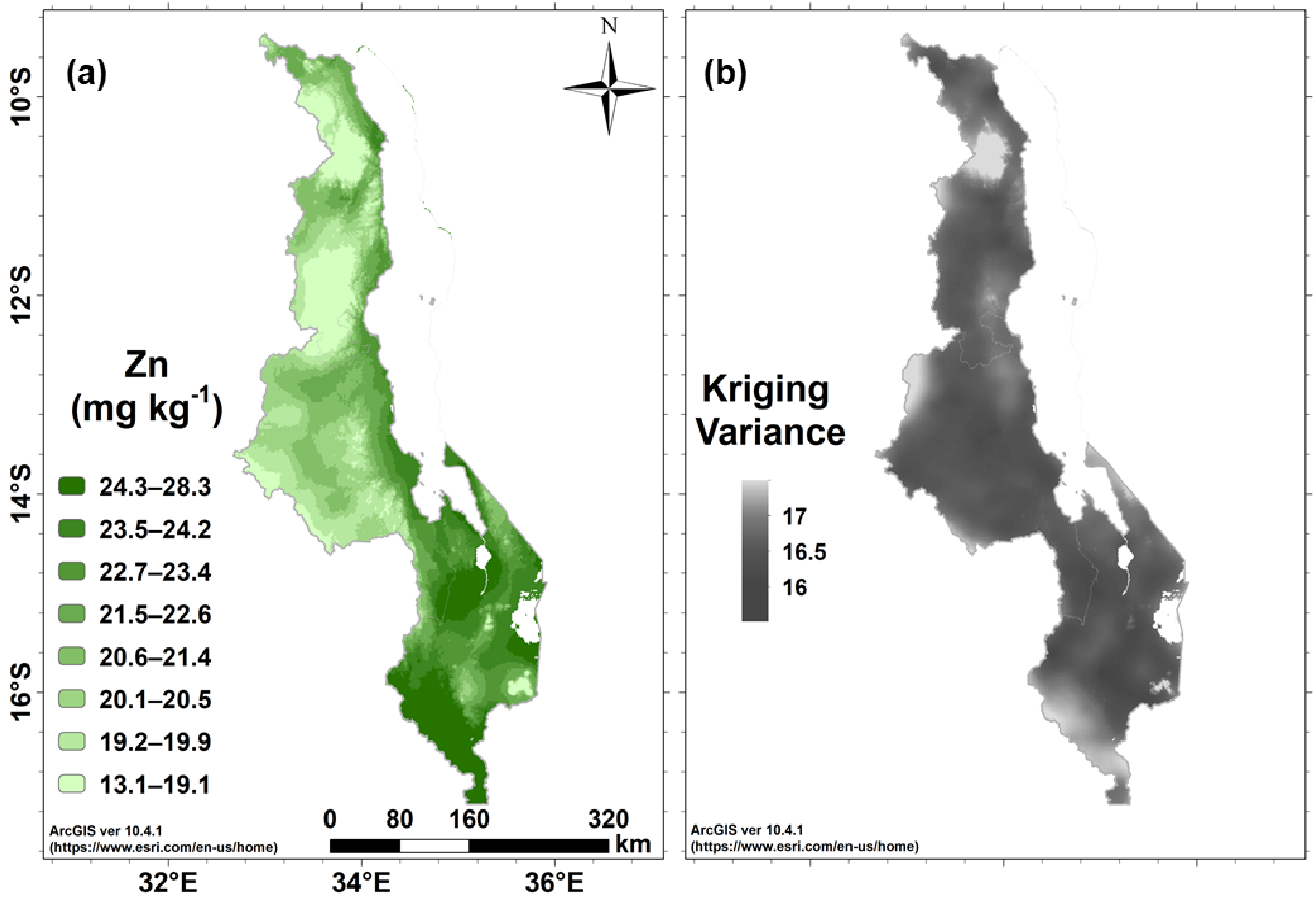
The sequential fitting of models with predictors for grain Zn conc.





- The p-values (open circles) for successive tests on predictors added to the model for grain Zn
- Tests are on addition of variables in the order given previously
- The solid circles are the threshold for rejection of each null hypothesis under the FDR control
- The predictive value of soil factors (pH, ZnE and ZnDTPA) for maize grain Zn concentration was significant (p<0.01 in all cases, with FDR controlled at <0.05)

Spatial mapping of maize grain Zn concentration across Malawi

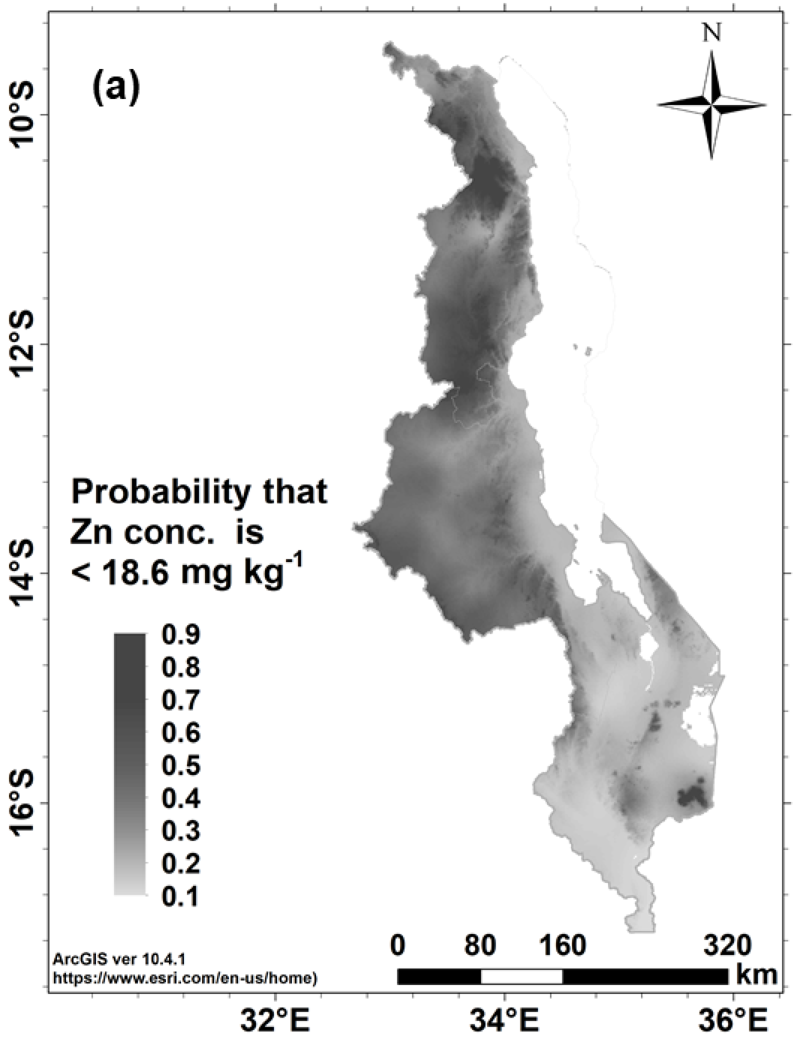


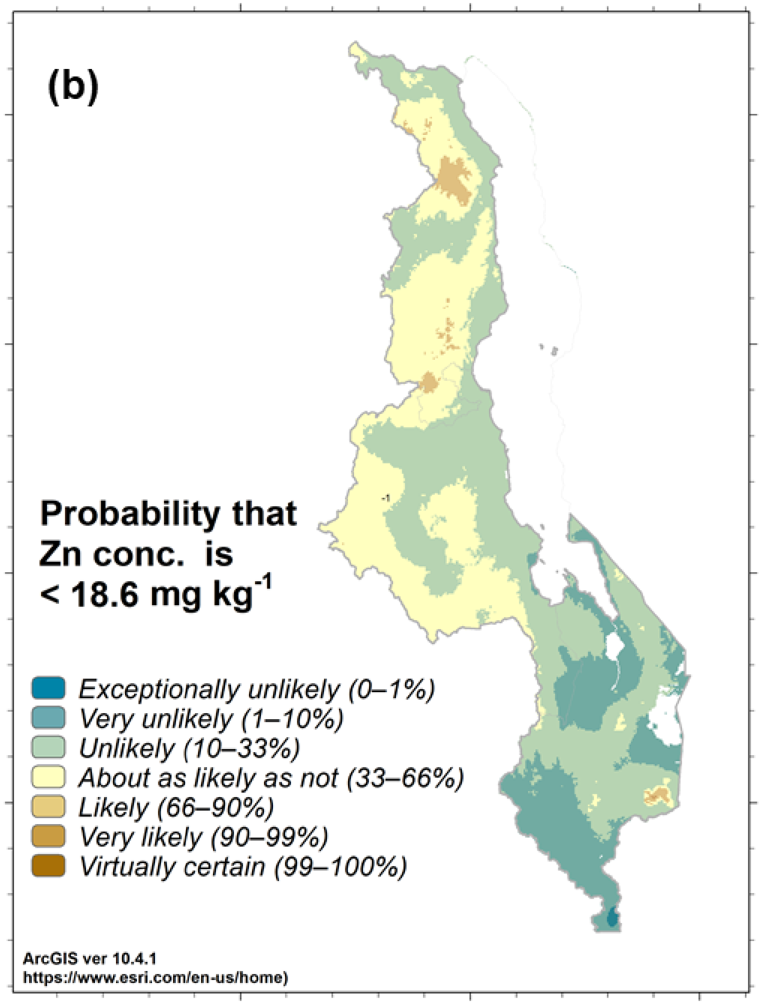
Grain Zn concentration in maize grain across Malawi

(a) Empirical Best Linear Unbiased Predictions

(b) the prediction error variance (expected squared error) of the E-BLUP.

Interpreting probabilistic information about grain Zn conc. being below threshold value





- Probability that the concentration of Zn in maize grain across Malawi is <18.6 mg kg^{-1} based on
  - (a) numerical scale
  - (b) expressed according to 'calibrated phrases'
- The information helps in decision making on taking appropriate interventions e.g agro-fortification

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Soil and landscape factors influence geospatial variation in maize grain zinc concentration in Malawi

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Dietary zinc (Zn) deficiency is widespread globally, and in particular among people in sub-Saharan Africa (SSA). In Malawi, dietary sources of Zn are dominated by maize and spatially dependent variation in grain Zn concentration, which will affect dietary Zn intake, has been reported at distances of up to ~100 km. The aim of this study was to identify potential soil properties and environmental covariates which might explain this longer-range spatial variation in maize grain Zn concentration. Data for maize grain Zn concentrations, soil properties, and environmental covariates were obtained from a spatially representative survey in Malawi (n = 1600 locations). Labile and non-labile soil Zn forms were determined using isotopic dilution methods, alongside conventional agronomic soil analyses. Soil properties and environmental covariates as potential predictors of the concentration of Zn in maize grain were tested using a priori expert rankings and false discovery rate (FDR) controls within the linear mixed model (LMM) framework that informed the original survey design. Mean and median grain Zn concentrations were 21.8 and 21.5 mg kg^{-1}, respectively (standard deviation 4.5; range 10.0–48.1). A LMM for grain Zn concentration was constructed for which the independent variables: soil $pH_{(water)}$, isotopically exchangeable Zn (Zn_E), and diethylenetriaminepentaacetic acid (DTPA) extractable Zn (Zn_{DTPA}) had predictive value ($p < 0.01$ in all cases, with FDR controlled at < 0.05).

Botoman, Chagumaira, Mossa et al., 2022

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Thank you !