Genotype, environment, and genotype x environment interaction effects on elemental micronutrient content in vegetable amaranth grown in the United States, Kenya, and Tanzania

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Introduction

Vegetable amaranth (*Amaranthus* spp.) is a leafy green vegetable consumed in over 50 countries across sub-Saharan Africa, South Asia, Southeast Asia, and the Caribbean (National Resource Council, 2006). High rates of micronutrient deficiencies in these regions have attracted attention to vegetable amaranth and other culturally preferred vegetable crops as easily available and economically sustainable sources of micronutrients (Weller et al. 2015).

The utility of vegetables to maintain or improve micronutrient health status in humans for Feed the Future initiatives and to be marketed as a "source" or "high source" of one or more essential micronutrients by international labeling practices is determined by the values reported in the USDA Nutrient Database for Standard Reference (Codex Alimentarius, 1997; Feed the Future. 2014). This nutrition information is not disaggregated by crop, yet recent observations have shown significant genotype effect in vegetable amaranth for Fe, Ca, Mg, and Zn contents (Byrnes et al., 2017). Assessing the effect of genotype x environment interaction (GEI) is necessary to evaluate the capacity for selecting genotypes for nutrition delivery.

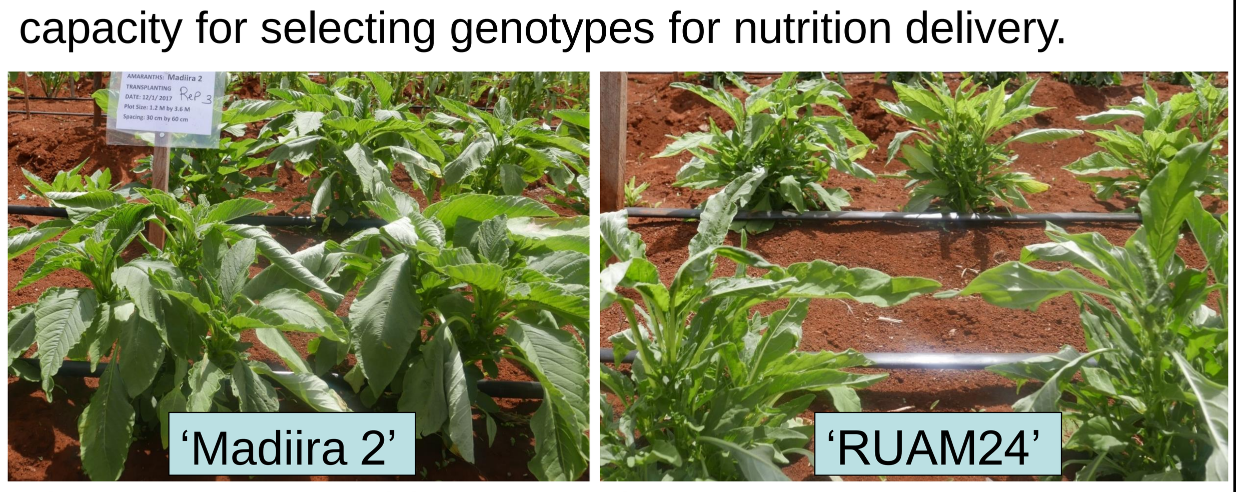

Fig.1. Two vegetable amaranth genotypes grown at Turbo, Kenya, Februrary 2017.

Materials and Methods

Table 1. Amaranth entries evaluated.

Genotype	Specie	Source
AC-45	*Amaranthus sp.*	World Vegetable Center
AC-NL	*A. cruentus*	
AH-TL	*A. hypochondriacus*	
Ex-Zan	*Amaranthus sp.*	
Madiira 1	*A. cruentus*	
Madiira 2	*A. cruentus*	
UG-AM-40	*Amaranthus sp.*	
Commercial	*Amaranthus sp.*	NJ13: Zambia Seed Co. TZ14: GYT 30 NJ15: Zambia Seed Co. KY17: EASeed
Local	*Amaranthus sp.*	NJ13: Johnny's TZ14: GYT 13 NJ15: Johnny's KY17: Market Procured
RUAM24	*A. tricolor*	Rutgers University

- All field experiments were arranged in randomized complete block design with three replications.
- Plants were grown in double rows spaced 30 cm between plants within rows with 14 plants per plot.
- Five of the 10 interior plants were randomly selected, oven-dried at 40°C, and mill-homogenized.
- Elemental micronutrient analysis was conducted on foliar subsamples from each genotype by inductively coupled plasma (ICP) mass spectrophotometry.
- NJ13 and NJ15=field-grown Northern New Jersey (Pittstown, NJ); TZ14= field-grown Arusha, Tanzania; KY17=field-grown Turbo, Eldoret County, Kenya

Results

Table 2. ANOVA table for genotype, environment, and GEI effects in Fe and Ca.

Source Fe	Df	Sum Sq	Mean Sq	F value	P value
Environment	3	149.771	49.924	52.8570	1.284e-05 ***
Replications within E	8	7.556	0.945	2.1208	0.04637 *
Genotype	9	50.555	5.617	12.6131	2.977e-11 ***
G x E	23	49.930	2.171	4.8745	2.661e-07 ***
Residuals	64	28.503	0.445		

Source Ca	Df	Sum Sq	Mean Sq	F value	P value
Environment	3	532508	177503	186.0869	9.748e-08 ***
Replications within E	8	7631	954	1.1566	0.3391
Genotype	9	60693	6744	8.1771	5.718e-08 ***
G x E	23	76275	3316	4.0212	5.596e-06 ***
Residuals	64	52781	825		

*Significant at the 0.05 level of probability.
***Significant at the .001 level of probability.

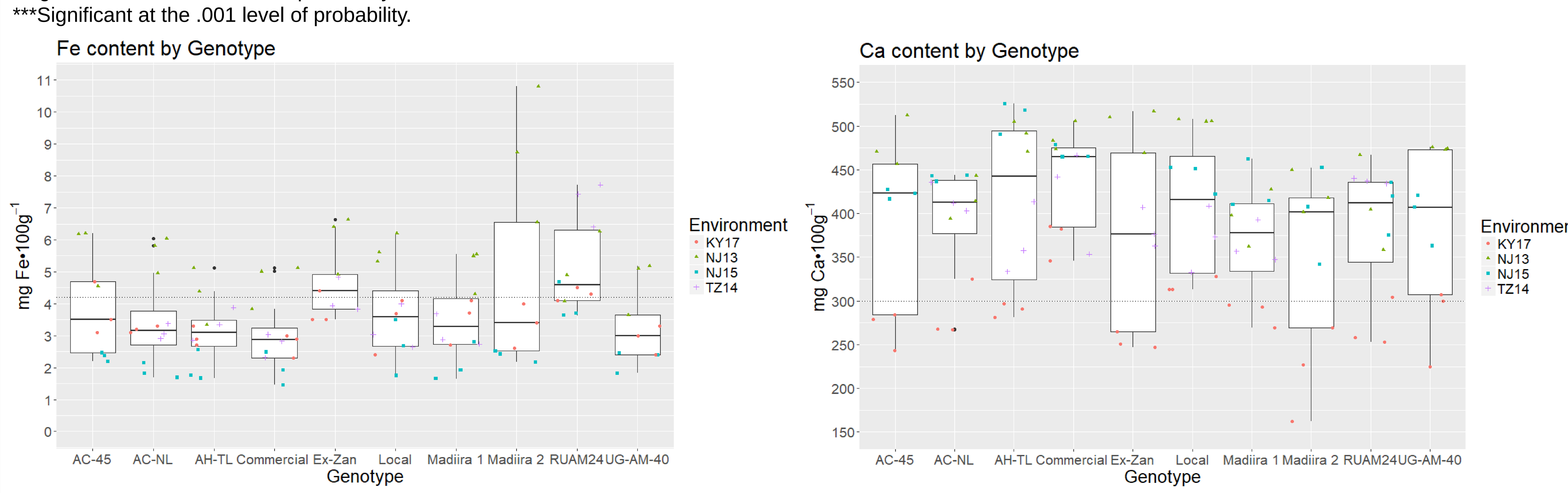

Fig. 2. Boxplots of Fe, Ca, Mg, content data by genotype at each environment, lower and upper hinges correspond to the first and third quartiles, upper and lower whiskers extend no further than 1.5* inter-quartile range; data beyond whiskers are indicated by a centered, black dot in addition to the environment-specific symbol. Data points of all replicates are detailed. Data for Zn not presented as results showed it to be a low source. High source thresholds as defined by *Codex Alimentarius Guidelines for Use of Nutrition and Health Claims* (Codex Alimentarius, 1997).

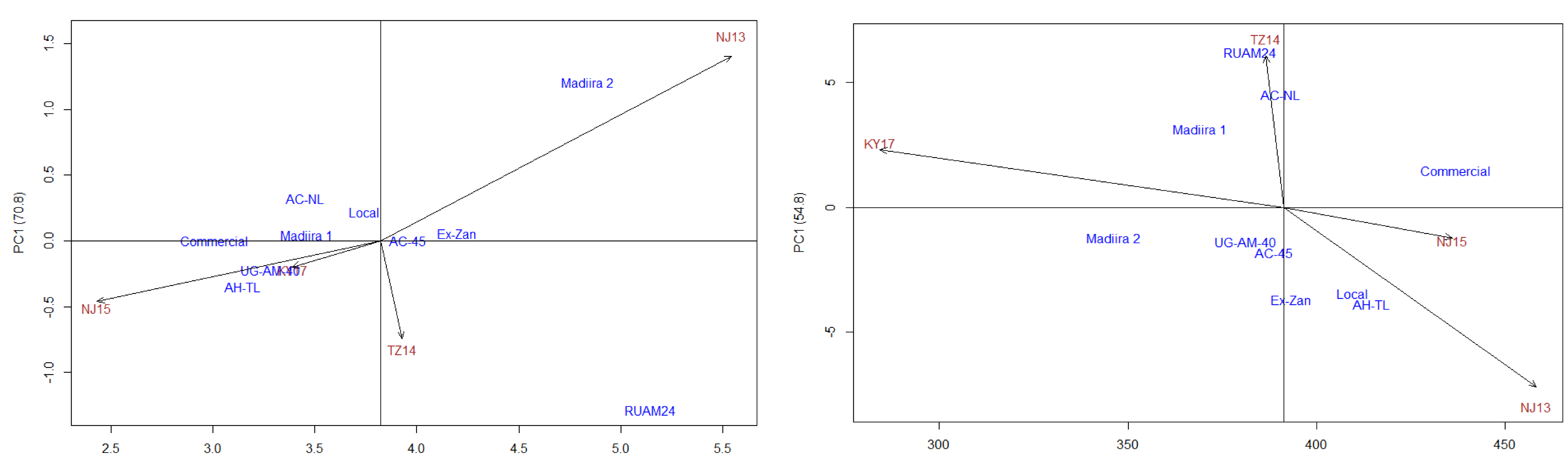

Fig. 3. Additive main effects and multiplicative interaction 1 (AMMI1) biplot showing the main and first principal components (PC1) effects of both genotypes and environments on Fe (left) and Ca (right) in vegetable amaranth.

Fe

- Three genotype means exceeded 4.2 mg Fe·$100g^{-1}$: 'Ex-Zan', 'Madiira 2', and 'RUAM24'.
- RUAM24 had highest mean and insignificant GEI in all trials except for positive GEI in TZ14.
- Ex-Zan had a high mean complemented by low PC score, 'AC-45' and 'Commercial' had low PC scores but moderate and low Fe content, respectively, each below high source threshold.
- Madiira 2 had the second highest mean due largely to a strong positive GEI in NJ13, yet low stability with all other data points falling below threshold (Fig. 2.), demonstrated by negative GEI in NJ15 and KY17 (Fig. 3.).

Ca

- All genotypes in all environments were above 300mg Ca·$100g^{-1}$ threshold, with exception of KY17, in which only 'Commercial' and 'Local' entries had means above threshold.

Mg

- All genotypes in all trials were above 90mg Mg·$100g^{-1}$, GEI effect was significant (*P* value < 0.001); data not presented.

Zn

- All genotypes in all trials were below 4.2mg Zn·$100g^{-1}$, GEI effect was significant (*P* value < 0.01); data not presented.

Discussion

- Selection for high and stable elemental micronutrient content is both feasible and necessary in vegetable amaranth.
- Genotypes 'Ex-Zan' and 'RUAM24' can be considered candidates to deliver high source levels of three elemental micronutrients commonly associated with deficiencies in humans (Fe, Ca, Mg).
- Results from this study show higher Fe, Ca, and Mg content than USDA Standard Reference data for raw amaranth leaves (2.32 mg Fe·$100g^{-1}$ n=--; 215 mg Ca·$100g^{-1}$ n=6; 55mg Mg·$100g^{-1}$ n=1) (U.S. Department of Agriculture. 2016).

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