# Effect of Genotype, Environment, and Genotype-Environment Interaction on Fe content of *Amaranthus* spp.

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## Summary

*Amaranthus* spp. is one of several African Indigenous Vegetables valued as a means of delivering essential micronutrients to resource-limited communities. However, the effect of phenotypic plasticity, or genotype-environment interaction (GEI) on the ability of this plant to deliver key nutrients is under-studied. The purpose of this study was to make observations on the extent of GEI on the Fe content of *Amaranthus* spp., ultimately toward making selections for high micronutrient content performance among otherwise advanced genotypes.

Five genotypes were analyzed for Fe content from trials in Pittstown, New Jersey (NJ), USA, and Arusha, Tanzania. Analysis of variance (ANOVA) results indicate that genotype effect was highly significant ($p<.001$), environment effect was significant ($p<.05$) and the effect of GEI was also highly significant ($p<.001$).

## Introduction

Iron deficiency anemia is estimated to afflict about 50% of all pregnant women and 40% of preschool-age children in developing countries[1]. Amaranth is among the most popular leafy green vegetables in sub-Saharan Africa and is a focus of recent efforts by the Horticulture Innovation Lab at UC Davis to link production of high-nutrient horticultural crops to the improvement of health status on the household and community level.

*Amaranthus* spp. has had considerable attention from researchers over recent decades for being an under-developed, under-utilized crop. As one of the few eudicots known to exhibit C4 photosynthesis[2], *Amaranthus* spp. is often proposed as a promising crop for low-input cultivation, especially in warmer climates.

Selection efforts are on-going by the World Vegetable Center to provide advanced genotypes for smallholder farms and household gardens to improve the availability and consumption of this crop for both income generation and to supplement diets. Demonstration of feasibility in selecting for Fe content or other problem micronutrients would be valuable toward these efforts and for the marketing of this crop in general.

## Materials and methods

### Table 1. Specie, genotypes, and origins of materials analyzed

| Specie | Genotype | Origin |
|---|---|---|
| *Amaranthus tricolor* | RUAM 24; PI 674263 | USDA GRIN |
| *Amaranthus cruentus* | AC-NL<br>AH-TL<br>Madiira 1<br>Ex-Zan | World Vegetable Center of East and Southern Africa |

Genotypes were transplanted and field-grown in complete randomized block design at Snyder Research Farm of Rutgers University, Pittstown, NJ in 2013 and the World Vegetable Center of East and Southern Africa in Arusha, Tanzania in 2014. Samples analyzed are exclusively from first-harvest foliar material only. Samples were dried upon harvesting and stored at NUANPP program laboratory, Rutgers University. Fertilizer regimens, soil texture, irrigation methods, and drying methods were non-analogous between locations. Fe content results are adjusted to represent fresh-weight estimates.

*Analysis*

Fe content was quantified by Inductively Coupled Plasma (ICP) analysis at the Penn State Agricultural Analytical Services Lab.

Elemental analysis was performed by Penn State Agricultural Analytical Services by ICP analysis of samples in replicates of three prepared and ground at NUANPP program laboratory.

*Statistics*

ANOVA was performed using R Studio with Agricolae package for main effects of genotype and environment, as well as for GEI on Fe content.

## References

1. World Health Organization, 2001. Iron Deficiency Anaemia Assessment, Prevention, and control: A guide for programme managers. United Nations Children's Fund.
2. Wang, J. L., Klessig, D. F., & Berry, J. O. (1992). Regulation of C4 Gene Expression in Developing Amaranth Leaves. The Plant Cell, 4(2), 173–184.
3. World Health Organization, 2015. *Codex Alimentarius: International Food Standards.* (CAC/GL 2-1985) and Guidelines for Use of Nutrition and Health Claims (CAC/GL 23-1997).
4. United States Department of Agriculture. National Nutrient Database for Standard Reference: Amaranthus Leaves, Raw. Release 27. The National Agricultural Library.

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## Results

### Fig 1. Fe content of genotypes at two locations

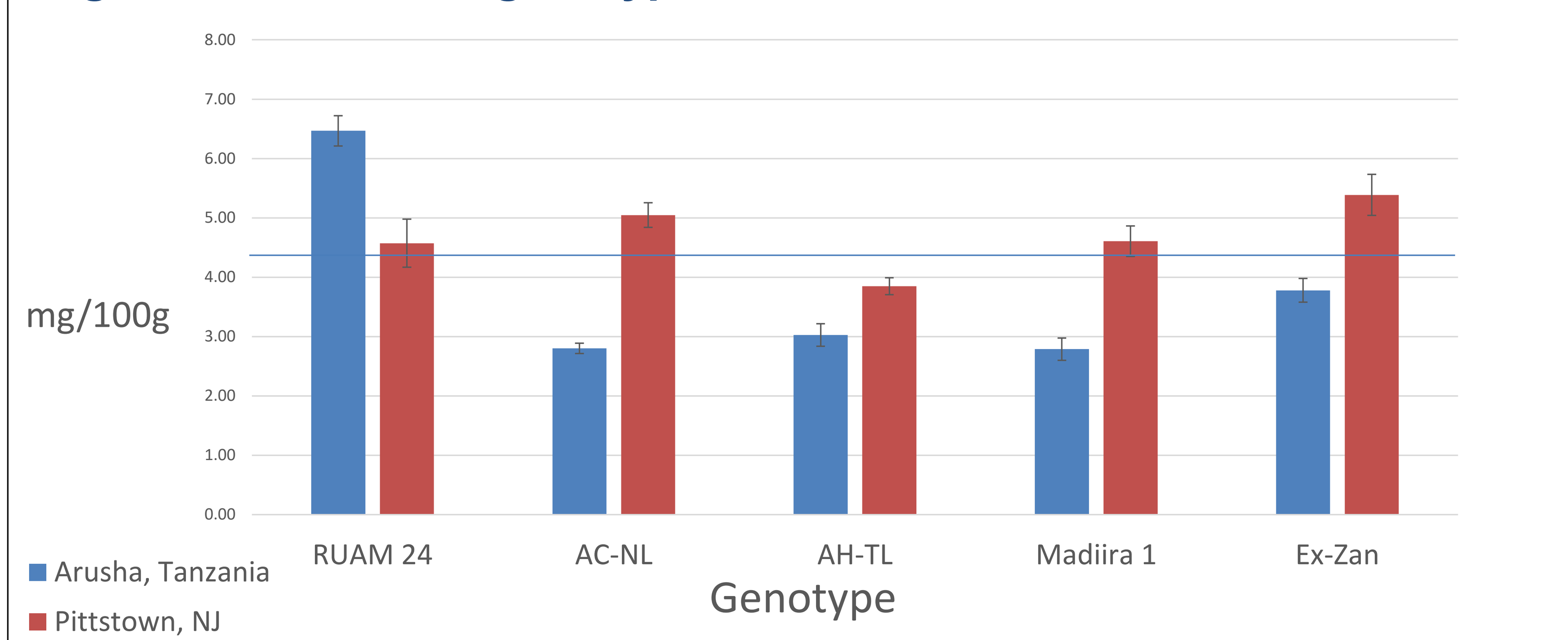


Fig.1 Data of mean Fe mg/100g fresh weight equivalence, analyzed from dry samples of five *Amaranthus* spp. genotypes in replicates of three per each of the two sites: Pittstown NJ, and Arusha, Tanzania. Error bars represent standard deviation of means. Blue horizontal line represents "high-source" threshold for Fe content as defined by the *Codex Alimentarius Guidelines on Nutrition Labeling*[3].

### Table 2. Analysis of Variance (ANOVA) Table

| | Df | Sum sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Environment | 1 | 6.35 | 6.35 | 15.60 | 0.01683 |
| Rep(Environment) | 4 | 1.63 | 0.41 | 0.99 | 0.44204 |
| Genotype | 4 | 16.77 | 4.19 | 10.17 | 0.00027 |
| Environment:Genotype | 4 | 16.44 | 4.11 | 9.97 | 0.00030 |
| Residuals | 16 | 6.60 | 0.41 | | |

Table 2. ANOVA table demonstrates that there was consistency within replicates at each environment. Among genotypes, a difference of strong significance was observed. A strong significance of environment-genotype interaction is observable, and a significant difference between the two environments, to a lesser degree, has been observed.

## Discussion

Half of the total observations across all genotypes and environments placed *Amaranthus* spp. above the "high source" threshold for Fe content of the *Codex Alimentarius* standards. All Fe content observations in this study were above that of the USDA reference data, being 2.32 mg/100g4. Each of the AVRDC genotypes had superior Fe content when grown in NJ as opposed to the single *Amaranthus tricolor* genotype, which had the highest value in this study from the Tanzania trial.

The most significant variation was determined by the ANOVA to be a result of genotype effect. This may indicate feasibility for selecting genotypes of high performance in Fe content.

The environment effect also accounted for significant variation among materials, indicating the need for observations from additional environments toward identifying ideal genotypes for stability as well as to score for discriminating power and representativeness of environments.

Given the observation of a highly significant environment-genotype effect and crossover of Fe content performance in the two environments presented here, it is predictable that genotypes can be identified which reliably perform best in particular environments, but not stably across all environments. However, considering the relatively small portion of the *Amaranthus* spp. germplasm which was studied here and the highly significant variation by genotype effect, further testing may elucidate genotypes which have high, stable per


RUAM24 (left) and Madiira 1 (right) in RCB, Arusha, Tanzania 2014. Photo: David Byrnes

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