Effect of GxE Interaction on Root Yield and Beta-carotene Content of Selected Sweetpotato (*Ipomoea batatas* (L) Lam.) Varieties and Breeding Clones

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A multilocational field trial involving nine sweetpotato clones of diverse origins was conducted across four different locations to investigate GxE interaction effects on commercial root yield and beta-carotene pigment content in roots. None of the high-yielding cultivars had satisfactory stability, according to biplots for total root yield based on the additive main effect and multiplicative interaction (AMMI) model. The lack of association of high root yield and stable performance suggests the need for further study to elucidate the nature of sweetpotato root-yield performance in response to varying agroecological conditions. Beta-carotene concentration increased in the roots of almost all tested clones when grown at a higher altitude. Clone SR 92.499-23 has been identified as the most efficient at producing and accumulating beta-carotene in relation to accumulation of root dry and fresh matter at high altitude.

Genotype-by-environment interactions (GxE) are of great interest when evaluating the stability of breeding clones under different environmental conditions. Sweetpotato is grown around the world in diverse environments, often by small farmers in marginal soils, using few inputs. In spite of its ability to adapt to harsh growing conditions, sweetpotato is sensitive to environmental variation, as shown by previous GxE studies on several traits (Bacusmo et al., 1988; Collins, et al., 1987; Hammet, 1974; Janssens, 1985; Jong, 1974; Kamalam et al., 1978; Kanua and Floyd, 1988; Martin et al., 1988; Naskar and Singh, 1992; Ngeve, 1993; Whyte, 1989).

A number of techniques for analyzing information in a GxE study are available (Hussein et al., 2000; Lin et al., 1986). While regression analysis attempts to define the GxE interactions by two parameters, the objective of most univariate stability statistics is to summarize the GxE interaction using only one parameter. Multivariate statistical methods have been introduced to explore multidirectionality and to extract more information out of this component of phenotypic variability (Hussein, 2000). The additive main effect and multiplicative interaction (AMMI) model is effective for gaining accuracy in GxE studies (Gauch, 1992) because it analyzes the interaction effect in a more statistically robust procedure. With the AMMI model, main effects (genotypes and environments) are first accounted for by a regular analysis of variance; thereafter, the interaction (genotypes x environments) is analyzed by a principal component analysis (Gauch, 1992), leading to a more exhaustive data analysis, accurate yield

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estimates, and reliable selections. Despite the presence of large GxE interactions in sweetpotato, the AMMI method has not been used to study this crop.

The predominant carotenoid in sweetpotato roots is beta-carotene (Takahata, 1995; Takahata et al., 1993), which represents the main source of pro-vitamin A in the roots. In the human body, this is converted into the essential nutrient vitamin A (Woolfe, 1992). In order to gain more information for successfully breeding beta-carotene-rich varieties of sweetpotato with higher nutritional value and yield, it is necessary to know the influence of the environment on these traits.

A multilocational sweetpotato trial was conducted in seven different locations in Peru, representing much of the agroecological diversity where sweetpotato is grown around the world. The information presented in this paper is a preliminary report involving the first four harvested field experiments where nine selected sweetpotato varieties and breeding clones were grown in four locations under two nitrogen levels. The objective of this study is to determine the magnitude of the GxE interaction, using the AMMI model, on commercial root yield and the content of beta-carotene pigments of these four harvests. This study also identified clones that performed well and remained stable under different environmental conditions.

Materials and Methods

The planting material was taken from virus-free mother plants grown in greenhouses. The experimental material consisted of advanced sweetpotato clones of diverse origins: JPKY 16.005 (Japan), Jewel (USA), Xushu 18 (China), SR 92.499-23, DLP 2462, and ARB-UNAP 74 (Peru), as well as the native cultivars ARB 535 (Peru) and Wagabolige and Tanzania (Uganda).

The experimental design was a randomized complete block with three replications. The experimental plots had four rows with 15 plants/row. Planting density was 1.0 m between rows and 0.30 m between plants. Additionally, two nitrogen levels were tested (0 and 80 N) and randomly distributed in blocks along with genotypes. Total number of environments comprised nitrogen levels by number of experimental sites. Field experiments included one or two local varieties as test crops. Various agroecological conditions at four different sites were considered: elevated tropic, rainfed (Oxapampa, 1800 m altitude, 1413 mm rain, (OXA0N, OXA80N)), arid Pacific lowlands, irrigated (Tacna, 32 m (TAC0N, TAC80N)), and La Molina, 240 m (LM0N, LM80N)), and mid-elevation tropics, rainfed (San Ramón, 800 m altitude, 1500 mm rain (SR0N, SR80N)). Five plants of the two central rows of every experimental plot were randomly selected and labeled at harvest time (150 days after planting) to generate composite samples of roots and aerial parts for determination of dry matter, beta-carotene, chlorophyll, and starch content. The remaining plants in central rows were harvested to estimate root yield per plot.

Root samples were diced and homogenized, after which two composite samples of 200 g and 500 g (fresh weight) were taken; the first for dry-matter determination and the second for beta-carotene determination and starch extraction. Starch was extracted using a kitchen blender for tissue maceration, followed by several washes of the starch sediment (Bainbridge et al., 1996, p. 80–92). Beta-carotene was determined with a spectrophotometer, as described by Lichtenthaler and Wellburn (1983).

Data processing for determining GxE interaction was done using the AMMI model. Statistical computations and estimation were carried out using procedures GLM (SAS Institute Inc., 1990a) and IML (SAS Institute Inc., 1990b).

Results and Discussion

The analyses of variance of the AMMI model for total root yield and beta-carotene content in storage roots (Table 1) show significant differences for environment and genotype main effects, as well as for GxE interaction. Genotype main effect appears to contribute more to the total variability of both traits than does the environment. Following the AMMI model, a principal component analysis (PCA) was carried out to decompose the GxE interaction for root yield and beta-carotene content in roots.

Only the first two PCA axes were significant (data not shown) after gathering 91% and 88.4%, respectively, of the total variability for both traits (total root yield and beta-carotene content). The loadings of the PCA axes are good indicators of factors contributing to the variability. In the case of genotypes, the first PCA axis loadings show that for total root yield, cultivars Xushu 18 and ARB 535 were important in the GxE interaction. Whereas for beta-carotene content in roots, the first PCA axis loadings show that cultivars SR 92.499-23 and ARB 535 were important.

The GxE component of the AMMI model is based on the product of PCA scores. The figure is not shown here, but the AMMI biplot involving the first two significant axes (PCA1 and PCA2) for total root yield showed all nine genotypes and eight environments dispersed around the center of the biplot, meaning that this trait shows a large amount of variability in genotypes and environments. This biplot showed large positive PCA1 scores for La Molina (LM0N and LM80N) and Tacna (TAC0N and TAC80N), which was coincident with total root yield above the grand mean (7.9 t/ha). In contrast, environments at Oxapampa (OXA0N and OXA80N) and San Ramon (SR0N) had negative PCA1 values and were low yielding. Genotypes exhibiting large positive PCA2 scores, such as Jewel and Xushu 18, showed the highest yield in La Molina, confirming that genotypes with large positive scores yield especially well in environments of the same sign. The converse also holds: genotypes with a large negative score, such as SR 92.499-23, yielded best in environments with a large negative score, such as Oxapampa (OXA0N and OXA80N) and San Ramon (SR0N). Cultivar Xushu 18 and environment Oxapampa are opposites, indicating that their contributions to the interaction would be in opposing directions. As expected, cultivar Xushu 18 ranked fifth in Oxapampa but ranked in first place in the other environments. Clones Tanzania and JPKY 16.005 were distinctive and yielded better in Tacna and Oxapampa, respectively.

Table 1. Mean squares of analysis of variance of AMMI model for total root yield (t/ha) and beta-carotene content in storage roots (mg/100 g FM) of nine sweetpotato cultivars grown in for locations under two N regimes (0 and 80), Peru, 1999/2000.

Source of variability	df	Root yield		BC content	
		t/ha	P>F	mg/100 g FM	P>F
Model	87	166.87	0.0001	2.09	0.0001
Environ	7	381.41	0.0001	5.35	0.0001
Blocks(Env)	16	6.0		1.19	0.0001
Genotype	8	905.36	0.0001	11.75	0.0001
GxE	56	80.52	0.0001	0.57	0.008
PCA1[1]	14	242.79		1.69	
PCA2[1]	12	58.56		0.38	
Residual	30	13.57		0.12	
Error	128	11.29		0.34	
Total	215				

[1] Principal component analysis axes, one and two respectively.

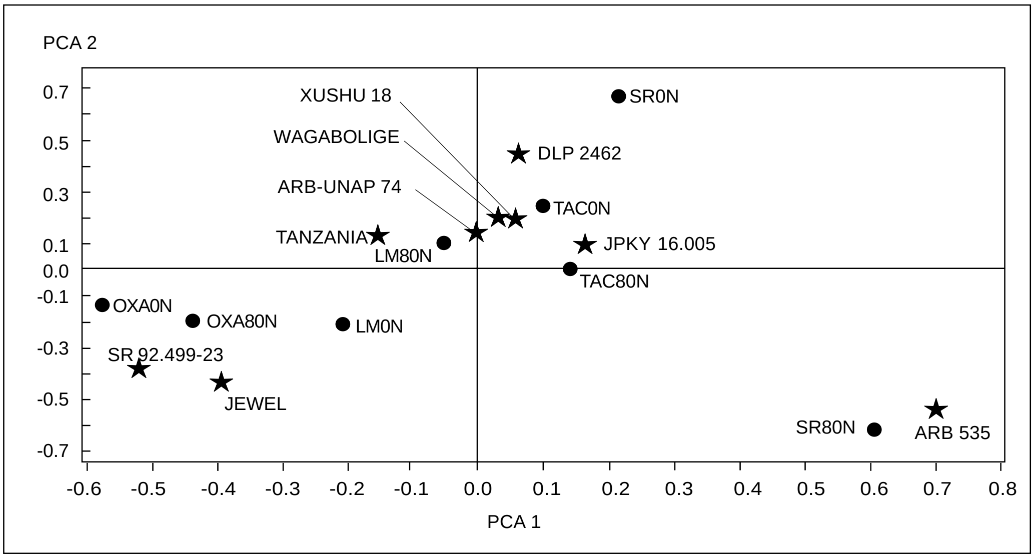

Figure 1. Biplot of principal components analysis (PCA) axis 2 vs. axis 1 for beta-carotene content in roots (mg/100 g) for nine sweetpotato cultivars grown in eight environments.

AMMI biplot PCA1 vs. PCA2 for beta-carotene content in roots for genotypes and environments (Figure 1) shows stable cultivars Tanzania, Wagabolige, ARB-UNAP 74, Xushu 18, and JPKY 16.005 clustered close to the center of the biplot. More unstable clones, such as ARB 535, DLP 2462, SR 92.499-23, and Jewel, were far from the center. Similarly, environments La Molina (LM0N and LM80N) and Tacna (TAC0N and TAC80N) are more stable than Oxapampa (OXA0N and OXA80N) and San Ramon (SR0N and SR80N). This figure also illustrates the dominant cultivars and environments with negative PCA1 scores that strongly influenced the GxE interaction, such as SR 92.499-23, ARB 535, Oxapampa (OXA0N and OXA80N), and San Ramon (SR80N).

There was a clear trend of increasing absolute values of beta-carotene (mg) in 100 g of fresh matter (FM) of roots in almost all tested clones (Figure 2). This was apparently influenced by agroecological factors at locations, probably associated with conditions of increasing altitude, such as radiation quality, mean temperatures and temperature amplitudes, or water stress. The increase in beta-carotene content was variety-dependent, ranging from 59% to 600%. Clones DLP 2462, SR 92.499-23, Wagabolige, Tanzania, Xushu 18, and ARB-UNAP 74 were the most responsive, at least doubling their beta-carotene content in Oxapampa (1800 m), compared to the lowest locations: Tacna (32 m) and

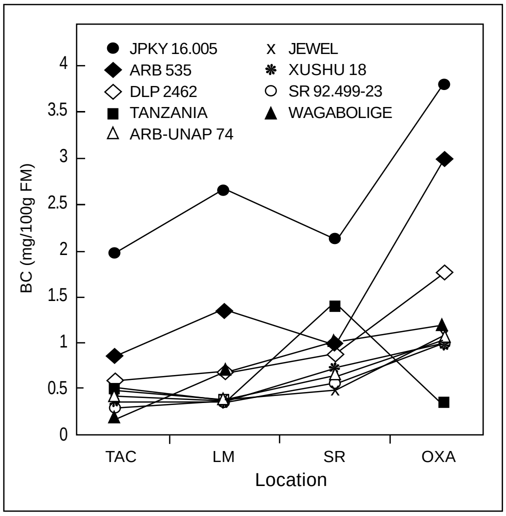

Figure 2. Interaction of beta-carotene concentration in roots of nine sweetpotato clones across four locations.

La Molina (240 m). Cultivars Jewel, SR 92.499-23, and Tanzania showed the highest beta-carotene content.

Lower partial pressure of CO_2—a condition that can be expected at high altitudes—negatively affects total dry-matter production (Kimball, 1983). Because of this, the beta-carotene content in root dry matter was calculated and related to total root dry-matter production for the same five plant samples for each clone and location (Figure 3). Both Jewel and SR 92.499-23 showed similar patterns of beta-carotene concentration, with the largest values by far of all clones tested in Oxapampa. However, the beta-carotene yield of SR 92.499-23 was 34% higher than that of Jewel at Oxapampa (1800 m) (Figure 2), which means that at Oxapampa, SR 92.499-23 was more efficient than Jewel in producing and accumulating beta-carotene in root dry matter.

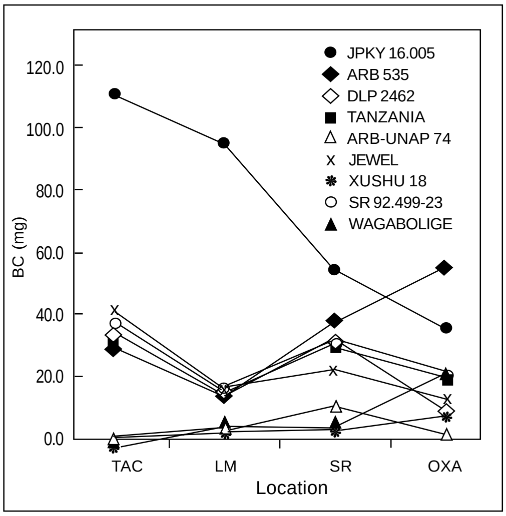

Figure 3. Interaction of beta-carotene content in relation to root DM production of nine sweetpotato clones across four locations.

Conclusions

According to the AMMI biplots, none of the high-yielding cultivars had satisfactory stability for total root yield. The lack of association between high root yield and stable performance suggests the need of further study on the response of sweet-potato root yield to varying agroecological conditions. However, promising new high-yielding cultivars have been identified. In Oxapampa, SR 92.499-23 and JPKY 16.005 outperformed the elite cultivar Xushu 18, which was the top performer at other sites and has the potential to replace locally grown varieties in the region.

The biplot for beta-carotene content in roots showed stability for cultivars Tanzania, Wagabolige, ARB-UNAP 74, Xushu 18, and JPKY 16.005. Clone SR 92.499-23 was less affected by high altitude for beta-carotene accumulation.

There was a trend of increasing beta-carotene concentration at increasing altitudes in the roots of almost all tested clones. This trend will be confirmed with three pending harvests at mid- and higher altitudes.

Considering the importance of beta-carotene as a precursor to vitamin A, it is recommended that further research and crop improvement be done in order to incorporate such traits as those shown by SR 92.499-23. This is particularly important for those high-altitude areas where poor or low-resource farming communities are more vulnerable to vitamin-A deficiency.

Acknowledgments

The authors thank Mr. Adelmo Párraga and Ms. Pilar Gálvez of the Universidad Nacional Daniel A. Carrión (Cerro de Pasco) and Dr. René Chávez of the Universidad Nacional Jorge Basadre (Tacna) for their cooperation in their respective experimental sites; and field technicians Mr. Roberto Martinez and Néstor Cárdenas for assisting in plant harvests and measurements.

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