PROGRESS AND PROSPECTS FOR POTATO BIOFORTIFICATION: DIVERSITY, RETENTION, BREEDING, AND DELIVERY

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Abstract – With HarvestPlus, CIP has undertaken biofortification of potato as a food-based strategy to combat micronutrient malnutrition, targeting Fe, Zn and vitamin C, as a promoter of mineral bioavailability. Ample genetic diversity for Fe and Zn concentrations exists and can be exploited in breeding programs seeking to increase the levels of these minerals in the diet. Boiling does not affect the Fe or Zn concentration of potatoes. However the retention of vitamin C varies significantly with cooking method. The bioavailability of Fe in potato can be greater than in cereals and legumes due to the presence of high levels of vitamin C and low levels of phytic acid. Caco-2 assays have shown that the Fe from yellow fleshed potato varieties is of higher bioavailability than that of pink and purple fleshed varieties, Following first realization of genetic gains in a diploid base population, 4x-2x crossing is in progress toward new breeding goals of higher bioavailable Fe and Zn concentrations in advanced tetraploid populations with disease resistance and tolerance to abiotic stress. NIRS calibrations developed to estimate iron and zinc allow distinction between varieties with high, medium and low concentration of these minerals. Participatory selection provides early feedback on farmer and consumer preferences and may speed delivery of biofortified varieties to targeted communities.

Keywords: Fe concentrations, Zn concentration, Bioavailability, NIRS, Participatory variety selection

Introduction

Micronutrient malnutrition diminishes the health and productivity of over half of the world's population, impacting primarily on the well being of women, infants and children (WHO, 1997). Biofortification is the process of breeding new varieties of staple food crops with increased mineral and vitamin concentration (Nestel *et al*., 2006). Potato is the world's third most important food crop and its production is expected to double in the next several years. Already an important source of energy, vitamins, minerals, and protein of high biological value, its significant, heritable variation for micronutrient concentration, low concentration of phytate, and high vitamin C make it a promising crop for biofortification. While population improvement is under way to develop biofortified varieties as components of the diet in targeted African and Asian countries, a concept of improved variety mixtures with complementary nutritional characteristics is under development in the Andes where diversity of landrace potatoes is high. NIRS technology can offer research breeding programs potential for estimating nutrient concentration of thousands of genotypes within relatively short time-frames (e.g., for selection purposes between harvest and planting the next season) and at low cost (Cozzolino, 2010; Haiyan and Yong, 2007).

Results and Discussion

Breeding potato for quality traits requires a continuous flow of new genes and allelic diversity into the commercial gene pool. Evaluation of the concentration of mineral, vitamin C, carotenoids and phenolic compounds of 872 accessions representing five taxonomic groups of cultivated potato: *Solanum stenotomum*, *S. goniacalyx*, *S. phureja*, *S. andigena*, *S. chaucha* and *S. tuberosum*; conserved in the in trust germplasm collection at CIP enabled the formation of a diploid and a tetraploid source population for nutritional enhancement. These species represent a rich source of quality, protection and production traits and possess the allelic diversity needed to broaden the genetic base of the commercial potato and to produce highly heterotic genotypes. Evaluation of 582 native Andean potato accessions in field trials over a period of 5 years revealed a range of Fe concentrations from 0.27-0.75 mg/100g on fresh weight basis (FW) and 11.24-30.82 mg/kg on dry weight basis (DW) (Figure 1A). Zn concentration in these same accessions ranged from 0.20-0.67 mg/100g FW and 8.53-26.22 mg/kg on dry weight basis (DW) (Figure 1B). Among 290 selections from 4 groups of bred germplasm (Populations LTVR and B), intermediate clones (LTVR-B) and varieties of world importance showed a range of Fe concentrations from 0.24-0.64 mg/100g FW and 11.2-24.48 mg/100g on dry weight basis (DW) (Figure 1C). Zn concentrations of the same accessions ranged from 0.14-0.85 mg/100g in fresh weight and 6.33-32.54 mg/kg on dry weight basis (DW) (Figure 1D). Among all potato germplasm studied, the *S. stenotomum* and *S. goniacalyx* group had higher maximum and mean concentrations of Fe and Zn than *S. phureja* and *S. andigena*. The data collected suggest that there is sufficient genetic variability to significantly increase Fe (by about 35 %) and Zn concentration (by about 30 %) by methods such as recurrent selection. Fe and Zn concentrations were significantly positively correlated ($r=0.5$, $P<0.05$) in the germplasm studied. A preliminary study of the effect of environment (E) and genotype x environment interaction (GxE) on mineral concentrations, revealed significant effects due to E and GxE interaction as well as genotype. Despite the significant GxE interaction, there were no dramatic changes in ranks, and cross over interactions were only noted among genotypes with similar ranges of micronutrient concentrations (Burgos et al 2007).

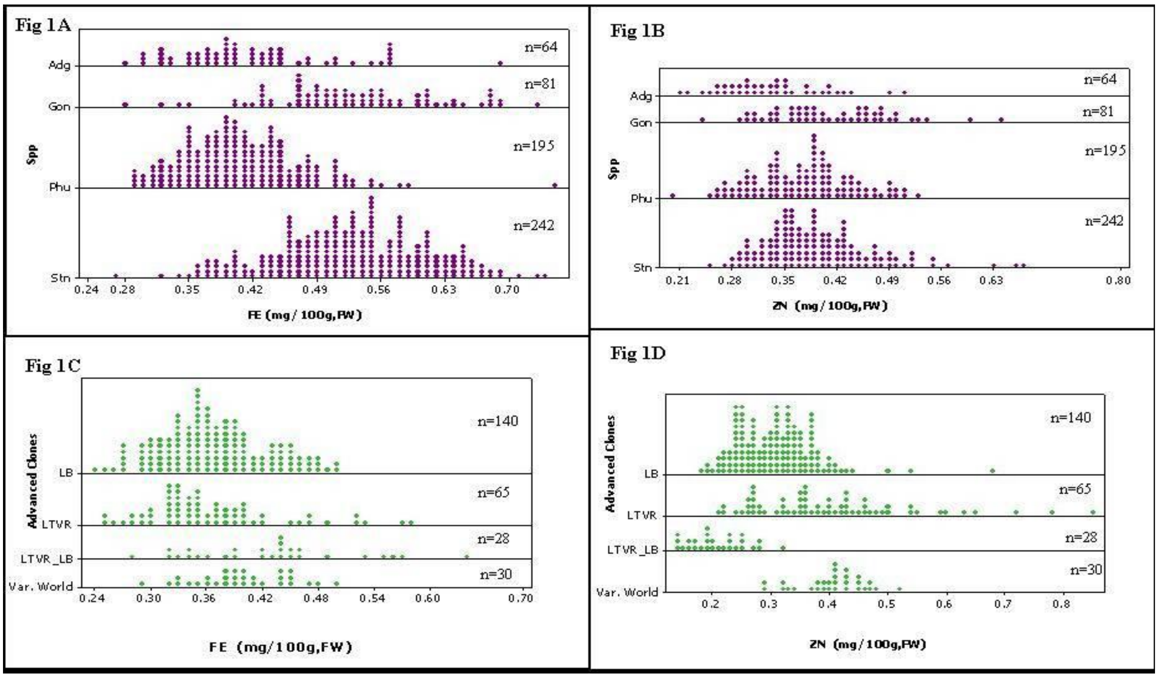

Figure 1. A and B – Frequency distribution of Fe and Zn concentrations in samples of four groups of

Andean landrace potatoes**;** C and D **–** Frequency distribution of Fe and Zn concentrations in samples of 4 groups of improved clones and varieties.

Since potatoes are eaten in various cooked and processed forms, it is important to determine the retention of micronutrients when screening and using genetic resources in breeding with food products in mind. Comparative analysis of Fe and Zn concentration of raw and cooked potatoes indicated no significant differences due to 'cooking' or 'genotype × cooking' interaction (Burgos et al 2007). Thus, information from Fe and Zn concentrations on raw tubers may be used directly in comparison among varieties and calculations of potential impact on the diet. On the other hand, cooking significantly affects the concentration of vitamin C in potatoes, with variation due to both genotype and cooking method. Boiling reduced the vitamin C concentration to a lesser degree than either baking or microwaving with percentages of vitamin C retention ranging from 53 to 97%, from 6 to 66% and from 6 to 39% among boiled, baked and microwaved potato accessions, respectively (Burgos et al 2008). The bioavailability of Fe in cooked tubers of potato samples with low, medium and high concentrations of Fe and respective enhancers (vitamin C) and inhibitors (phenolic compounds); and of extrinsic Fe presented with potato was estimated using the in vitro Caco-2 cell assay (Glanh et al., 1998) in collaboration with the Plant Soil and Nutrition Laboratory of USDA, Ithaca, NY, USA. Among these samples the Fe of the yellow-fleshed varieties was of higher bioavailability than that of the pink and purple-fleshed varieties. Figure 2 illustrates the relationship of Fe, Zn. Vitamin C and phenolic compound concentrations in a sample of 101 landrace accessions. Chemical composition suggests that bioavailability would generally be high in the *S. phureja* group, which is relatively high in vitamin C and low in phenolic compounds, although as mentioned above, cooking met change the ranking of varieties for Vitamin C concentration.

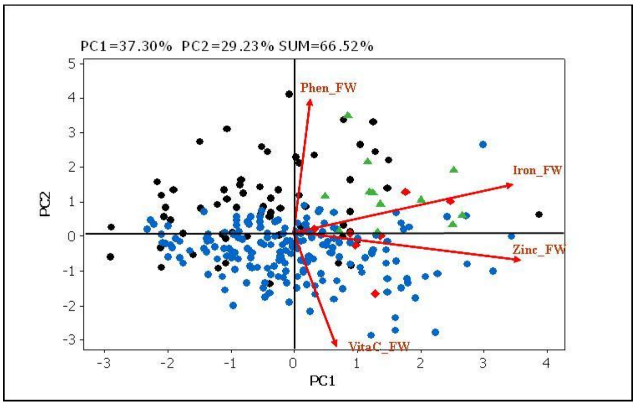

Figure 2. Biplot showing the relationship of Fe, Zn. vitamin C and phenolic compound concentrations of Andean landrace potatoes.

To date, two cycles of recombination have been carried out among selected micronutrient-dense genotypes of diploid Andean potato germplasm. Heritabilities of 0.45, 0.91 and 0.54 for Vitamin C, Fe and Zn concentration respectively estimated in the first cycle, permitted significant genetic gains of more than 40% for Fe concentration and more than 20% for Zn concentration in the second cycle (Figures 3 A and B). Progenitors with high general combining ability for both high Fe and Zn concentration were identified. Interploid (4x-2x) crossing is in progress toward new breeding goals of higher bioavailable Fe and Zn concentrations in advanced tetraploid populations with resistance to the most important potato diseases) and tolerance to abiotic stress.

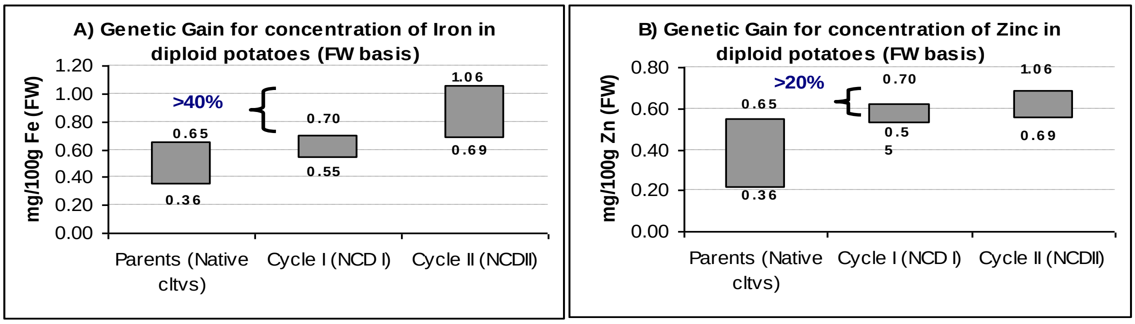

Figure 3. A and B – Genetic gains for mineral concentration in diploid potato population after two cycles of recombination.

Feasibility of developing NIRS calibrations for mineral estimation in freeze-dried potato tuber samples has recently been evaluated. Reference values for mineral content were obtained by ICP in a total of 150 freeze dried potato samples. The reference values of 108 samples and their respective scans were used to develop a calibration to estimate Fe and Zn concentration in freeze dried potato samples and the other 42 samples were used to validate the calibration model. The NIRS calibration equation for Fe and the external validation showed high coefficient of determination (0.78 and 0.85, respectively; Table 1 and Table 2) and the calibration equation for Zn and the external validation of the calibration showed medium coefficients of determination (0.52 and 076, respectively; Table 1 and Table 2). These results indicate that it is possible to distinguish potato genotypes with low, medium and high concentration of Fe by NIRS analysis. NIRS calibrations provide new, more rapid and economical means to estimate micronutrient concentrations for timely decision-making in the course of population improvement.

Table 1. Variation of concentrations as measured by reference methods, NIRS-calibration and cross validation statistics for Iron and Zinc concentrations in potato.

	Reference Values			Calibration		Cross Validation	
Trait	Range [a]	Mean [a]	SD [a]	R^2_c	SEC [a]	R^2_{cv}	SECV [a]
Iron (N=103)	8.9 – 47.9	20.4	7.1	0.78	3.2	0.75	3.26
Zinc (N=105)	9.9 – 24.3	15.6	2.4	0.52	2.56	0.5	2.62

SD = standard deviation, R^2c = coefficient of determination in calibration, SEC = standard error of calibration, R^2cv = coefficient of determination in cross validation, SECV = standard error of cross validation, a = mg 100 g-1 in dry weigh.

Table 2. Variation of concentrations as measured by reference methods for Iron and Zinc in potato samples for external validation with randomly selected sample spectra and NIRS-validation statistics.

	Reference Values			*External* Validation	
Trait	Range [a]	Mean [a]	SD [a]	R^2_v	SEP(C) [a]
Iron (N=42)	10.5 – 41.8	22.6	8.1	0.85	3.33
Zinc (N=42)	9.9 – 28.1	17	5.2	0.76	3.22

SD = Standard deviation, R^2v = coefficient of determination in validation, SEP(C) = standard error of prediction corrected for bias, a = mg 100 g-1 in dry weight.

CIP's strategy for the deployment of biofortified potato clones in the Andes will build on previous successful experiences of participatory varietal selection. Participatory and decentralized selection will be conducted among 20 to 30 biofortified clones, together with development agents, farmers and other stakeholders in highland areas where potato production and consumption and child malnutrition overlap. During 2010-2011, participatory varietal selection was conducted among micronutrient dense landrace and improved clones from CIP's breeding program with 8 groups of women in Chopcca Communities of Huancavelica, Peru. Farmer evaluators were informed about the importance of Fe, Zn and vitamin C in the diet and the variation among potato clones for nutritional value. The accessions were grown and managed in the farming communities and evaluated for plant and tuber type, yield and taste. Both men and woman ranked the clones and enumerated the selection criteria they considered most appropriate at both the flowering and harvest stage of crop development. Locally important preference criteria included stem thickness, profuseness of flowering, stolon size, disease resistance, yield levels, number of tuber eyes, earliness, texture, cooking time and flavor. Selected clones are maintained in the communities as part of a multi-faceted strategy to improved on farm productivity and nutritional status, while selection criteria will be incorporated into further cycles of breeding to reach higher mineral concentrations in varieties that meet farmers' and household needs.

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