Major Achievements in Breeding for Drought Tolerance and High Iron Orange-fleshed Sweetpotato in Mozambique: Lessons Learned and Achievements in Phase 2 (2014-2019)

SASHA Sweetpotato Action for Security and Health in Africa

- Successful second round of accelerated breeding completed, with the release of 4 orange-fleshed (OFSP) and 3 purple-fleshed (PFSP) drought-tolerant sweetpotato varieties in 2016. Third round will be completed in 2019.
- Early season and terminal drought have negative effects on storage root yield (Fig. 1).
- Thick vines offer a morphological adaption to drought which may offer an advantage for remobilization of assimilates from leaves and stems to storage roots.
- Many widely adopted varieties are early bulking and satisfy piece meal harvesting, a desired trait given the predicted shortened seasons in Southern Africa under climate change.
- Among the 15 drought-tolerant OFSP released in 2011, Delvia and Irene have emerged as the most widely-adapted across different agro-ecologies.
- First enhanced iron (Fe) OFSP clone (MUSG15052-2) selected from Umbeluzi populations.
- Fe bioavailability study from comparing enhanced Fe OFSP clone to low Fe clone conducted among Malawian women of reproductive age by ETH-Zurich in 2019.

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Fig 1. Highthroughput evaluation of drought tolerance at Umbeluzi Research Station (Credit G. Makunde)

What was the problem?

Drought is defined as the inadequacy of available water through rainfall or irrigation to meet the crop water requirement. Drought is considered the major limitation to sweetpotato production in Southern Africa, where most agriculture is dependent on unimodal rainfall. Unimodal rainfall systems also tend to have less diverse food systems than bimodal systems found in East and Central Africa. This is reflected in the very high levels of vitamin A deficiency (69%) found among children under five years of age in Mozambique. In addition, anemia (75% of pre-school children and 52% of pregnant women) and other Fe deficiencies are widespread in Mozambique and neighboring countries in Southern Africa. Iron deficiency impairs mental development and capacity to learn in children and adolescences while reducing adults' ability to do physical labor, with increased risk of death for women during child birth.

What objectives did we set?

The objectives were to (i) select and release drought tolerant genotypes as varieties from breeding trials, (ii) understand the mechanism(s) governing drought tolerance in sweetpotato to enhance selection and improve breeding efficiency (iii) improve dry matter content and other quality traits like beta-carotene, iron and zinc. Specifically, for quality traits, the selected clones were to meet 200% RDA for young children of pro-Vitamin A, 25% RDA of iron and 35% RDA of zinc under high intakes. Once sufficient progress had been made in breeding for iron (Fe), another objective to measure Fe bioavailability from a conventionally-bred, Fe- enhanced OFSP clone (MUSG15052-2) was set.

Where did we work?

For drought field trials and initial identification of the enhanced Fe clone, we worked in Mozambique at four locations: Maputo, Umbeluzi, and Chokwe in the South,

Fig 2. Long-time collaborators Jose Ricardo (IIAM) and Maria Andrade (CIP) in front of massive crossing block (Credit J. Low)

Fig 3. Participant with OFSP test meal in iron bioavailability multi-meal feeding trial in Malawi (Credit J. Low)

and Gurué in the Center. In addition, there was a site in Mansa in Northern Zambia.

For the iron bioavailability study, we worked at the Laboratory of Human Nutrition, Institute of Food, Nutrition and Health, ETH Zurich, Zurich, Switzerland, Germany to assist with the design and implementation of a multiple-meal feeding trial conducted in collaboration with the College of Medicine, University of Malawi, Zomba, Malawi and International Potato Center, Maputo, Mozambique for storage root production.

What did we achieve during SASHA Phase 2?

This joint CIP-IIAM effort successfully implemented its second round of accelerated breeding (Fig. 2). During Phase 1, 15 drought-tolerant OFSP were released in 2011. In 2016, seven additional drought tolerant varieties were released: four orange-fleshed (Alisha, Ivone, Victoria, Lawrence); three with significant amounts of purple-flesh (Bita, Caelan and Bie)[1]. Victoria, Lawrence and Bita are classified as dual purpose, with an excellent balance of storage roots for human consumption and foliage for animal feed. These types are particularly preferred in dry areas where raising livestock is an important economic activity.

The varieties released in 2016 demonstrate a 7% average genetic gain in dry matter over the 2011 releases. Some utilize different mechanisms of drought tolerance. For example, Alisha and Ivone are early maturing, doing very well in a short growing season, thus avoiding drought. Caelan and Bita have high vine vigor and better stomatal regulation[2] under drought conditions. Between 2011 and 2016, we saw an average increase in beta-carotene (pro-vitamin A) by 16%; iron by 6%; and zinc by 18%.

Our quality laboratory continued to be an essential part of our breeding program. During the past five years more than 66,200 samples were processed, providing data on macro- and micronutrient contents. The tissue culture lab and linked screenhouses assured the provision of quality pre-basic material to several dissemination programs. Three of those programs (Emergency relief in the South; VISTA in the Nampula and Zambézia Provinces, and Nutritious Sweetpotato for Niassa Province) coordinated the delivery of quality planting material to over 400,000 households. Delvia and Irene have emerged as the most widely-adapted across different agro-ecologies. These varieties, in addition to outcompeting dominant local varieties yield-wise, were easy to establish, have good multiplication rates and were able to sprout well after the dry season. Notably, Irene has been released in Cote d'Ivoire, Madagascar, and Kenya. Moreover, 229,263 seed generated from crossings was shared with 14 African breeding programs, Bangladesh, Brazil, India and the USA. More than one million botanical seed are in storage.

On a fresh weight basis, the enhanced Fe OFSP clone, MUSG15052-2 has 12.4 µg Fe/g, <0.1 µg phytic acid/g, 14 µg ascorbic acid/g on a fresh weight basis (fwb) compared to an OFSP variety with a typically lower concentration of iron (Irene) with 6.4 µg Fe/g, <0.1 µg phytic acid/g, 46 µg ascorbic acid/g. The Fe content is stable across environments in Mozambique. Preliminary results from the iron bioavailability studies conducted in Malawi (Fig. 3) showed fractional Fe absorption from both MUSG15052-2 and Irene test meal types was 5.8%. However, fractional Fe absorption varied based on initial ferritin status of the woman. Those with low status absorbed 8.1%; those with adequate status, only 3.6%. The enhanced iron clone provided 0.09 mg absorbable iron per 100 grams of cooked OFSP. This would supply 14.1% of the target 50% Estimated Average Requirement (EAR) for absorbable iron for children 1.5-4.5 years of age and 6.4% for young women of reproductive age. Levels of absorption may have been negatively affected by significant levels of polyphenols found in the roots. Iron absorption might be enhanced by increasing the vitamin C in the roots. Both are areas that will require further examination.

Where there any key challenges or lessons learned?

Early season and terminal drought have negative effects on storage root yield. Drought can occur at any time during the growth cycle. Early season drought occurs soon after planting until storage root initiation and can have devastating effects on yield, depending on its duration and intensity. Above ground, early season drought affects the photosynthetic capacity of sweetpotato by reducing leaf area. Terminal or late season drought occurs during the mid–to-late bulking stages of sweetpotato. Below the ground, all roots might be directed to search for diminishing water sources leading to formation of skinny pencil roots. Pencil roots cannot switch their role later to become storage roots. Meanwhile, terminal drought affects the bulking process by reducing the number of photosynthesizing leaves, with cracking soil promoting weevil attack, with subsequent reduction in root quality.

Remobilization of assimilates[3] from leaves and steams to storage roots occurs as a mechanism for drought tolerance under terminal drought stress and vine survival in dry areas. Thick vines offer a morphological adaption to drought and offer an advantage for remobilization of assimilates. The varieties Caelan, Bita and Alisha have thick vines and do well under terminal drought conditions. Vine survival is an easy to assess critical trait in drought prone areas. Varietal survivability is judged by the ability of root to sprout after a lengthy period of storage, and subsequent growth and spread in the nursery beds.

Unpredictability of drought and associated stress. Time of occurrence, duration and severity of drought is unpredictable in nature and not repeatable. The interaction of drought and heat as well as other biotic stresses makes breeding for drought-prone areas complex. Weevils are associated with drought stress and significantly reduce quality of storage roots. Farmers in dry areas favor early maturing varieties as they can escape weevil damage enabled by drought.

Early maturity is a key drought adaptive trait. The new varieties Ivone and Alisha are early maturing. Predictive climate change models indicate shortened seasons in Southern Africa.

The most serious challenge faced was having sufficient irrigation water at the Research Stations due to pump breakdowns or the drying up of water sources. In addition, stray cattle and goats occasionally wreaked havoc on experimental plots. Selection for drought tolerant clones requires evaluation in optimum environments in addition to the drought-prone environments. Diligent supervision and sufficient resources are essential for the maintenance of such a complex program.

[1] For details on each variety, refer to the Sweetpotato Digital Catalogue on Sweetpotato Varieties available at www. Sweetpotatoknowledge.org.

[2] Stomata regulation is the process in the leaves to control the amount of water and solutes within them by opening and closing their guard cells.

[3] An assimilate an organic material, such as sugar and carbohydrates.

Fig 4. One of the candidate purple-flesh clones for release in 2019 (Credit M. Andrade)

What's next?

The third round of accelerated breeding is expected to result in the release during 2019 of five high-yielding drought tolerant OFSP varieties and two purple-fleshed varieties, with better shape and improved storability compared to earlier releases (Fig. 4). The research team will continue to employ drones to measure canopy temperature depression, stomatal density, etc. as part of their advanced phenotyping effort initiated in 2019. During the next five years, the program will focus on institutionalization of best breeding practices, including high throughput phenotyping for drought tolerance; OFSP hybrid development between the population in Gurue (50 parents) and that in Umbeluzi (50 parents); continued improvement of iron & zinc levels in OFSP populations; greater emphasis on breeding for processing into products; crop modelling and genomic prediction in identifying where and when any combination of alleles or traits are beneficial in specific drought scenarios; and measurement of genetic gain in breeding trials and released varieties on-farm.

Iron is now a key trait considered for selection in the breeding program and there is need to continue improvement of Fe & Zn orange-flesh and non-orange-flesh populations. Another bioavailability study on Zn will be required once enhanced levels of Zn are reached in the population.

Partners

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Related publications:

Godwill S. Makunde, et al. 2018. *Adapting sweetpotato production to changing climate in Mozambique*. Open Agriculture 3:122-130

Maria I. Andrade, et al. 2017. Vine survival of sweetpotato (*Ipomoea batatas* [*L*] *Lam*) *cultivars subjected to long dry spells after the growing season in Mozambique*. Open Agriculture 2(1): 58-63

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Maria I. Andrade, et al. 2016. *Alisha', 'Anamaria', 'Bie', 'Bita', 'Caelan', 'Ivone', 'Lawrence', 'Margarete' and 'Victoria' sweetpotato*. HortScience 51(5), 597-600.

Maria I. Andrade, et al. 2016. *Genotype x environment interaction and selection for drought adaptation in sweetpotato* (*Ipomoea batatas* [*L*.] *Lam*) *in Mozambique*. Euphytica 209, 261-280

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