Vitamin A Maize

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<table>
<tr><td colspan="2">Target Micronutrient</td><td colspan="2">Vitamin A</td></tr>
<tr><td colspan="2">Target Country</td><td colspan="2">Zambia, secondary countries: Nigeria, Ghana</td></tr>
<tr><td colspan="2">Baseline Content</td><td colspan="2">0 ppm</td></tr>
<tr><td colspan="2">Target Increment</td><td colspan="2">15 ppm</td></tr>
<tr><td colspan="2">Target Level in Crop</td><td colspan="2">15 ppm</td></tr>
<tr><td colspan="2">Nutrition Factors</td><td>Original Assumption</td><td>Measured/Revised[1]</td></tr>
<tr><td rowspan="2">Maize Consumption, grams/day (dry weight)</td><td>Women</td><td>300 g/d</td><td>287 g/d</td></tr>
<tr><td>Children</td><td>200 g/d</td><td>172 g/d</td></tr>
<tr><td colspan="2">β-carotene Retention (%)</td><td>50%</td><td>37.5%</td></tr>
<tr><td colspan="2">β-carotene Absorption (%)</td><td>8%</td><td>17%</td></tr>
<tr><td colspan="2">Absorbed Vitamin A as % of EAR</td><td>50%</td><td>50%</td></tr>
<tr><td colspan="4">Releases</td></tr>
<tr><td>1st Wave</td><td colspan="2">6–8 ppm (40–60% target increment)</td><td>Released: Zambia, 2012; Nigeria, 2012; Ghana, 2012</td></tr>
<tr><td>2nd Wave</td><td colspan="2">8–12 ppm (60–80% target increment)</td><td>Planned: Zambia, 2015; Ghana, 2015; Nigeria, 2015</td></tr>
<tr><td>3rd Wave</td><td colspan="2">>15 ppm (>100% target increment)</td><td>Planned: 2017–18</td></tr>
</table>

[1]Zambia

Breeding to Date: During HarvestPlus Phase I (Discovery, 2003–2008), initial screening of more than 1,500 maize germplasm accessions found ranges of 0–19 ppm provitamin A in existing maize varieties. Natural genetic variation in some lines exceeded the trial average by at least 60% for β-carotene and provitamin A (1,2). These nutrients were consistently expressed in the maize inbred lines across different growing conditions, and further assessment indicated that there was potential to increase the levels of multiple carotenoids simultaneously (1,2). Degradation rate of carotenoids is not significant during grain/ear drying, but during storage, degradation occurs after three months and is higher in milled grain than whole kernels (2,unpublished data). Carotenoid degradation rate is dependent on the genotype and can range from 60–90% after 12 months of storage (2,unpublished data).

In Phase II (Development, 2009–2013), the use of DNA-based techniques, such as association mapping studies, led to the identification of loci associated with provitamin A carotenoids and the development of DNA markers that have led to accelerated genetic gain in breeding for increased provitamin A content (3,4,5). The most important locus identified to date is the β-carotene hydroxylase 1 (crtRB1); validation experiments showed this rare allele often doubles, and sometimes triples, the total concentration of provitamin A carotenoid content in maize grain, mainly by increasing the content of β-carotene (3). Breeding programs at the International Maize and Wheat Improvement Center (CIMMYT), the International Institute of Tropical Agriculture (IITA), and the Zambia Agriculture Research Institute (ZARI) for provitamin A maize began in 2007 and have operated at full scale since 2011. The breeding pipeline includes materials from the two lead institutions, CIMMYT (tropical mid-altitude) and IITA (tropical lowlands), as well as local germplasm. Mainstreaming of provitamin A into product development is estimated at 10% for CIMMYT for the global maize breeding effort and 80% for the relevant mid-altitude target zone, and 40% for IITA.

Five hybrids and three synthetics were released in 2012, 3 in Zambia, 4 in Nigeria, and 1 in Ghana, all with 6–8 ppm provitamin A (about 50% of the target increment). The varieties combine competitive grain yield and strong farmer preferences in addition to higher provitamin A content in comparison to commercially available hybrids.

Future Releases: Eight hybrid leads and three open-pollinated varieties (OPVs) with up to 11 ppm provitamin A were submitted to the 2013/14 National Performance Trials (NPTs) in Zambia as well as in Ghana and Nigeria, and release of these 2nd-wave varieties is expected in 2015. 3rd-wave hybrid leads are being evaluated at 7–9 sites in Zambia and Zimbabwe during 2013/14, and in Ghana and Nigeria in 2014/15. Most of these hybrids include lines carrying CrtRB1 and other alleles, with levels of provitamin A exceeding 15 ppm. Future breeding efforts focus on developing higher yielding, more robust hybrids exploiting specific adaptation for the different agroecological zones.

Capacity Building: Zambian capacity to conduct carotenoid analysis using high-performance liquid chromatography (HPLC) has been strengthened at ZARI, Mt. Makulu. Additional HPLC capacity was established by the HarvestPlus nutrition team at the Tropical Disease Research Centre (TRDC).To accelerate breeding at National Agricultural Research Systems (NARS) and seed companies, HarvestPlus/CIMMYT provides technical assistance and supports outsourcing of provitamin A molecular marker application and the use of double haploid production.

Regional Testing: HarvestPlus with CIMMYT and NARS partners expanded its regional testing and established an Elite Hybrid Trial in 2012 comprised of released hybrids and leads along with respective inbred lines. NARS in Malawi, Zimbabwe, Ethiopia, Uganda, Democratic Republic of Congo, and Rwanda test, based on their demand, different types of nurseries. HarvestPlus with IITA has also organized regional variety and hybrid trials and dispatched them to partners in Benin, Ghana, Liberia, Sierra Leone, Mali, and Nigeria. Agronomic and provitamin A data from multiple sites per country allows high precision identification of fast-track candidates and inbred lines for breeding, as well as higher effectiveness in targeted breeding for yield and provitamin A stability based on adaptive pattern. By substituting temporal-by-spatial environmental variation in large-scale regional testing, testing steps can be eliminated and time-to-market shortened by 1–2 years.

Highlights:

- Five hybrids and three OPVs have been released; these are competitive with commonly cultivated maize cultivars in grain yield and resistant to the prevalent major tropical diseases.
- Hybrids and OPVs with up to 15 ppm provitamin A content are in the development pipeline.
- CrtB1 markers are now being fully utilized in breeding at CIMMYT.
- In additional to breeding for provitamin A, both CIMMYT and IITA are also breeding for zinc content. Elite tropical maize inbred lines and hybrids with zinc content >30 ppm have been identified in our breeding programs. Hybrids and OPVs have been developed from the best inbred lines and are being evaluated in multi-location trials in Central America and West Africa.

Challenges:

- The chemical mechanism of carotenoid degradation is not well understood. It may be possible to breed for decreased degradation rates in maize, or usefully exploit allelic variation for additional genes in the carotenoid pathway.

Released Varieties

Release Name	Overall Average Yield[1]	Grain Texture	Provitamin A Content
Zambia			
GV662A	3.86 t/ha	Semi flint	6.9 ppm
GV664A	4.46 t/ha	Semi dent	7.1 ppm
GV665A	3.85 t/ha	Flint	7.8 ppm
Nigeria			
Ife maizehyb-3	5.74 t/ha	Semi flint	8.0 ppm
Ife maizehyb-4	5.20 t/ha	Semi flint	7.8 ppm
Sammaz 38 (OPV)	3.54 t/ha	Semi flint	6.3 ppm
Sammaz 39 (OPV)	3.56 t/ha	Semi flint	6.7 ppm
Ghana			
CSIR-CRI Honampa (OPV)	5.2t/ha		6.2 ppm

[1]NPT data

1. Menkir, A; et al. 2008. Carotenoid diversity in tropical-adapted yellow maize inbred lines. *Food Chemistry* 109 (3): 521–529.
2. Menkir, A; et al. 2012. Recent advances in breeding maize for enhanced pro-vitamin a content, pp. 66–73. In *Meeting the Challenges of Global Climate Change and Food Security through Innovative Maize Research*. Proceedings of the Third National Maize Workshop of Ethiopia. Addis Ababa, Ethiopia.
3. Babu, R; et al. 2012. Validation of the effects of molecular marker polymorphisms in LcyE and CrtRB1 on provitamin A concentrations for 26 tropical maize populations. *Theor Appl Genet* doi 10.1007/s00122-012-1987-3
4. Yan, J; et al. 2010. Rare genetic variation at Zea mays crtRB1 increases b-carotene in maize grain. *Nat Genet* 42:322–329.
5. Kandianis, CB; et al. 2013. Genetic architecture controlling variation in grain carotenoid composition and concentration in two maize populations. *Theor Appl Genet* 126:2879–2895.