Nutritionally Enhanced Crops and their Safety Assessment:

Biofortified Sorghum

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Biofortified Sorghum

- Sorghum Background
- Africa Biofortified Sorghum Project
- Safety Assessment
Sorghum - Origin

Center of origin is in Africa
Sorghum - Plant

- Cane-like stalk
- 14-18 leaves
- Seeds bunched
- Fibrous roots
Sorghum - Agronomics

- Drought tolerant
- Flood tolerant
- 60-70d to flower
- 120d to harvest
- Cold sensitive
- Able to grow in poor soils
Sorghum – Farm Practices

- Usually non-irrigated
- Limited pesticide or fertilizer use
- Manual planting/weeding/harvesting
Sorghum - Uses

- Food
  - Bread, porridge, beer, fermented foods

- Feed
  - Grain, forage, stover

- Materials
  - Fencing, building, fuel
Sorghum - Consumption

- Staple food for 300 million people
Sorghum - Consumption

Botswana, Burkina Faso, Cent African Rep, Chad, Ethiopia, Gambia, Haiti, Kenya, Malawi, Mali, Namibia, Niger, Nigeria, Senegal, Somalia, Sudan, Swaziland, Tanzania, Zimbabwe

Gabon, Rwanda, Uganda

India

Pakistan

Bangladesh

Data from http://www.who.int/foodsafety/areas_work/chemical-risks/gems-food/en/
Sorghum - Challenges

Food/dietary challenges?

- Very low pro-vitamin A content
- Low iron and zinc bio-availability
- Poor protein digestibility
Africa Biofortified Sorghum Project

Objectives

• Targeted traits
• Technology access and transfer
• Capacity building
• Biosafety policy/regulations developed
• Biotech acceptance
• Improved product development/delivery
Key Participants:

- Africa Harvest
- DuPont Pioneer
- National Biotechnology Development Agency (NABDA)
- Institute for Agricultural Research (IAR)
- Kenyan Agricultural & Livestock Research Organization (KALRO)
Biofortified Sorghum – Vitamin A

Goal

• Deliver a sorghum line that can provide 30-50% of the Recommended Daily Allowance of vitamin A in children during 4-6 months of ambient air storage

= content, conversion, stability
Biofortified Sorghum – Vitamin A

Method

• Overexpress phytoene synthase gene (Zea mays) and carotenoid reductase gene (Erwinia uredovora) that catalyze steps in the carotenoid biosynthetic pathway.
Biofortified Sorghum – $\beta$-carotene

Results
- Content
- Stability
- Conversion
Biofortified Sorghum – Fe & Zn

Goal

• Increase bioavailability of Fe and Zn
Biofortified Sorghum – Fe & Zn

- Reduced-phytate (phytic acid)
  - Phosphorous storage complex
  - Binds zinc and iron
  - Decreases bioavailability
Biofortified Sorghum – Fe & Zn

• How it works
  • PhyA gene breaks down phytate, “releasing” Fe and Zn (Phytate reduction as sorghum flour is soaked with water)
  • Os-NAS2 gene increases Fe/Zn uptake from the soil
  • Os-YSL1 increases Fe/Zn accumulation

• Resulting in
  • 1.5X increase in Fe and Zn levels in sorghum
  • 5X increase in bioavailability of Fe and Zn
  • Normal seed germination
**Biofortified Sorghum – Fe & Zn**

<table>
<thead>
<tr>
<th></th>
<th>Texas 430</th>
<th>Improved ICRISAT Lines</th>
<th>ABS (Fe + PhyA) event</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fe Content</strong></td>
<td>25 ug/g</td>
<td>70 ug/g</td>
<td>50 ug/g</td>
</tr>
<tr>
<td><strong>Fe with 100 g sorghum consumed/day</strong></td>
<td>2.5 mg/day</td>
<td>7 mg/day</td>
<td>5 mg/day</td>
</tr>
<tr>
<td><strong>% Fe Availability</strong></td>
<td>10%</td>
<td>10%</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Content Available to Mammals/day</strong></td>
<td>0.25 mg/day (8% of EAR)</td>
<td>0.7 mg/day (23% of EAR)</td>
<td>2.5 mg/day (83% of EAR)</td>
</tr>
<tr>
<td><strong>100% EAR</strong></td>
<td>3 mg/day for 1 – 3 year old</td>
<td></td>
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</tbody>
</table>

*Similar biofortification data available for zinc
**Estimated Average Requirements
Safety Assessment Steps

- Problem Formulation
- Addressing questions
- Safety Analysis
Protection Goals, Product Goals

Basic:
- No adverse effects on human health
- No adverse effects on livestock health
- No adverse effect on biodiversity
- (Comparator: typical varieties)

Nutrition
- Substantially equivalent (or improved)
Product / Safety Assessment

- Agronomic
- Environmental
  - Growing area
  - Pests/non-pests
  - Weediness
- Human
Agronomic Assessment

- Phenotype in glass house
- Phenotype in field
- Pest/disease susceptibility
Ecological Assessment

Any plausible hypotheses?

• Changes in pest response that might indicate changes in non-target response?

• Changes in agronomic parameters that might lead to increased weediness in crop (or receptive wild relatives)?
Confined Field Trials

Kenya, Nigeria

No differences observed in agronomic parameters.
Sorghum Pests Africa

African weaver bird
(Quelea quelea)

Sorghum midge
(Contarinia sorghicola)

Parasitic weed
(Striga hermonthica)

No differences observed in pest response.
Gene flow and Weediness

Weediness factors include:

• Increased growth rate
• Increase in seed production/distribution
• Seed or vegetative dormancy
• Increased ecological fitness
Gene flow and Weediness

Out-crossing is common

- **Johnsongrass** *(Sorghum halepense)*
- **Shattercane** *(Sorghum bicolor ssp drummond)*
Gene flow and Weediness

- Research in Kenya and USA
- Weediness/Fitness
- Will be repeated with final transgenic event

No differences observed in characteristics associated with increased weediness.
Biofortified Sorghum - Dietary

- No plausible hypotheses for changes in composition that would affect food or feed safety

- No indications of changes in composition - other than vitamin A and Fe/Zn bioavailability
Biofortified Sorghum – Next Steps

- Determine/optimize final constructs
- Agronomics & environmental
- Human & livestock
- Regulatory approval
- Seed production
- Education
For more information:
www.biosorghum.org