Metabolic engineering of carbon pathways to enhance yield of root and tuber crops

„CAssava Source-Sink“

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Central Goal of the CASS Project

Improving cassava yield by optimizing assimilate allocation and utilization
Cassava agricultural performance and yield/ha is already good in parts of the world…

...but remains sub-optimal in world regions with highest population growth
Production of the Four Most Important Carbohydrate Crops (2013)

Rice

Wheat

Potato

Maize

http://www.factfish.com/statistic/cassava%2C%20production%20quantity
Production of Cassava (2013)

http://www.factfish.com/statistic/cassava%2C%20production%20quantity
Two African Countries are Among the Top 5 Producers Worldwide

The CASS project focuses on Nigeria but other parts of the world will benefit.
Why does the CASS Project Focus on Cassava?

Cassava

.... is very robust and withstands droughts

.... it grows in poor soils

.... it can be harvested between 10 and 30 months after planting

.... propagation occurs via stem cuttings

.... it serves as "safe" food reserve

.... It can be processed to many nutritious products
Cassava is a multifaceted food

- cooked
- fried
- chips
- fermented
- dried
- baked
- Pulp (Fufu, Gari)
- Tapioka starch (from dried Cassava roots)

- ..... and more....
Concerning Yield, Nigeria is Behind Other Countries (2013)

http://www.factfish.com/statistic/cassava%2C%20production%20quantity
Potential Reasons for Low Yield

- Pathogens
  - Bacterial leaf blight
  - Fungal diseases
  - Insects
  - Viruses
- Postharvest losses
- Low fertilizer input
- Physiology
The CASS Project Focuses on Source-to-Sink Relations

Assimilation → Allocation → Utilization

Source

\[\text{CO}_2, \text{light, minerals, } H_2O\]

Assimilates

Vasculature

Sink

Growth & Development

Support

Assimilates

Coordination

Signals
The CASS Approach

- Understanding the metabolic processes limiting cassava yield and starch accumulation in storage roots under optimal growth conditions.

- Exploration of the genetic space of total biomass and starch yield in a range of cassava genotypes and especially farmer-preferred varieties.

- Engineering source-to-sink relations in transgenic cassava plants to increase total biomass and starch yield.
The CASS Project Structure

- **Cassava genotypes**
  - GMPs (sink-source)
  - Cassava Improved root yield
  - In depth profiling
- **Marker GMPs**
  - Metabolic concepts/models
  - Database
X-ray Computed Tomography (CT) to Understand Storage Root Growth
Detailed Molecular Profiling of Cassava Physiology and Metabolism

- Omics

Photosynthesis and Respiration
FW / DW
Starch and sugars
\( \text{NO}_3^- \) and amino acids
Organic acids
Phosphorylated metabolites
Other metabolites
Ions
Protein content
Enzyme activities
Flux measurements
(Phospho)proteomics
Transcript(omic)s
mi/siRNAs

Genotype: TME7
Sample Processing, Data Storage, Model Development

- Samples: IITA, FAU
- Genotypes: IITA
- Analysis: ETH, MPI, UK, FAU
- Fluxome: MPI
- Data storage: BTI
- Data mining: all
- GM and non-GM strategies for yield improvement
- New genotypes

Mathematical model: ETH
CASS Data are used to Engineer Optimized Source-to-Sink Relations

I. Source capacity

II. Transport capacity

III. Sink strength
The CASS Push-Pull Strategy

Improving cassava productivity by engineering optimized source-to-sink relations

- Improved photosynthesis
- Reduced photorespiration
- Improved sucrose availability
- Altered sugar sensing

- Improved allocation to desired sinks
- Accelerated storage organ initiation
- Improved sucrose hydrolysis
- Improved starch accumulation
- Reduced starch breakdown
- Altered signalling
Improving the Cassava Source Capacity

- Improved leaf architecture

- Improved efficiency of C3 photosynthesis

- Removing feedback signals

- Reduced photorespiration

- Improved sucrose availability
CASS has Efficient Cassava Transformation Capacity Available

Complete cycle: 8 to 9 months

**FEC induction**
- Plantlet multiplication (4-6 weeks)
- Auxillary meristems (3 days)
- Somatic embryos (cycle, 6-10 weeks)

**FEC multiplication**
- Agrobacterium-mediated transformation
- Friable embryogenic callus (cycle, 10-52 weeks)

**Transformation, selection, regeneration**
- Antibiotic selection (5-8 weeks)
- Regeneration (up to 8 weeks)
- Maturation (up to 6 weeks)

Adapted from: Bull et al. (2009) Nature Protocols
Thank you and stay tuned...

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