Genetically modified crops under research and development in Africa

Banana (*Musa spp*)

Bananas are a staple food and good source of income for a number of African countries especially East and Central Africa (Viljoen, 2010). Bananas are a source of potassium, magnesium, copper, manganese and vitamin C, but are low in iron and vitamin A (Wall, 2006). Productivity is also affected by pests such as parasitic nematodes and weevils, and diseases like bacterial wilt, *Fusarium spp* and black sigatoka (Shotkoski *et al*., 2010; Viljoen, 2010). Therefore current goals for improvement of banana by African institutions include increasing iron and beta carotene content (the precursor for vitamin A), resistance to bacterial wilt, nematodes and weevils (FARA, http://www.fara-africa.org/biotech-management-africa/; Kasozi, 2010). Field trials with genetically modified (GM) biofortified bananas were planted in Uganda in 2010 (Wamboga-Mugirya, 2011). GM banana plants with improved resistance to bacterial wilt were planted in a confined field trial in Uganda in 2010 (Tripathi, 2011). GM bananas with improved weevil and nematode resistance were tested in the screen house and approved for confined field trial evaluation in Uganda in 2012 (SourceWatch, 2012). The specific genes, approaches, and participating agencies are summarized in the table below.

Banana GM traits under development in Africa

Banana bacterial wilt (*Xanthomonas campestris pv. Musacearum*) resistance	
1. Importance of bacterial wilt	• Bacterial wilt is the most devastating disease to banana production causing 80-100% yield loss[5]
2. Symptoms of bacterial wilt	• Yellowing and complete wilting of banana plants starting with peripheral leaves[18]
3. Susceptible varieties	• All cultivated banana varieties[17]
4. How the disease is spread	• Planting infected suckers, using contaminated farm tools, insects that feed on male buds[18]
5. Management practices	• Cutting and burning or burying infected plants, using clean farm tools, removal of male buds using forked sticks[18]
6. Limitations of using cultural practices	• Highly labour intensive[17]
7. Limitations to conventional breeding	• No sources of resistance among *Musa* germplasm[17]
8. Potential sources of resistance for genetic engineering under development	• *Pflp* and *Hrap* genes from sweet pepper[14]
9. Mode of resistance	• *Pflp* and *Hrap* confer resistance against bacterial pathogens through $harpin_{pss}$-mediated hypersensitive response[1, 3]
10. Research partners	• AATF, Academia Sinica, IITA, NARO-Uganda[14, 16]
11. Funding	• Gatsby Charitable Foundation and United States

	Agency for International Development (USAID)[14]
12. Stage of development	• Confined field trial-Uganda[16]

AATF: African Agriculture Technology Foundation, IITA: International Institute for Tropical Agriculture, NARO: National Agricultural Research Organisation (Uganda)

Banana parasitic nematode and weevil (*Cosmopolites sordidus)* resistance	
1. Importance of nematodes and weevils	• Banana parasitic nematodes lead to 40-60% yield loss; weevils lead to 50-70% yield loss[5]
2. Damage by nematodes and weevils	• Nematodes feed on roots and weevils feed on the corm impairing water and nutrient uptake, leading to reduced yield, plant toppling and snapping[4, 13]
3. Susceptible varieties	• East African highland bananas[11, 19]
4. How nematodes and weevils are spread	• Planting infested suckers[4, 13]
5. Management practices	• Pairing and hot water treatment of suckers[11, 19]
6. Limitations of using cultural practices	• Highly labour intensive[11, 19]
7. Limitations to conventional breeding	• Limited genetic variability for resistance in *Musa* germplasm, cultivated bananas are sterile, highly polyploid & have long generation time[15]
8. Potential sources of resistance for genetic engineering under development	• *Bt cry* genes (cry5B, cry6A), cystatins[14]
9. Mode of resistance	• When *cry* proteins are consumed by the target pest, they are cleaved under alkaline conditions. The resultant activated toxin binds to the gut membrane forming pores that lead to death[7, 10]. • Cystatins prevent dietary action of cysteine proteinases, suppressing growth[2]
10. Research partners	• NARO-Uganda, Univ. California (San Diego), Univ. Leeds, Univ. Pretoria[14]
11. Funding	• Bioversity International, Government of Uganda, Rockefeller Foundation and USAID[14]
12. Stage of development	• Confined field trial-Uganda[12]

NARO: National Agricultural Research Organisation (Uganda)

Bananas enriched with iron and vitamin A	
1. Micronutrient deficiency in Africa	• Micronutrient deficiency is a big problem among the poor communities that predominantly rely on one food source[8]
2. Effects of iron deficiency	• Retarded growth, reduced immunity and anaemia[9]
3. Effects of vitamin A deficiency	• Blindness, retarded growth and reduced immunity[9]
4. Sources of iron	• Iron supplements, animal products, green vegetables, cereals, red/brown beans[22]
5. Sources of vitamin A	• vitamin A supplements, animal products, carrots, papaya, pumpkins, green vegetables[22]
6. Limitations to using iron and vitamin A sources	• They are expensive for the poor people especially those who depend on one food source[8]
7. Limitations to conventional breeding	• Limited sources of high iron and vitamin A in *Musa* germplasm, cultivated bananas are sterile, highly polyploid & have long generation time[15, 20]
8. Potential sources of biofortification for genetic engineering under development	• *FROS2* gene from soybean for iron content and *APsy2* gene from yellow maize and Asupina bananas for beta carotene content, the precursor for vitamin A[6]
9. Research partners	• NARO-Uganda, QUT[14]
10. Funding	• Bill and Melinda Gates foundation[14].
11. Stage of development	• Confined field trial-Uganda[21]

NARO: National Agricultural Research Organisation (Uganda), QUT: Queensland University of Technology (Australia)

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Cassava (*Manihot esculenta*)

Cassava is a very important drought and heat tolerant food staple in Sub-Saharan Africa (Hillocks, 2002). Cassava roots are very rich in carbohydrates but low in proteins, vitamins and other micronutrients (Sayre *et al*., 2011). Cassava production is also constrained by different abiotic and biotic stresses, which include pests such as cassava green mite and cassava mealy bug, and diseases like cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) (Bull *et al*., 2011). Efforts are under way by African institutions to develop biofortified cassava, and cassava that can withstand CMD and CBSD (Taylor *et al*., 2012). The transgenic cassava for CMD resistance is undergoing field evaluation in Uganda and Kenya (Taylor *et al*., 2012). There is also ongoing work to transform farmer-preferred varieties naturally resistant to CMD with siRNAs specific to the brown streak virus (The Donald Danforth Plant Science Center, www.danforthcenter.org/science/programs/international_programs/virca/). Field trials for biofortified cassava were approved in 2009 and 2010 in Nigeria and Kenya respectively (The Donald Danforth Plant Science Center, www.danforthcenter.org/science/programs/international_programs/bcp/). The specific genes, approaches and participating institutions are summarized in the table below.

Cassava GM traits under development in Africa

Cassava with resistance to cassava mosaic disease (CMD) and brown streak disease (CBSD)	
1. Importance of CMD and CBSD	• CMD and CBSD are the most prominent cassava diseases causing 30-60% yield loss[8]
2. Symptoms of cassava mosaic disease	• Characteristic leaf mosaic patterns, leaf chlorosis, leaf distortion, reduced leaflet size and general plant stunting[3].
3. Symptoms of brown streak disease	• Irregular yellow blotchy chlorosis associated with lower leaves, leaf drying and shoot die back under severe conditions, root malformation and dry corky rot in the root cortex[6].
4. Susceptible varieties	• Most cultivated cassava varieties[3, 6, 13]
5. How the diseases are spread or transmitted	• Planting infected materials, white flies[6, 13]
6. Management practices	• Pesticides to kill white flies, clean planting materials[3, 6]
7. Limitations of using pesticides	• Pesticides are expensive and pose risk to human health and the environment[3, 6]
8. Limitations to conventional breeding	• Limited sources of resistance in cassava, high heterozygosity and strong inbreeding depression[6, 15]
9. Potential sources of resistance for genetic engineering under development	• Harpin dsRNAs targeting specific cassava mosaic virus and brown streak virus sequences [9, 12]

10. Mode of resistance	• The dsRNA separates and binds to the virus RNA after infection, which is then degraded preventing virus replication or progression[9, 12].
11. Research partners	• Danforth Center, ETH Zurich, KARI, NaCRRI [9, 10, 12]
12. Funding	• Bill and Melinda Gates Foundation, Howard G. Buffett Foundation, Monsanto Fund, USAID [9]
13. Stage of development	• Confined field trial-Uganda, Kenya[9, 10]

KARI: Kenya Agricultural Research Institute, NaCRRI: National Crops Resources Research Institute (Uganda).

Cassava enriched with iron, protein and vitamin A, and improved storage qualities	
1. Level of malnutrition in Africa	• Malnutrition is a serious problem in the poor communities that rely primarily on one food source[8]
2. Effects of iron deficiency	• Retarded growth, reduced immunity and anaemia[7]
3. Effects of vitamin A deficiency	• Blindness, retarded growth and reduced immunity[7]
4. Effects of protein deficiency	• Stunted growth, reduced immunity, muscle wasting, fluid retention (edema)[5]
5. Sources of iron	• Iron supplements, animal products, green vegetables, cereals, red/brown beans[14]
6. Sources of vitamin A	• vitamin A supplements, animal products, carrots, papaya, pumpkins, green vegetables[14]
7. Sources of protein	• Animal products, legumes e.g. soybeans, beans[4]
8. Limitations to using these sources	• They are expensive for poor people especially those who depend on one food source[8].
9. Limitations to conventional breeding for improved iron, vitamin A and protein	• Limited sources of genetic variability for biofortification, high heterozygosity and strong inbreeding depression in cassava[15]
10. Potential sources of biofortification for genetic engineering under development	• *FEA1*gene for iron content; *Erwinia crtβ* and *Arabidopsis* DXS for β-carotene, the precursor for provitamin A; HNL and zeolin for improved protein[8].
11. Post harvest storage qualities of cassava roots	• Cassava roots rapidly deteriorate after harvest becoming unpalatable and unmarketable[8].
12. Limitations to conventional breeding	• Sources with longer shelf life qualities are not available in the cassava[8].

13. Potential sources of improved storage qualities for genetic engineering under development	• alternative oxidase (AOX)[8]
14. How the cassava roots' shelf life was extended	• Over-expression of AOX in transgenic cassava roots reduced reactive oxygen species (ROS) associated with post harvest physiological deterioration. Enhanced β-carotene extended shelf life by quenching ROS[8].
15. Research partners	• Danforth Center, ETH Zurich, NARS (Kenya, Nigeria)[8, 10]
16. Funding	• Bill and Melinda Gates Foundation[10]
17. Stage of development	• Confined field trial-Kenya, Nigeria[8].

AOX: alternative oxidase, DXS: 1-deoxyxylulose-5-phosphate synthase, HNL: hydroxynitrile lyase, NARS: National Agricultural Research Systems.

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Cotton (*Gossypium hirsutum*)

Cotton is the major source of cash income and foreign exchange in Sub-Saharan Africa (Hillocks, 2009). Insect pests especially cotton bollworms are the major constraint to cotton production in Africa (Hillocks, 1995; Javaid, 1995). African institutions in partnership with Monsanto Company are field testing *Bt* cotton expressing cry1Ac and cry2Ab and herbicide tolerant cotton (Biotech Uganda, 2010; Dahi, 2012; Waturu *et al*., 2008). The *Bt* cotton showed improved resistance against the bollworms in Egypt (Dahi, 2012). *Bt* cotton significantly reduced the bollworm populations in Kenya (Waturu *et al*., 2008). *Bt* cotton and herbicide tolerant cotton field tested in Uganda showed improved resistance to cotton bollworms and improved herbicide tolerance respectively (ABSPII, http://www.absp2.cornell.edu/projects; Biotech Uganda, 2010; Miti, 2009). The specific genes, approaches and participating institutions are summarized in the table below.

GM cotton (*Gossypium hirsutum*)

Bollworm resistance	
1. Importance of the cotton bollworm	• Cotton bollworms are the most damaging insect pests causing yield losses of up to 60% [6]
2. Damage by the cotton bollworm	• Bollworm larvae feed on leaves, flower buds, flowers and bore into fruits/pods[6].
3. Susceptible varieties	• Most cultivated cotton varieties[6]
4. How cotton bollworms are spread	• Fully grown larvae pupate in soil, adults emerge & lay eggs on host plants, which coincides with early flowering of host plants[6].
5. Management practices	• Synthetic pesticides, inspecting for eggs or young larvae before they enter fruits, destroy plant debris after harvesting, plough soil after harvesting to expose pupae to the sun and natural enemies, crop rotation, biological control[4, 6, 7]
6. Limitations of the commonly used management practices	• Synthetic pesticides are expensive for the resource poor farmers and pose risk to human health & the environment, cultural practices are labour intensive & limited control by biological agents[4, 6, 7]
7. Limitations to conventional breeding	• Limited sources of bollworm resistance in cultivated cotton[4].
8. Potential sources of resistance for genetic engineering under development	• *Bt cry* genes (cry1Ac, cry2Ab)[5]
9. Mode of resistance	• When *cry* proteins are consumed by insect larvae, they are cleaved under alkaline conditions. The resultant activated toxin binds to the gut membrane forming pores that lead to death[8, 10]

10. Research partners	• Monsanto, NARS (Uganda, Kenya, Egypt)[3, 9 11]
11. Stage of development	• Confined field trial-Uganda, Kenya, Egypt[2, 3, 11].

NARS: National Agricultural Research Systems.

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Cowpea (*Vigna unguiculata*)

Cowpea is a very important drought tolerant food legume and source of income in Sub-Saharan Africa (Langyintuo *et al*., 2004). It is a good source of proteins, vitamins and mineral nutrients (Timko and Singh, 2008). However, cowpea production is constrained by insect pests such as aphids, thrips, bruchids, pod-sucking bugs and the pod borer (*Maruca vitrata*) (Dugje *et al*., 2009). African scientists in partnership with international agencies are developing farmer-preferred cowpea varieties with resistance to the pod borer using a royalty free cry1Ab gene from Monsanto (AATF, www.aatf-africa.org/projects/aatf_projects/cowpea_improvement). The transgenic cowpea lines are undergoing field trial evaluation in Nigeria and Burkina Faso (AATF, 2012). Confined field trials are planned for Ghana upon regulatory approval (CSIRO Plant Industry, 2010).The specific genes, approaches and participating institutions are summarized in the table below.

GM Cowpea (*Vigna unguiculata*)

Pod borer (*Maruca vitrata*) resistance	
1. Importance of the pod borer	• The pod borer is the most devastating insect pest of cowpea causing yield losses of 0.5-2.5 tons per ha[5]
2. Damage by cowpea pod borers	• Larvae feed on tender plant parts, stem, peduncles, flower buds and pods[5].
3. Susceptible varieties	• Most cultivated cowpea varieties[5]
4. How cowpea pod borers are spread	• Adults rest on the undersurface of host plant leaves where they lay eggs, the larvae then move to tender host plant parts. The pod borer has more than 39 host plants, mostly members of the family Fabaceae[2, 6]
5. Management practices	• Synthetic pesticides, crop rotation, weeding, pruning, biological control[3, 6]
6. Limitations of the commonly used management practices	• Synthetic pesticides are expensive and pose risk to human health and the environment, cultural practices are labour intensive and farmers lack management capability, limited control by biological agents[1, 2, 3]
7. Limitations to conventional breeding	• Cowpea is incompatible with its close relatives that contain natural resistance[1].
8. Potential sources of resistance for genetic engineering under development	• *Bt cry* genes (cry1Ab)[10]
9. Mode of resistance	• When *cry* proteins are consumed by insect larvae, they are cleaved under alkaline conditions. The resultant activated toxin binds to the gut membrane forming pores that lead to death[8, 9]
10. Research partners	• AATF, CSIRO (Australia), IITA, Kirkhouse, Monsanto, NARS (Nigeria, Ghana, Burkina Faso),

	NGICA (U.S), PBS (U.S)[10]
11. Funding	• Rockefeller Foundation and USAID[10]
12. Stage of development	• Confined field trial-Nigeria, Burkina Faso[11]

AATF: African Agriculture Technology Foundation, NGICA: Network for the Genetic Improvement of Cowpea in Africa, CSIRO: Commonwealth Scientific and Industrial Research Organisation, NARS: National Agricultural Research Systems, PBS: Program for Biosafety Systems.

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Maize (*Zea mays* L.)

Maize is one of the most important sources of energy for the poor in Africa (Smale *et al*., 2011). Maize production is limited by various environmental factors such as insect pests, diseases and abiotic stresses (FARA, 2009). Current efforts by African institutions to improve maize productivity include developing maize with resistance to stem borers, maize streak virus (MSV) and drought tolerance (AATF, www.aatf-africa.org/projects/aatf_projects//wema; Mugo *et al*., 2002; Shepherd *et* al., 2007; Thomson *et al*., 2010). Laboratory, greenhouse and field studies showed that the *Bt* maize for stem borer resistance controlled only four (*Chilo partellus, Chilo orichalcociliellus, Eldana saccharina* and *Sesamia calamistis*) of the five major stem borers in Kenya and non of the *Bt* genes used was effective against all the stem borers (Mugo *et al*., 2005), thus the need for additional *Bt* genes for the economically important species (*Busseola fusca*) (De Groote *et al*., 2011). Transgenic maize for resistance to the maize steak virus showed delayed symptom development during greenhouse studies and is ready for a confined field trial in South Africa upon regulatory approval (Thomson *et al*., 2010). Drought tolerant maize (MON 87460) is under confined field trial testing in South Africa, Kenya and Uganda (Thomson *et al*., 2010). Greenhouse studies in South Africa for maize expressing genes from a desert plant (*Xerophyta viscosa*) also showed enhanced tolerance to drought (Grange, 2009). The specific genes, approaches and participating institutions are summarized in the table below.

Maize GM traits under development in Africa

Stem borer resistance	
1. Importance of maize stem borers	• Stem borers are the most widely distributed and most damaging pests, causing 15% grain yield loss and total crop loss under drought stress[9].
2. Damage by stem borers	• Young larvae feed on young leaf tissues causing drying of growing points. Adult larvae tunnel into the stem and feed internally leading to impaired nutrient uptake, lodging and stem breakage. Larvae damage ears exposing them to fungal attack[4]
3. Susceptible varieties	• Most cultivated maize varieties[14]
4. How stem borers are spread	• Moths emerge from undestroyed plant debris into the next crop[5]
5. Management practices	• Use of synthetic pesticides, destruction of crop residues, intercropping with non-host crops, crop rotation, manipulation of planting dates, ploughing in crop residues, monitoring, use of biopesticides like neem, biological control[5]
6. Limitations of the commonly used management practices	• Synthetic pesticides are expensive and pose risk to human health and the environment, cultural practices are labour intensive and farmers lack management capability, limited control by biological agents[5]
7. Limitations to conventional breeding	• Limited sources of resistance, pest resistance in maize is polygenic, genetic and logistical challenges during

	screening and selection[14]
8. Potential sources of resistance for genetic engineering under development	• *Bt cry* genes (cry1Ab, cry1Ac, cry1B, cry1E, cry1Ca and cry 2Aa)[8]
9. Mode of resistance	• When *cry* proteins are consumed by the insect larvae, they are cleaved under alkaline conditions. The resultant activated toxin binds to the gut membrane forming pores that lead to death[7, 10]
10. Research partners	• CIMMYT, KARI[9]
11. Funding	• Syngenta Foundation for Sustainable Development[9]
12. Stage of development	• Confined field trial-Kenya[2]

KARI: Kenya Agricultural Research Institute, CIMMYT: International Maize and Wheat Improvement Center

Maize with resistance to maize streak virus (MSV)	
1. Importance of the maize streak virus (MSV)	• MSV is the most devastating viral disease that can lead to total crop loss[11]
2. Symptoms of maize streak virus	• Chlorotic streaks on the leaves, plant stunting, and failure to produce cobs and seed[11]
3. Susceptible varieties	• Most cultivated maize varieties[11]
4. How the disease is transmitted	• Leaf hoppers[11]
5. Management practices	• Pesticides[11]
6. Limitations of using pesticides	• Pesticides are expensive and pose risk to human health and the environment[11]
7. Limitations to conventional breeding	• Limited sources of resistance, resistance is polygenic in maize, resistance is sometimes linked to undesirable traits[11]
8. Potential sources of resistance for genetic engineering under development	• The mutated MSV replication-associated protein gene (*rep*$^{1\text{-}219Rb\text{-}}$) [12]
9. Mode of resistance	• The mutated gene in transgenic maize produces a defective Rep protein that binds to the viral Rep protein after infection and inhibits virus replication[11]
10. Research partners	• Pannar Seed (South Africa), Univ. Cape Town[12]
11. Stage of development	• Greenhouse containment-South Africa[17]

Drought tolerance	
1. Importance of drought	• Drought is a serious problem in agricultural systems that rely on rainfall leading to crop failure[15]
2. Effects of drought	• Leaf rolling and leaf loss leading to reduced photosynthesis, stunted plants, pollination/fertilization disruption leading reduced yield, premature plant death under severe conditions[6]
3. Susceptible varieties	• Most cultivated maize varieties[6]
4. Management practices	• Irrigation[6]
5. Limitations to using irrigation	• Irrigation is very expensive and not always available for the resource poor farmers[15]
6. Limitations to conventional breeding for drought tolerance	• Limited genetic variability for drought tolerance in maize[15]
7. Potential sources of drought tolerance for genetic engineering under development	• *cspB* from *Bacillus subtilis*[17] • *XvSap1*, *XvAld1*, *XvPrx2*, *XvG6* genes from *Xerophyta viscosa*[17]
8. Mode of drought tolerance	• *cspB* functions as an RNA chaperone that binds to single stranded DNA or RNA; stimulates growth following stress acclimatization[1]. • Genes from *Xerophyta viscosa* code for enzymes involved in drought-associated protein, antioxidant and carbohydrate biosynthesis[17]
9. Research partners	• AATF, CIMMYT, Monsanto, NARS (Uganda, Kenya, S. Africa, Tanzania, Mozambique)[15] • Univ. Cape Town[17]
10. Funding	• Bill and Melinda Gates Foundation and Howard G. Buffett Foundation[15]
11. Stage of development	• Confined field trial-Uganda, Kenya & S. Africa[17] • Greenhouse containment- South Africa[3]

CIMMYT: International Maize and Wheat Improvement Center, AATF: African Agricultural Technology Foundation, NARS: National Agricultural Research Systems.

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Rice (*Oryza sativa*)

Rice is one of the most rapidly growing food sources in Sub-Saharan Africa, especially in urban areas where consumer preferences have shifted in favor of rice (WARDA/ FAO/SAA, 2008). Factors affecting rice production include biotic, abiotic stresses and lack of good agronomic practices (WARDA/ FAO/SAA, 2008). Drought, salinity and limited fertilizer use are some of the factors that lead to low rice yields and quality (AATF, www.aatf-africa.org). African institutions in partnership with other international agencies are developing Nitrogen Use Efficient Water Use Efficient and Salt Tolerant (NEWEST) rice (AATF, 2012). The specific genes, approaches and participating agencies are summarized in the table below.

GM rice (*Oryza sativa*)

Water-use efficient, nitrogen-use efficient and salt tolerant rice	
1. Importance of drought, salinity and nitrogen deficiency in Africa	• Drought, salinity and inadequate fertilizer use are increasingly becoming serious problems leading to low rice yields and quality[8]
2. Effects of drought	• Reduced number of panicles reduced spikelets number per panicle, reduced grains per panicle and reduced grain size[5].
3. Effects of nitrogen deficiency	• Stunted growth, leaf chlorosis / reduced leaf area hence photosynthesis, reduced tillering[9].
4. Effects of salinity	• Reduced seedling growth and crop stand, reduced tillering, reduced panicle number and panicle length[6].
5. Susceptible varieties	• Most cultivated rice varieties[8].
6. Management practices	• Irrigation in water deficit areas, fertilizer application to add nitrogen to the soil[8]
7. Limitations of using irrigation and fertilizers	• Irrigation and inorganic fertilizers are very expensive for the resource poor farmers[8]
8. Limitations to conventional breeding	• Sources with combined water use efficiency, nitrogen use efficiency and salt tolerance are not available in rice[8].
9. Potential sources of improved nitrogen use efficiency and salt tolerance for genetic engineering under development	• Drought tolerant rice breeding lines are being transformed with AlaAT from barley for nitrogen use efficiency and *AtNHX1* from *Arabidopsis* for salt tolerance[2].
10. Mode of action	• Over-expression of AlaAT enhances increased nitrogen uptake, which is then incorporated into the key transport amino acids[3]. • *AtNHX1*encodes a vacuolar Na^+/H^+ antiporter leading

	to increased uptake of Na^+ into the plant cell vacuoles, sequestering toxic Na^+ away from the cytoplasm hence improving salt tolerance [4].
11. Research partners	• AATF, Arcadia Biosciences, CIAT, Japan Tobacco, NARS (Burkina Faso, Uganda, Nigeria, Ghana), PIPRA, Univ. California[7].
12. Funding	• United Kingdom's Department for International Development and USAID[7]
13. Stage of development	• Laboratory regeneration- Arcadia Biosciences[2].

AlaAT: alanine aminotransferase, AATF: African Agriculture Technology Foundation, CIAT: International Center for Tropical Agriculture, NARS: National Agricultural Research Systems, PIPRA: Public Intellectual Property Resource for Agriculture.

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Sorghum (*Sorghum bicolor*)

Sorghum is a drought and heat tolerant staple in the semi-arid areas of Africa (Ashok Kumar *et al*., 2010). However, it has a low iron and zinc content, low pro-vitamin A and poor protein digestibility (Ng'uni *et al*., 2011). To improve the nutritional status of sorghum, African scientists in collaboration with other international institutions have developed biofortified sorghum with improved iron, zinc and pro-vitamin A content, and protein quality and digestibility under the African Biofortified Sorghum (ABS) Project (ABS, www.biosorghum.org). Lysine and net protein digestibility has been improved by suppression of kafirin species, the hydrophobic protein bodies resistant to digestion (Taylor and Taylor, 2011). Iron and zinc availability has been improved by suppression of a gene involved in phytate biosynthesis (Kruger *et al*., 2012). The biofortified sorghum is undergoing confined field trial evaluation in Nigeria and Kenya and more confined field trials are planned for South Africa, Burkina Faso and Egypt (Wambugu *et al*., 2012). The specific genes, approaches and participating institutions are summarized in the table below.

GM Sorghum (*Sorghum bicolor*)

Sorghum with improved iron, zinc, pro-vitamin A content, improved protein quality and digestibility	
1. Level of malnutrition in Africa	• Malnutrition is a serious problem among the poor communities that rely primarily on one food source[5].
2. Effects of iron deficiency	• Retarded growth, reduced immunity and anaemia[7]
3. Effects of zinc deficiency	• Reduced immunity, retarded growth[12]
4. Effects of vitamin A deficiency	• Blindness, retarded growth and reduced immunity[7]
5. Effects of protein deficiency	• Stunted growth, reduced immunity, muscle wasting, fluid retention (edema)[3]
6. Sources of iron	• Iron supplements, animal products, green vegetables, cereals, red/brown beans[11]
7. Sources of zinc	• Meat, eggs, nuts, cheese, legumes e.g. beans[12]
8. Sources of vitamin A	• vitamin A supplements, animal products, carrots, papaya, pumpkins, green vegetables[11]
9. Sources of protein	• Animal products, legumes e.g. soybeans, beans[2]
10. Limitations to using these sources	• They are expensive for the poor people especially those who depend on one food source[6].
11. Limitations to conventional breeding	• Sources that accumulate high levels of iron, zinc, pro-vitamin A and high quality protein are not available in the sorghum germplasm or its close relatives[9].
12. Potential sources of biofortification for genetic engineering under development	• RNAi suppression of phytate and kafirin[4, 8]

13. Research partners	• AATF, Africa Harvest, CORAF/WECARD, CSIR (S. Africa), Danforth Center, ICRISAT, NARS(Kenya, Nigeria, Burkina, S. Africa) Pioneer, Univ. California (Berkeley), Univ. Pretoria(S. Africa)[9]
14. Funding	• Bill and Melinda Gates Foundation and the Howard Buffet Foundation[10].
15. Stage of development	• Confined field trial-Kenya, Nigeria[10] • Greenhouse containment-South Africa[10]

CSIR: Council for Scientific and Industrial Research, ICRISAT: International Crops Research Institute for Semi-Arid Tropics, NARS: National Agricultural Research Systems, AATF: African Agriculture Technology Foundation, CORAF/WECARD: West and Central African Council for Agricultural Research and Development.

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Sweet potato (*Ipomoea batatas*)

Sweet potato is a very important highly adaptable food crop that produces large amounts of food per unit area in Sub-Saharan Africa (Mwanga *et al*., 2011). It is a very good source of carbohydrates, vitamins A, B and C, iron, potassium, zinc, protein and fiber (Low *et al*., 2009). Sweet potato production is constrained by diseases such as sweet potato virus disease and *Alternaria* blight, and pests like the weevils (*Cylas spp*.) (Mwanga *et al*., 2011). African scientists in partnership with scientists from international institutions are developing transgenic sweet potatoes expressing *Bt cry* proteins for the control of the most important weevil species in East Africa (SASHA, 2012). The transgenic sweet potatoes were developed at the International Potato Center in Peru and field tested in Puerto Rico. The results provided the basis for transfer to Uganda and Kenya in 2011 (Kasozi, 2012). The transgenic sweet potato lines have undergone greenhouse evaluation and await confined field trial evaluation (SASHA, 2012). The transformation system has been optimized for African farmer preferred sweet potato varieties and the transgenic events that have been developed in Uganda and Kenya are ready to be tested (SASHA, 2012). The specific genes, approaches and participating institutions are summarized in the table below.

GM sweet potato (*Ipomoea batatas*)

Weevil (*Cylas spp.*) resistance	
1. Importance of the sweet potato weevil	• Weevils are the major sweet potato pests in Africa causing 60-100% yield loss[6]
2. Damage by the sweet potato weevil	• Weevils feed on leaves, stems and inside tubers. Weevil damage exposes the tubers to secondary rots[2].
3. Susceptible varieties	• Most cultivated sweet potato varieties[1]
4. How sweet potato weevils are spread	• Weevils survive in tubers and stems, infesting succeeding or neighbouring sweet potato crop[2].
5. Management practices	• Crop rotation, early planting, clean planting material, destroy crop residues, flooding fields, hilling area around the plant, planting cuttings deep in the soil, timely harvesting and biological control[2].
6. Limitations of the commonly used management practices	• Cultural practices are labour intensive and farmers lack management capability, limited control by biological agents[6].
7. Limitations to conventional breeding	• Limited sources of resistance in sweet potato, sweet potato is highly heterozygous, polyploid, has low seed set and is incompatible with its close relatives that carry resistance[6].
8. Potential sources of resistance for genetic engineering under development	• *Bt cry* genes (cryET33/cryET34, cry7Aa1, cry3Ca1)[9]
9. Mode of resistance	• When *cry* proteins are consumed by insect larvae, they are cleaved under alkaline conditions. The resultant activated toxin binds to the gut membrane forming

	pores that lead to death[4, 7]
10. Research partners	• Auburn Univ., BecA, CIP, Danforth Center, Kenyatta Univ., NaCRRI-, NARL-Uganda, Univ. Ghent, Univ. Puerto Rico[8]
11. Funding	• Bill and Melinda Gates Foundation, Rockefeller Foundation and USAID[8]
12. Stage of development	• Greenhouse containment-Uganda, Kenya[8]

CIP: International Potato Center, NaCRRI: National Crops Resources Research Institute (Uganda), NARL: National Agricultural Research Laboratories (Uganda), BecA: Biosciences Eastern and Central Africa (Kenya).

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