World Agroforestry Centre

NEPAD
TRANSFORMING AFRICA

African Orphan Crops Consortium

2015 Progress Report

African Orphan Crops Consortium, a NEPAD-led public-private partnership to empower African plant breeders and farmers.

An agroecological and genomics-based approach to ending malnutrition.

This report was assembled by Lloyd Timberlake, Cathy Watson and Tabitha Obara.

Cover photos (clockwise from top left):

Shea oil, rich in omega-3 fatty acids, drizzled on to mashed peas, a traditional dish in northern Uganda © C Watson

A karité or shea tree *(Vitellaria paradoxa)*. These trees span 21 African countries and are a source of oil, fruit and livelihoods for millions. © L Deenan

Cleome spp or spiderplant growing in Kenya. AOCC is sequencing the genome of this highly nutritious vegetable. © C Watson

Field trials of Bambara groundnut, the high protein indigenous plant that breeder Busiso Mavakeni is improving - see p.8.

A cocoa farmer in SW Côte d'Ivoire: her desire is more access to Bush Mango or *Irvingia gabonensis* © C Watson

AFRICAN ORPHAN CROPS CONSORTIUM 2015 PROGRESS REPORT

The goal of the African Orphan Crops Consortium (AOCC) is to make the nutritious indigenous plants that are raised in the home gardens of Africa or that grow in the fields, forests and common lands of the continent even more nutritious than they already are -- as well as more productive and resilient. The aim is to improve the diets and livelihoods of the 600 million people who live in rural Sub-Saharan Africa.

Led by the New Partnership for Africa's Development (NEPAD), the technical body of the African Union (AU), the young Consortium, founded in 2011, has already achieved great success. It has graduated its first class of African plant-breeding scientists and technicians. It has begun sequencing the genomes of crops on its list of 101 important species. It also has raised significant funding and created an uncommon collaboration of governments, companies, NGOs and scientific bodies to help it reach its goals.

Dr. Ibrahim Assane Mayaki, CEO NEPAD Agency

Dr. Ibrahim Assane Mayaki, the Chief Executive Officer of NEPAD Planning and Coordination Agency, states:

"NEPAD Agency has put the harnessing of science, technology and innovation on the front burner to boost and stimulate every sector for the acceleration and sustainable development of Africa, especially in meeting our top priority thematic issue on food and nutrition security.

It is our vision and mandate to link the most powerful tool to the most expert hand in a totally controlled environment as in genomics.

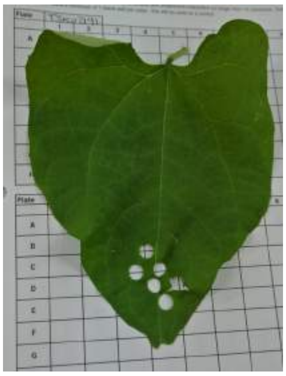
We are quite delighted to be part of the Consortium in sequencing the genomes of under-utilized African crops that will provide breeders with the tools to create improved varieties for our populace and the farmers for better quality of life."

This report charts the Consortium's progress through 2015.

A farmer in her field of finger millet, an African orphan crop, in northern Uganda. © DFID

The intensely human story behind AOCC

Imagine you are a plant breeder in Burkina Faso or Uganda or any of the 21 African countries where *karité* or the shea tree is a cornerstone of the ecology. You have spent years studying the tree. Now you have found a shea tree with particularly large fruit. The nutritious pulp is intensely tasty, and the kernel, with its oil, is exceptionally ample. What a find! After oil palm, shea is the most important oil crop in Africa, consumed by 80 million people.



On another trip to the field, you find a shea tree that grew very fast, according to the women who process its kernels. You want to cross these two trees to breed "super" offspring. The two trees might combine in such a way that you end up with a fast growing variety of shea tree with large fruit. That is your *hope.*

However, all you *can* do is hope. Without knowing the genetic profile of the seedlings that you produce by crossing the two trees, you have to wait until they start fruiting, which can take 20 years, before you will know if you have achieved your goal. If they do not produce the fruit with the qualities that you want, you have to start all over again. It's the work of the entire lifetime for a scientist.

All this is changing with AOCC, which is enabling African plant breeders to determine the profile of a young plant when it has produced just one or two leaves. By punching a plant's leaves and analyzing the genome, scientists can now check for the presence of the genes they want - rather than wait until the plant matures, exhibiting or not exhibiting the sought after traits. Instead of a lengthy hit-and-miss process, genetics-assisted breeding can improve a plant species in a matter of years.

AOCC will sequence the "reference" genome of 101 African orphan crops and a further 100 lines of each species. Although much more needs to happen besides this, eventually crop genomes will be uncovered for scientists to use in accelerated classical plant breeding -- genes are not cut, spliced or inserted from other species.

So far genetic analysis is advanced on 19 species, including finger millet, spider plant, cashew, Mobola plum, African locust *(Neré), Uapaca kirkiana* and Marula. The aim, according to ICRAF scientist Prasad Hendre is the "targeted improvement in nutrition, yield, climate resilience, stress tolerance, nutrient use efficiency and other traits". The end result will be improved varieties for smallholders and sumptuous dietary diversity on farms and in markets. The vision is African scientists using genetics to end stunting, hunger and chronic malnutrition in Africa.

Tree crops, including shea butter (right front) from *Vitellaria paradoxa,* known as "women's gold", for sale in a Gambian market. © J Baxter

Dr Firew Mekbib focuses on the Ethiopian potato (*Plectranthus edulis*), a super orphan on which there has been no research. "We need to de-orphanize and microtuberise it," said the associate professor at Haramaya University. He plans a superior cultivar by 2018 and a center to research 40 orphan crops. He and the three researchers below were all students on the first intake of the African Plant Breeders Academy, held at the World Agroforestry Centre (ICRAF) in 2014.

Dr Sunday Makinde from Lagos State University is breeding the fluted pumpkin or *Telfairia occidentalis*, a vine from the rain forest ecosystem, the seeds and leaves of which are used in daily dishes called egusi and ogbono. The plant is usefully drought tolerant and the seeds are high in protein and fat. It is eaten by an estimated 35 million people in Nigeria alone. "The problem is that you cannot tell the male and female plant apart until they flower. Only the female produces pumpkin so the farmers cannot tell which to grow when they are young," says the botanist.

Dr Wonder Nunekpeka from Ghana's Biotechnology and Nuclear Agricultural Research Institute is working on *Hibiscus sabdariffa*. "It produces iron rich leaves when other vegetables are in scarcity, and is very important for women and children who are suffering from anaemia," said the researcher who has already started breeding with samples from Ghana's coastal and Guinea savannah and rain and deciduous forests. ""My crop has been an orphan but is not anymore! I will be a father for it. What made it to be orphan was that it is low yielding."

Dr Godson Nwofia is an associate professor at the Michael Okpara University of Agriculture. His orphan crop is cocoyam - *Xanthosoma sagittifolium* and *Colocascia esculenta*. "If you go to the internet, you get little or no information on these. Production in Nigeria used to be the world's highest but has halved because of leaf blight. If we do not work on it, how will we recover it?" Cocoyam is a critical weaning food, its starch more digestible than that of yam or cassava. Cocoyam flowers erratically, however, so is hard to hybridize. It is only vegetatively propagated. "Yet if the crop remains a clone, any disease can come and it is gone," says Nwofia, who also wants to make this "woman's crop" attractive to men too. "Right now no man will touch it. We need to prove that it can put money into pockets."

Cocoyam grows up bamboo poles in an agroforestry system in the Delta in Nigeria. Behind it are rubber trees. A sampling of bush mango or *Irvingia gabonesis*, another AOCC priority crop, is in the foreground to the left. Maize is also flourishing in this diverse and resilient system.

Origins

Despite advances in agricultural production, some 14% of the global population -- one billion people -- are chronically hungry, and over a third are affected by single or multiple micronutrient deficiencies. A further two billion regularly experience food insecurity.

In Sub-Saharan Africa, more than one third of the population suffers chronic hunger; that is some 234 million people, including 58 million children under the age of five. Many African children are stunted – low height for age – a condition that if not corrected in early childhood means poor cognitive abilities and low earning power through the child's lifetime. About 40% of children aged less than five in East Africa are stunted.

In Sub-Saharan Africa, there are high rates of protein-calorie malnutrition and micronutrient deficiency (primarily iron, zinc, and vitamin A). As a result, there are high incidences of low birth weight, infant mortality, anemia and iodine deficiency, and a growing incidence of chronic nutritional disorders, such as diabetes, obesity, and cardio-vascular disease

Improving farm yields is an obvious and significant part of the answer; however, low yields, low nutritional content, environmental stress, difficulties in propagation, harvest losses, disease, and high labor costs are factors that limit agricultural success.

Rural African families grow most of what they eat. What if the crop varieties they grow could be made more nutritious, higher yielding and more resilient in the face of climate change, drought and pests?

This is the premise behind the African Orphan Crops Consortium (AOCC). The idea is so powerful that already there is interest in creating orphan crops consortiums in other parts of the planet, such as India and China.

In 2010, Mars, Incorporated finished mapping the genome of cacao, the plant from which chocolate is made. Noticing how relatively quick and inexpensive such genetic sequencing had become, Mars Chief Agricultural Officer Howard Shapiro began discussing with African officials the idea of sequencing and annotating the genomes of African "orphan' crops. The crops are termed *orphans* because they are not important to international trade and are thus relatively little studied by science. However, they are central to the culture of and diets of hundreds of millions of African families.

Shapiro received the backing of Dr. Ibrahim Mayaki, CEO of the New Partnership for Africa's Development (NEPAD) Planning and Coordinating Agency, which has as its primary thematic area food and nutrition security. In the summer of 2011, the two convened a meeting in Washington DC of like-minded organizations – including NGOs, companies and international scientific bodies – to discuss ways forward.

After only a few months' work, the AOCC was accepted at the Clinton Global Initiative annual meeting in 2011 as an organization to develop a comprehensive program to alleviate stunting and malnutrition in Africa. It has been presented at every Clinton Global Initiative meeting since then.

> "*Just as with the cacao genome sequence, all the scientific results of the AOCC work will be made freely available to all over the Internet.*"

Dr Joan Simam is a KEMRI-WELLCOME fellow in the AOCC genomics laboratory, which is hosted at the World Agroforestry Centre (ICRAF) in Nairobi. She is involved in the RNA sequencing of the AOCC crops.

Below, in alphabetical order, are listed the partners of the AOCC and their roles and contributions. This is a working list as new partners join frequently. In 2011 Dr. Mayaki presented the AOCC project concept to African Heads of State at the African Union Assembly, which voted to endorse the initiative, making all African governments partners in the Consortium as well.

- **Agricultural Research Council (ARC)**, Pretoria
- **Biosciences eastern and central Africa-International Livestock Research Institute** (BecA-ILRI) is a shared agricultural research and biosciences platform providing laboratory services to African and international scientists conducting research on African agricultural challenges. It provides AOCC with lab and project support, training of breeders, and the curation of germplasm used by AOCC.
- **BGI** (Shenzhen, China) is one of the world's leading sequencing organizations. It is involved in sequencing, annotating, assembling and curating many of the 101 African orphan crop genomes
- **Google** (Mountain View, USA) provides rapid transfer of AOCC data worldwide using cloud space.
- **Illumina Inc.** (San Diego) develops technology and kits for use in genetic research and has provided the AOCC with reagents to sequence the gene complement of 50 species.
- **iPlant Collaborative** (Tucson) a collaborative that has developed a cyber-infrastructure for data-intensive biology driven by high-throughput sequencing, phenotypic and environmental datasets, has helped AOCC with analysis and curation of sequence and genotype data.
- **LGC** (Hoddesdon, UK) is an international life sciences measurement and testing company, providing reference materials, genomics solutions and analytical testing products and services; it has provided genotyping services for AOCC plant breeders
- **Mars, Incorporated** (Maclean, USA) is one of the world's largest privately-owned food companies; it has provided over $2 million for the African Plant Breeding Academy, scholarships for breeding programs and support for AOCC lab personnel.
- **New Partnership for Africa's Development (NEPAD)** has provided administrative, logistical and political support for AOCC.
- **Thermo Fisher Scientific** (Waltham, USA) helps companies and organizations solve their research challenges; it has donated four Proton sequencers and four Chef Stations and reagents for 10,000 African orphan crop lines. Recently acquired Life Technologies which had donated four Ion proton machines to AOCC.
- **University of California at Davis** (USA), one of the world's leading agricultural universities, supports the African Plant Breeding Academy and its laboratory.
- **UNICEF** (New York) supports the development of AOCC.
- **VIB and Plant Systems Biology at the University of Gent** (Ghent): VIB is a non-profit research institute in the life sciences with 1,200 scientists conducting strategic basic research on the molecular mechanisms; it has helped AOCC with bioinformatics and annotation of plant genomes.
- **World AgroForestry Centre ICRAF** (Nairobi) hosts the AOCC lab and the African Plant Breeders Academy lab and helps manage its data.
- **World Wildlife Federation** (DC) has worked with the AOCC since its inception, helping with initiation and vision.

Fruit of *Dacryoides edulis* or safou in the market in Cameroon. The fruits are widely traded in the region and are boiled, fried or roasted to accompany staples dishes. The kernel is fed to livestock. © J Baxter

AOCC network

The AOCC also works through a network of other organizations involved in the agriculture and horticulture of Africa:

- Bioversity
- CIAT
- Cleome consortium
- Crop Breeding Institute, Zimbabwe
- Crops for the Future Research Centre
- Fababean consortium
- Hohenheim University
- ICARDA
- ICRAF
- Lentil Sequencing consortium
- National Research Council - Canada
- NWO Food & Business Applied Research Fund
- Pan African Bean Alliance
- Sweet Potato Consortium
- USDA-ARS Subtropical Horticultural Research Station
- USDA-ARS, Wisconsin
- World Vegetable Centre

The AOCC network continues to expand, adding major crop consortiums, CGIAR centers, universities, government institutions and foundations. The network serves as the connection to plant breeders, seed production specialists and farmers to deliver the products of the AOCC. They also serve as an advisory group for input and feedback for the AOCC program.

A farmer holds a bambara groundnut plant, displaying the healthy number of groundnuts on its roots. © Mlka Andrianoellsen

The Bambara groundnut (Vigna subterranea) is one of the 101 crops that are the focus of AOCC. It yields well in marginal areas that are too arid for the common groundnut, maize and even sorghum. This highly nutritious African grain legume — grown by 70% of farmers in Zimbabwe — contains 17–25% protein, 42–65% carbohydrates and 6% lipids. Challenges with Bambara groundnut iinclude the time it takes to mature and the need for greater resistance to disease.

Busiso Mavankeni (left) is a Chief Research Officer with Zimbabwe's Crop Breeding Institute and was one of four women on the first course of the African Plant Breeding Academy, which is part of AOCC. Her ambition is to breed a cultivar of the Bambara groundnut that matures in 90-100 days rather than the current 140. "That would have a great impact on food security in my country," said the Zimbabwean plant breeder. "With what I have learnt at AfPBA, I am going to speed up our work in breeding when I get home."

Progress – Plants and Laboratory

To fulfill its goal of generating genomics resources for the selected crops, the AOCC is coordinating three major activities in parallel. Whole genome sequencing is being done at BGI in China, re-sequencing at AOCC genomics lab at ICRAF, and transcriptome sequencing at the Agricultural Research Council (ARC) in Pretoria with Illumina's support.

The AOCC Genomics Lab, opened in September 2014, is a state-of-the-art sequencing and genotyping lab to establish breeding programs in African orphan crops and support African breeders. It was established with donations from ICRAF, Mars, ARC and Life Technologies now Thermofisher. The lab is fully staffed by three technical staff and a manager, Dr. Prasad Hendre.

The purpose-designed space is equipped with four of the latest Ion Proton Sequencers, associated automation and all reagents to sequence 10,000 African lines from 101 species. Base salaries have also been secured.

Through crop networks and partners, the 100 accessions for each of 20 African crops are being collected. Thus far 12 common bean lines have been sequenced. Data are being transferred to public websites. Spider plant, lentils, Bambara groundnut and Ethiopian mustard were being worked on in 2015, while BGI was sequencing the baobab tree, the dried fruit of which contains twice as much calcium as spinach, three times the vitamin C of oranges and four times more potassium than a banana. Both the European Union and the US Food and Drug Administration have approved dried baobab fruit pulp as a food ingredient.

Robert Kariba is a molecular lab technician in the AOCC genomics lab. He demonstrates one of the donated machines. © C Watson

Dr Alice Muchugi is head of the Gene Bank at ICRAF. © C Watson

In 2015 a total of 41 species were at various stages of lab activities. Genomes of 24 species were being sequenced at BGI, with the genome of finger millet almost complete and four more nearing the generating of draft assembly.

As some of the species have difficulties in generating assemblies due to heterozygosity and unknown genome size, it was decided to include unplanned activities like finding genome size by c-value estimation and knowing genome complexity by k-mer survey, as a prelude to whole genome sequencing. K-mer survey has begun for eight difficult species with unknown genome information. For those already being sequenced, it is not being undertaken unless found essential. For re-sequencing, AOCC has received germplasm from 12 species, with re-sequencing started for three species at various stages of completion. For annotating genome draft assemblies, RNA sequencing was also included as essential activity in the middle of 2015. While RNA isolation procedure was being standardized at the AOCC genomics lab, ARC was experimenting with RNA tags for multiplexing of RNA sequencing efforts. Ten more genomes are being done in the network.

Progress – Training

The African Plant Breeding Academy (AfPBA) graduated its first class in December 2014 at the World Agroforestry Center (ICRAF) in Nairobi.

"The African Orphan Crops Consortium and its new African Plant Breeding Academy represent an unprecedented opportunity to leverage the training programs we have developed for plant breeders in Africa. The partnerships allow African breeders to take advantage of the latest technologies to rapidly advance development of crops that are important to African diets and health," says Allen Van Deynze, Director of Research at the University of California, Davis' Seed Biotechnology Center

Using the well-established model and expertise of the University of California, Davis, the AfPBA teaches top African plant breeders to apply the latest strategies and technologies in plant breeding to develop new well-adapted, nutritious crop varieties.

Twenty-one breeders from 11 countries across Africa and 19 institutions, including four women, graduated in Class I. As a final evaluation, each student was required to develop a proposal for a plant breeding program and present it in class, where they were critiqued by instructors and fellow students for 1.5 hours. In this manner all students participated, discussed, reviewed and learned from each other. This group of students built a strong relationship and cohort that will continue to work together. AOCC instructors and partners will continue to support participants to ensure that they succeed.

AOCC filled its second class from 252 applicants. Thirty students from 19 countries and 28 institutions began training in June 2015 at ICRAF on what will be a rigorous 6-week program that stretches over 13 months. The AOCC will invite select students from Class I to begin to teach the curriculum, with the goal of completely transferring teaching to African instructors by the end of the program. The goal of the AOCC is to train 250 plant breeders and support personnel in six years.

Grants to launch and enhance plant breeding programs for African orphan crops have been established and will be awarded to AfPBA graduates. Additional fellowships are available through partner, BecA/ILRI.

The second cohort of senior African plant breeders training with AOCC in December 2015.

"Among other topics, we've covered building breeding populations, analysis of variants, phenotyping, how to select for nitrogen use efficiency and drought resistance, and experimental design," said Professor Emerita Rita Mumm from the University of Illinois

Dr Daniel Adewale, 47, is the world's African yam bean expert. He has a personal stake in this plant, the grains of which he ate as a child.

"I know from experience that yam bean keeps you feeling filled. When you eat it in the morning, you take longer before you get hungry. This makes it a choice food for farm laborers."

The hard seed coat is one characteristic that he wants to breed out. "The yam beans that my mother cooked used to take four hours, taking too much energy."

African yam bean (*Sphenostylis stenocarpa*) is highly nutritious and culturally valued but underappreciated by policy makers. Rich in calcium and phosphorus, its crude protein content is higher than that of cowpeas or the common bean.

Dr Adewale was a student on the first AfPBA course.

Progress – Funding & the Future

AOCC presents an extraordinary return on investment. Although an estimated $5M will be needed for each of the 101 crops, the majority of the funds will be dedicated to developing breeding programmes based in national agricultural research organizations in Africa, the dissemination of new varieties, and outreach to populations about the vital nutrition, especially vitamins and micronutrients, contained in these crops.

Large though $5 million per crop may sound, it pales in comparison with expenditure on food aid: the UN spent $2.5 billion on food aid for Africa in 2011-2014. Furthermore, each year over 80% of all global agricultural research funds are spent on the genetic improvement of the eight major world staples, such as rice, wheat and corn. Yet similar genomic and other breeding efforts applied to African crops could greatly reduce malnutrition. AOCC is closing this disconnect between malnourished populations requiring food aid in a context where highly prized nutritious crops exist but have not been capitalized upon, yet the cost of genomic approaches has radically decreased. Forification as a nutritional strategy is also less likely to bring the strong gains of the AOCC approach. Much of Africa's population buys little food that can potentially be fortified.

Three major grants have been obtained to leverage AOCC resources in breeding programs for finger millet(s) and spider plant. Five additional grants were submitted to in 2015. The US National Science Foundation awarded a grant for the study of the genomics of shea to the University of New Hampshire, ICRAF, the West African Centre for Crop Improvement and the Cocoa Research Institute of Ghana. Many grants include AfPBA students.

In 2015 AOCC received the prestigious Greater Good Initiative award from Illumina, Inc. This provided $100,000 in sequencing reagents to AOCC and will allow AOCC to sequence the transcriptome of 50 African orphan crops in South Africa at the ARC with Dr. Jasper Rees, who graciously contributed the labor for this project. The project coordinates closely with the AOCC lab at ICRAF in Nairobi.

To date AOCC has raised an estimated $32M in cash or in-kind contributions, with an additional $20M to be sourced to complete Phase One, which involves sequencing the 101 African orphan crop reference genomes, sequencing 100 lines from each of these crop species, and training 250 plant breeders and technicians. Phase Two involves integrating genomic tools and strategies to develop new orphan crop varieties. Phase Three involves working with seed companies and smallholder farmers to adopt and deliver diverse and nutritious crop varieties for African farmers and consumers. National and international governments and bodies are urged to contribution to this initiative .

Appendix One - The botanical and common names of AOCC's 101 crops

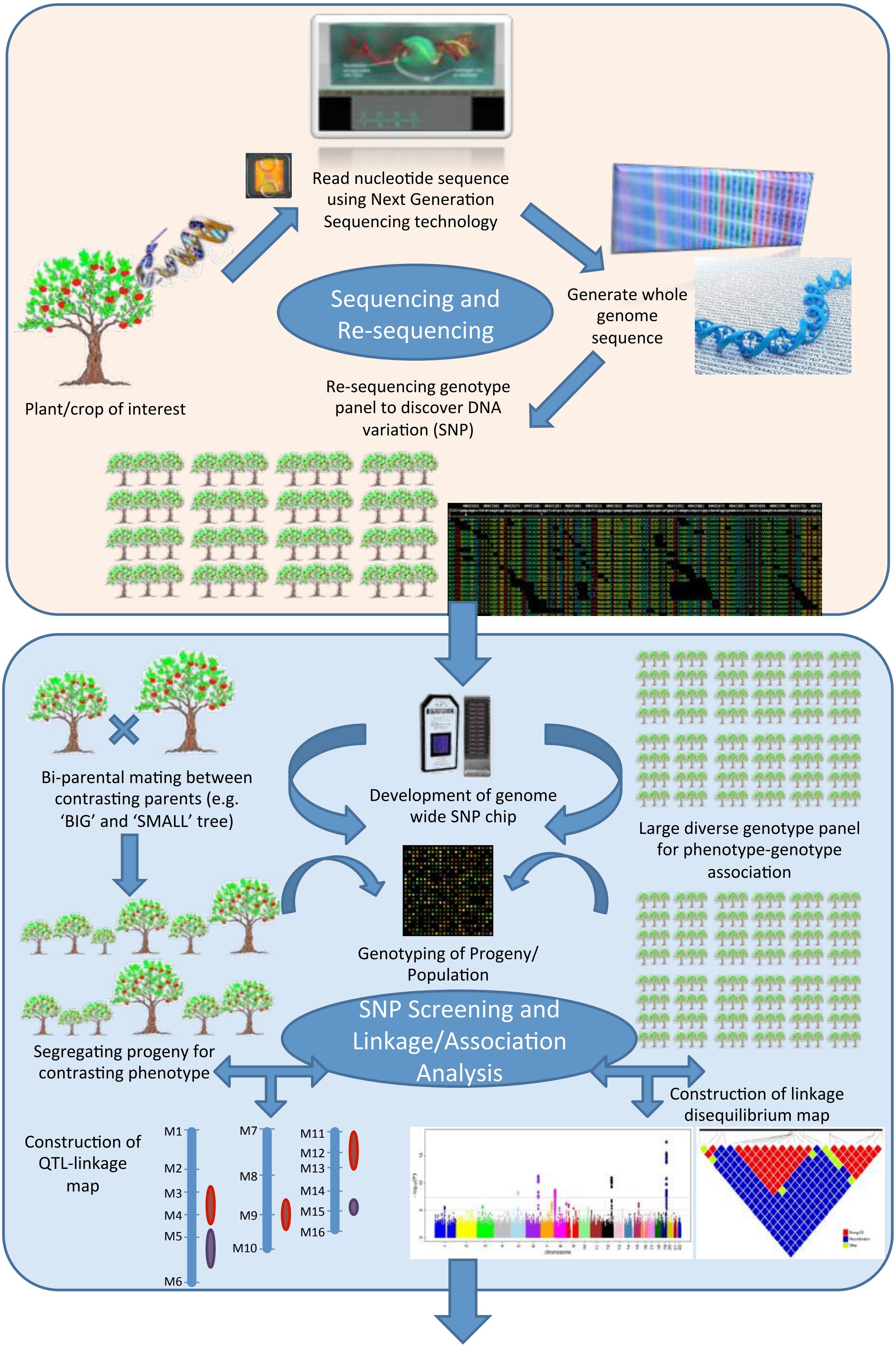
	Scientific name	Common name		Scientific name	Common name
1	*Adansonia digitata*	Baobab	52	*Abelmoschus caillei*	Okra
2	*Adansonia kilima*	Baobab	53	*Allium cepa*	Onion
3	*Allanblackia floribunda*	veg tallow tree	54	*Amaranthus blitum*	Amaranth
4	*Anacardium occidentale*	Cashew	55	*Amaranthus cruentus*	Grain amaranth
5	*Annona senegalensis*.	Wild Custard Apple	56	*Amaranthus tricolor*	Vegetable amaranth,
6	*Annona reticulata*	Custard Apple	57	*Basella alba*	Vine spinach
7	*Artocarpus heterophyllus*	Jack Tree	58	*Brassica carinata*	Ethiopia Mustard
8	*Artocarpus altilis*	Breadfruit	59	*Cassia obtusifolia*	Sickle Senna
9	*Balanites aegyptiaca*	Balanites	60	*Celosia argentea*	Celosia
10	*Boscia senagalensis*	Aizen, Nabedega	61	*Citrullus lanatus*	Watermelon
11	*Canarium madagascariense*	Canarium nut, Ramy nut	62	*Cleome gynandra*	Spiderplant
12	*Carica papaya*	Papaya	63	*Colocasia esculenta*	Taro
13	*Carissa spinarum*	Carissa	64	*Corchorus olitorius*	Jute mallow
14	*Casimiroa edulis*	White sapote	65	*Crassocephalum rubens*	Yoruban bologi
15	*Chrysophyllum*	Star apple	66	*Crotalaria juncea*	Sunn hemp
16	*Cocos nucifera*	Coconut	67	*Crotalaria ochroleuca*	Rattlebox
17	*Dacryodes edulis*	African Plum	68	*Cucumis metuliferus*	Horned Melon
18	*Detarium senegalense*	Sweet detar	69	*Cucurbita maxima*	Pumpkin
19	*Diospyros mespiliformis*	African persimmon	70	*Cyphomandra betacea*	Cape tomato
20	*Dovyalis caffra*	Kei Apple	71	*Digitaria exilis*	Fonio
21	*Elaeis guineensis*	Oil Palm	72	*Dioscorea alata*	Yams
22	*Faidherbia albida*	Acacia (Apple-ring)	73	*Dioscorea dume torum*	Bitter yam
23	*Garcinia livingstonei*	African Mangosteen	74	*Dioscorea rotundata*	Yams
24	*Garcinia mangostana*	Mangosteen	75	*Eleusine coracana*	Finger Millet
25	*Gnetum africanum*	African Gnetum	76	*Ensete ventricosum*	Enset
26	*Hibiscus sabdariffa*	Roselle	77	*Ipomoea batatas*	Sweet Potato Leaves
27	*Icacina oliviformis*	False yam	78	*Lablab purpureus*	Lab lab Bean
28	*Irvingia gabonensis*	Sweet bush mango	79	*Lens culinaris*	Lentils
29	*Landolphia spp*	Gumvines	80	*Macrotyloma geocarpum*	Geocarpa groundnut
30	*Lannea microcarpa*	Tree grapes	81	*Momordica charantia*	Bittergourd
31	*Macadamia ternifolia*	Macadamia	82	*Musa acuminata AAA Group*	Bananas
32	*Mangifera indica*	Mango	83	*Musa balbisiana*	Bananas
33	*Moringa oleifera*	Drumstick tree,	84	*Musa x paradisica AAB Group*	Plantains
34	*Morus alba*	Mulberry	85	*Passiflora edulis*	Passion Fruit
35	*Opuntia monacantha*	Prickly pear	86	*Phaseolus vulgaris*	Green Bean
36	*Parinari curatellifolia*	Mobola plum	87	*Plectranthus esculentus*	African Potato
37	*Parkia biglobosa*	African Locust	88	*Plectranthus rotundifolius*	African Potato
38	*Persea americana*	Avocado	89	*Solanum aethiopicum*	African Eggplant
39	*Pistacia vera*	Pistachio	90	*Solanum nigrum*	African Nightshade
40	*Psidium guajava*	Guava	91	*Sphenostylis stenocarpa*	Yambean
41	*Ricinodendron heudelotii*	Ground Nut Tree	92	*Talinum fruticosum*	Ceylon spinach
42	*Saba comorensis*	Rubber vines	93	*Telfairia occidentalis*	Fluted gourd

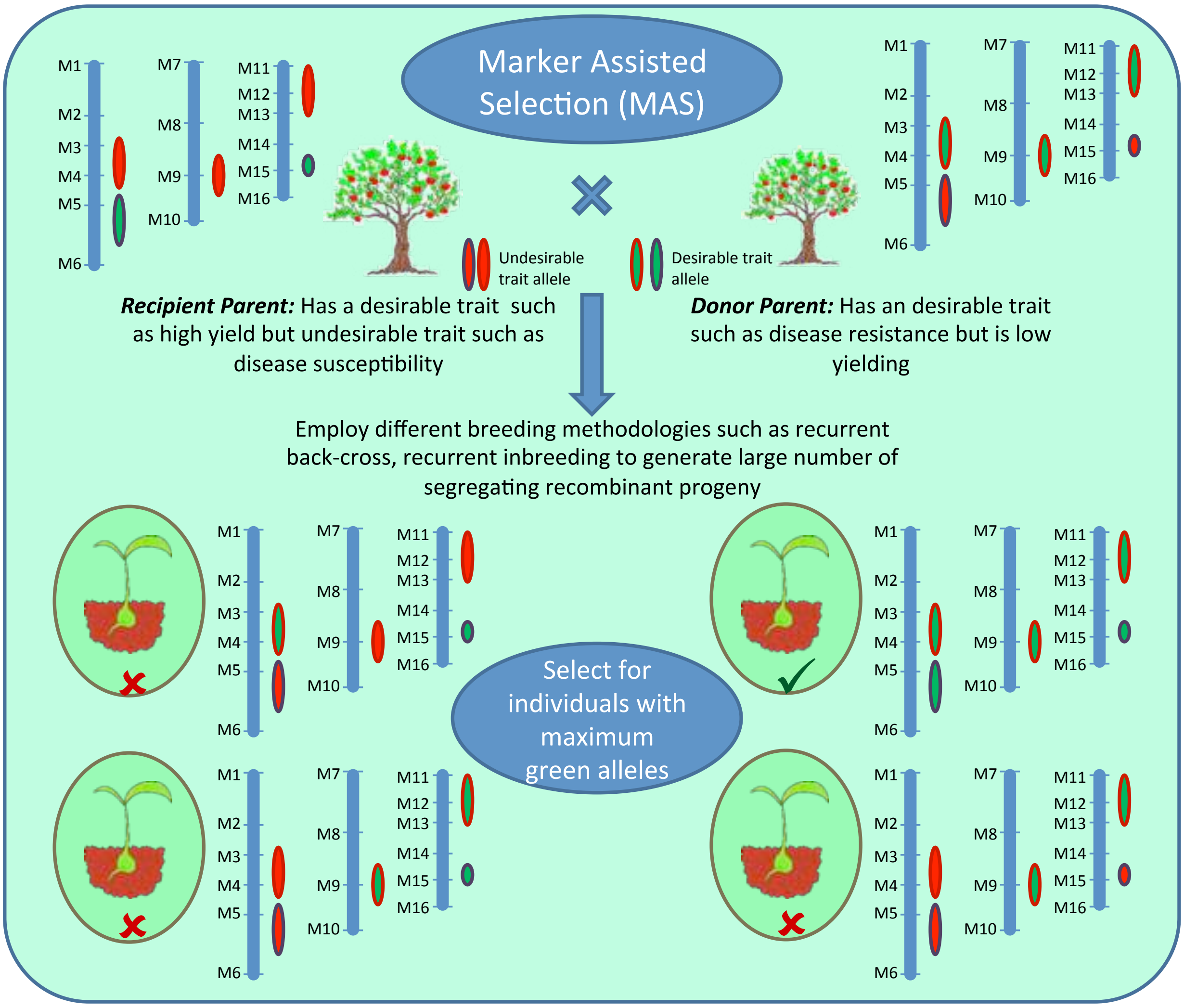
43	*Sclerocarya birrea*	Marula	94	*Tylosema esculentum*	Marama bean
44	*Strychnos spinosa*	African Orange	95	*Vangueria madagascariensis*	African Medlars
45	*Syzygium guineense*	Water berry	96	*Vangueria infausta*	African Medlars
46	*Tamarindus indica*	Tamarind	97	*Vicia faba*	Favabean
47	*Uapaca kirkiana*	Wild loquat	98	*Vigna radiata*	Mungbean
48	*Vitellaria paradoxa*	Shea Butter	99	*Vigna subterranea*	Bambara groundnut
49	*Vitex doniana*	Chocolate berries	100	*Xanthosoma sagittifolium*	Elephant ears
50	*Ximenia caffra*	Sour plum	101	*Xanthosoma spp*	Cocoyams, Arrowroots
51	*Ziziphus*	Jujube			

Appendix Two - Progress to date on analysis of 44 out of the 101 crops

	Species name	WGS (whole genome sequencing)	K-mer	Re-seq	C value	Transcriptome
1	*Celosia argentea*	ON	ON	Yet to begin	To be decided	Tissue collected
2	*Cleome gynandra*	ON	Yet to begin	2 done	To be decided	Tissue collected
3	*Digitaria exilis*	ON	Yet to begin	Yet to begin	To be decided	Yet to begin
4	*Eleusine indica*	Draft assembly	Yet to begin	37 done	To be decided	Yet to begin
5	*Lablab purpureus*	ON	ON	Yet to begin	To be decided	Tissue collected
6	*Phaseolus vulgaris*	ON	Yet to begin	12 done	To be decided	Yet to begin
7	*Solanum aethiopicum*	Towards draft assembly	ON	Yet to begin	To be decided	Tissue collected
8	*Solanum nigrum*	ON	ON	Yet to begin	To be decided	Tissue collected
9	*Vigna subterranea*	ON	ON	DNA	To be decided	Tissue collected
10	*Brassica carinata*	Yet to begin	Yet to begin	DNA	To be decided	Tissue collected
11	*Carica papaya*	Yet to begin	Yet to begin	Yet to begin	Done	Tissue collected
12	*Lens culinaris*	Yet to begin	Yet to begin	DNA	To be decided	Yet to begin
13	*Musa*	Yet to begin	Yet to begin	DNA	To be decided	Yet to begin
14	*Adansonia digitata*	ON	ON	DNA	ON	Tissue collected
15	*Adansonia kilima*	ON	ON	Yet to begin	Yet to begin	Yet to begin
16	*Anacardium occidentale*	ON	ON	Yet to begin	Done	Tissue collected
17	*Annona senegalensis*	Towards draft assembly	ON	Yet to begin	Yet to begin	Tissue collected
18	*Artocarpus altilis*	ON	ON	Yet to begin	Done	Yet to begin
19	*Artocarpus heterophyllus*	ON	ON	Yet to begin	Yet to begin	Yet to begin
20	*Dovyalis caffra*	ON	ON	Yet to begin	Done	Tissue collected
21	*Faidherbia albida*	Towards draft assembly	ON	Yet to begin	Done	Tissue collected
22	*Parinari curatellifolia*	ON	ON	DNA	Yet to begin	Yet to begin
23	*Parkia biglobosa*	ON	ON	Yet to begin	Yet to begin	Yet to begin
24	*Saba senegalensis*	ON	ON	Yet to begin	Yet to begin	Yet to begin
25	*Sclerocarya birrea*	ON	ON	DNA	Done	Yet to begin
26	*Uapaca kirkiana*	ON	ON	DNA	Yet to begin	Yet to begin
27	*Casimiroa edulis*	ON	ON	Yet to begin	Yet to begin	Yet to begin
28	*Moringa oleifera*	Towards draft assembly	ON	Yet to begin	Done	Tissue collected
29	*Dacryodes edulis*	Yet to begin	ON	Yet to begin	Done	Yet to begin
30	*Allanblackia stuhlmannii*	Yet to begin	Yet to begin	Yet to begin	Done	Tissue collected
31	*Detarium microcarpum*	Yet to begin	ON	Yet to begin	Yet to begin	Yet to begin
32	*Garcinia livingstonii*	Yet to begin	ON	Yet to begin	ON	Yet to begin
33	*Mangifera indica*	Yet to begin	Yet to begin	Yet to begin	Done	Tissue collected
34	*Morus alba*	Yet to begin	Yet to begin	Yet to begin	Done	Tissue collected
35	*Psidium guajava*	Yet to begin	Yet to begin	Yet to begin	Done	Tissue collected
36	*Strychnos cocculoides*	Yet to begin	Yet to begin	DNA	Yet to begin	Yet to begin
37	*Strychnos spinosa*	Yet to begin	Yet to begin	Yet to begin	Done	Yet to begin
38	*Syzygium guineense*	Yet to begin	ON	Yet to begin	Done	Yet to begin
39	*Tamarindus indica*	Yet to begin	ON	Yet to begin	Done	Yet to begin
40	*Vitellaria paradoxa*	Yet to begin	ON	Yet to begin	Yet to begin	Yet to begin
41	*Ziziphus mauritiana*	Yet to begin	ON	Yet to begin	Done	Tissue collected
42	*Irvingia gabonensis*	Yet to begin	Yet to begin	Yet to begin	Yet to begin	Yet to begin
43	*Ricinodendron heudelotii*	Yet to begin	Yet to begin	Yet to begin	Yet to begin	Yet to begin
44	*Vitex doniana*	Yet to begin	Yet to begin	Yet to begin	Yet to begin	Yet to begin

Appendix Three - Schema: genomic science driving crop improvement




Marker Assisted Selection (MAS)
Undesirable trait allele
Desirable trait allele
Recipient Parent: Has a desirable trait such as high yield but undesirable trait such as disease susceptibility
Donor Parent: Has an desirable trait such as disease resistance but is low yielding
Employ different breeding methodologies such as recurrent back-cross, recurrent inbreeding to generate large number of segregating recombinant progeny
Select for individuals with maximum green alleles
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
M12
M13
M14
M15
M16

The World Agroforestry Centre is a member of the CGIAR Consortium

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