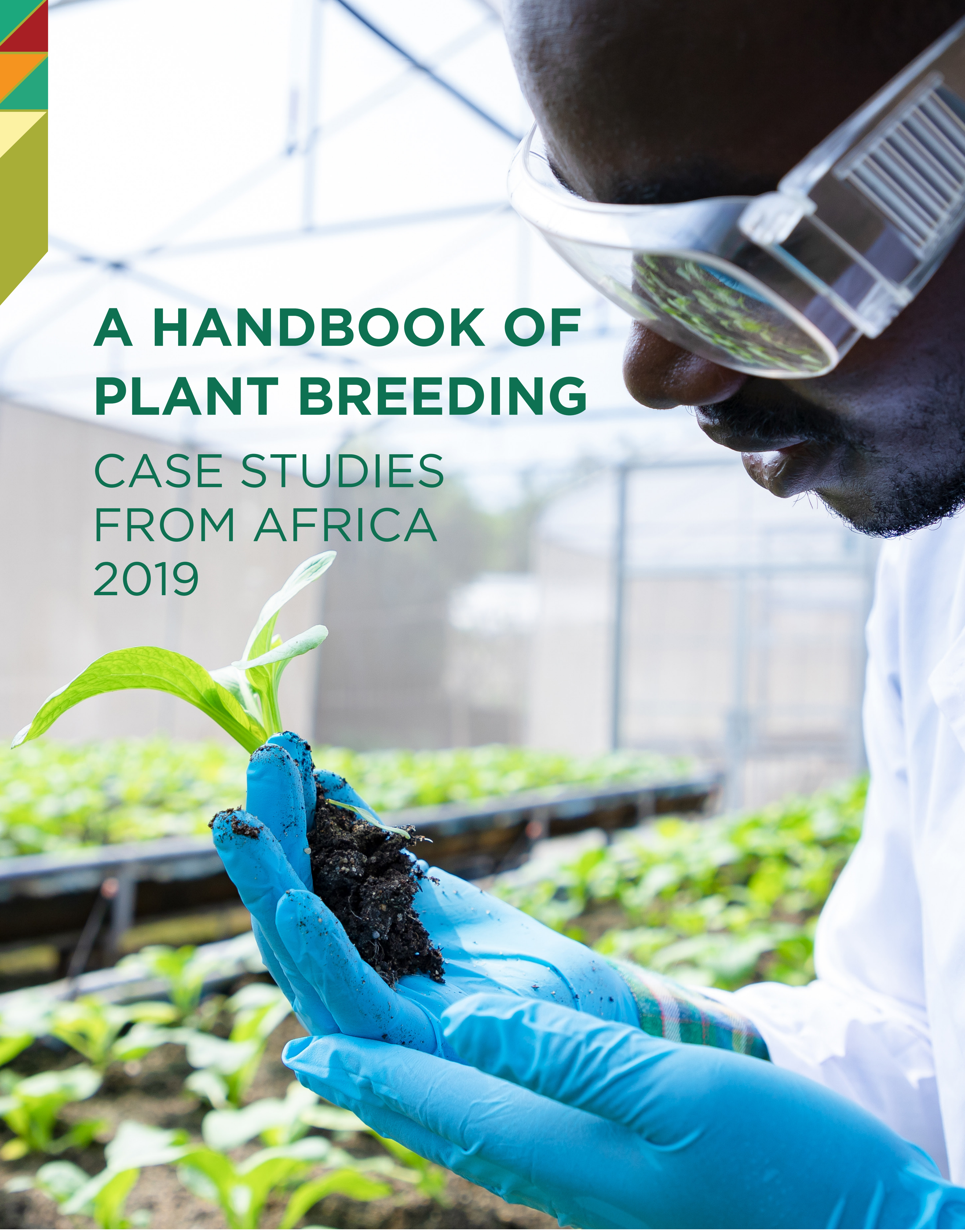


A HANDBOOK OF PLANT BREEDING

CASE STUDIES FROM AFRICA

2019

AGRA
Growing Africa's Agriculture

BILL & MELINDA GATES foundation

The ROCKEFELLER FOUNDATION

UKaid
from the British people

USAID
FROM THE AMERICAN PEOPLE

A HANDBOOK OF PLANT BREEDING

CASE STUDIES FROM AFRICA

2019

A Handbook Of Plant Breeding: Case Studies From Africa, 2019

Authors:
Pangirayi Tongoona
West Africa Centre for Crop Improvement, University of Ghana

Victor Adetimirin
University of Ibadan, Nigeria

Rufaro Madakadze and Caroline Adala Oremo
Alliance for a Green Revolution in Africa

Aleck Kondwakwenda and Cousin Musvosvi
African Centre for Crop Improvement, University of Kwazulu Natal, South Africa

ISBN: 978-0-9980765-6-0

Disclaimer:

The opinions expressed in this report are those of the authors and do not reflect the official policy or position of AGRA, its employees, partners or its affiliates in any way. The mention of specific companies, manufacturers or their products, whether or not these have been patented, does not imply endorsement or recommendation or approval by AGRA, its employees, partners or their affiliates in preference to others of a similar nature that are not mentioned. The descriptions, charts and maps used do not imply the expression of any opinion whatsoever on the part of AGRA concerning the development, legal or constitutional status of any country.

PREFACE

By 2050, the world population is expected to reach 9 billion and will require more food than today's population. A large proportion of the increased demand will come from developing countries. Increased production and access to food requires higher yields from the same pieces of land as there is reduced land for expansion. Increased yields can be accomplished through the development of high yielding varieties of a wide range of crops adapted to the agro-ecologies and tolerant of or resistant to biotic and abiotic stresses.

The initiatives of the Alliance for a Green Revolution in Africa (AGRA) towards the transformation of African agriculture are bringing in the much-desired results of increased productivity of African priority crops, and improvements to the livelihoods of the farmers and farm-families that are largely responsible for feeding the continent and driving its agro-economy. The work by AGRA on seed systems was one key approach to increase crop productivity. This work included funding the training of plant breeders, plant breeding operations for priority staple crops, growth of local private seed companies, and agrodealer development to ensure access to the improved seeds by the farmers.

Training plant breeders is an important component of the multi-pronged strategies for achieving these results. In 2006 there were fewer than 500 active plant breeders in sub-Saharan Africa, excluding South Africa. Increasing these numbers to ensure coverage of the wide range of priority crops, traits and agro-ecologies was an initial undertaking of AGRA through funding of African institutions to train PhD, MSc and plant breeding technicians from 18 countries. This resulted in the training of 495 crop improvement scientists with more than 80% of these plant breeders working on 15 priority staple crops, namely maize, rice, sorghum, wheat, finger millet, pearl millet, beans, cowpeas, soybeans, pigeon pea, faba bean, sweet potato, Irish potato, cassava, and banana. The trained scientists have now released 170-plus improved crop varieties of a wide range of crops. Plant breeding education in partner African universities at the MSc level then evolved into the Improved MSc for Cultivar Development in Africa (IMCDA), which features an e-curriculum with modern breeding techniques, robust data analysis, and internships in public and private seed companies with breeding pipelines to ensure students are trained on development of products with increased genetic gains.

The plant breeding e-curriculum is an important milestone in AGRA's intervention in plant breeding education in Africa. Developed by Iowa State University (ISU), USA, in partnership with three African universities, namely Kwame Nkrumah University of Science and Technology (KNUST), Ghana; Makerere University, Uganda; and University of KwaZulu-Natal (UKZN), South Africa, it was designed to increase the competencies of plant breeders in the management and optimization of cultivar development pipelines using state-of-the-art technologies. In general, e-learning encourages self-learning and makes teaching and learning more interactive. The ISU led Plant Breeding e-curriculum for Africa (PBEA), provided a unique platform for teachers and students to overcome the limitations of the capacities of partner African institutions, offering learning opportunities of the most up-to-date knowledge and cutting-edge techniques as are available in top-rated institutions in developed countries.

This book provides information for teachers, students, and plant breeders on the status of breeding activities for priority African crops. The case studies focus on maize, sorghum, pearl millet, rice, cowpea, groundnut, sweet potato, and cassava in the West African countries of Burkina Faso, Ghana, Mali, Niger, and Nigeria respectively. In East and Southern Africa, the case studies are from Ethiopia, Malawi, Mozambique, Kenya, Rwanda, Tanzania, Uganda, Zambia, and Zimbabwe. These can be included in the e-curriculum as examples of breeding activities in Africa and case studies in any plant breeder training program anywhere in Africa to showcase practical breeding methods that are being used can be further utilized developing improved crop varieties. The information was gathered through questionnaires and selected visits to breeding programs. The interaction with practicing plant breeders provides a clear picture of the conditions under which plant breeders in the sub-region work, their challenges and resilience measures, and their successes.

ABBREVIATIONS AND ACRONYMS

AGRA	Alliance for a Green Revolution in Africa
Anth	Anthracnose
ARI	Agricultural Research Institute
AVT	Advanced Variety Trials
AYT	Advanced Yield Trials
BB	Bacterial Blight
BCMV	Bean Common Mosaic Virus
BMS	Breeding Management System
BTC	Belgian Technical Services
CBSD	Cassava Brown Streak Disease
CIAT	International Center for Tropical Agriculture
CIP	International Potato Center
CIRAD	Centre de Cooperation Internationale en Recherche Agronomique pour le Développement
CMD	Cassava Mosaic Disease
CRS	Catholic Relief Services
DH	Doubled Haploids
DNA	Deoxyribonucleic acid
EUCORD	L'European Cooperative Pour le Development
FAO	Food and Agricultural Organization of the United Nations
GLS	Gray Leaf Spot
HKI	Hellen Keller International
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IIAM	Agricultural Research Institute of Mozambique
IITA	International Institute of Tropical Agriculture
ISU	Iowa State University
IMCDA	Improved MSc for Cultivar Development in Africa Iowa State University
IVT	Intermediate Variety Trials
KALRO	Kenya Agricultural and Livestock Research Organization
KNUST	Kwame Nkrumah University of Science and Technology
MAS	Marker Assisted Selection
MLND	Maize Lethal Necrosis Disease

MSc	Master of Science
MSV	Maize Streak Virus
NARO	National Agricultural Research Organization
NARS	National Agricultural Research Systems
NEVT	National Elite Variety Trials
NGO	Non-Governmental Organization
NLB	Northern Leaf Blight
NPT	National Performance Trials
OFSP	Orange-Fleshed Sweet Potato
OPV	Open Pollinated Variety
OYT	Observation Yield Trial
PMiGAP	Pearl Millet Genome Wide Association Mapping Population
PYT	Preliminary Yield Trial
QTL	Quantitative Trait Loci
RAB	Rwanda Agricultural Board
RR	Root Rots
RUVT	Regional Uniformity Variety Trial
SCCI	Seed Control and Certification Institute
SEMI	Seed Enterprise Management Institute
SSA	Sub-Saharan Africa
UKZN	University of KwaZulu-Natal
USA	United States of America
USAID	United States Agency for International Development

Contents

List of Tables

List of Figures

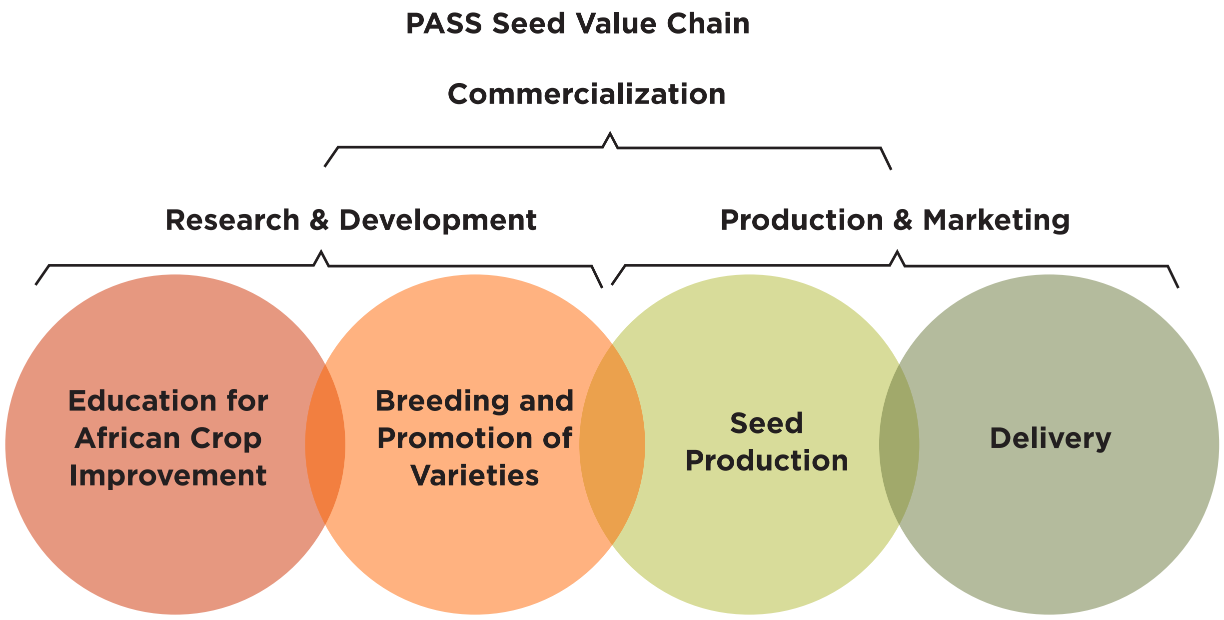
1 | Supporting Africa's Plant Breeding Priorities

Agriculture continues to be sub-Saharan Africa's largest area of economic activity, accounting for 40% of gross domestic product (GDP) and 60–80% of employment. As it has been throughout the world, increasing the level of farmer productivity is a prerequisite for economic growth and development in most African countries. Increasing crop yields has consistently been shown to reduce hunger and increase income among inhabitants of rural areas, where Africa's food shortages are most pronounced. However, for such productivity gains to be achieved strong home-grown technologies generated on the continent are critical; these come from well-trained scientists. Recent advances in the breeding of higher-yielding, better-adapted crop varieties and breakthroughs in the development of localized, low-cost seed supply systems in sub-Saharan Africa have generated renewed hope for agricultural development in Africa. Many of these advances were originally achieved through funding and oversight provided by The Rockefeller Foundation (RF). This program has since been scaled up through additional funds provided by The Rockefeller Foundation and The Bill and Melinda Gates Foundation (BMGF), entitled the Program for Africa's Seed Systems (PASS), the first program of the Alliance for a Green Revolution (AGRA) in Africa started in 2006 (Fig.1) . Wide experience throughout Africa has shown that local adaptation is a key criterion for adoption of higher-yielding varieties, in part because Africa's agro-ecologies are highly diverse and because African farming depends on variable rains and uses very few external inputs. Wherever breeding has resulted in combining higher yield potential with good adaptation to local conditions for production and utilization, uptake by farmers has been encouraging.

The primary aim of the PASS initiative was to catalyze increased yields on smallholder farms throughout Africa through the breeding and promotion of higher-yielding, locally adapted crop varieties coupled with the vigorous promotion and localized supply of seed of these new varieties through private African seed companies and farmer-operated seed enterprises. PASS operated along a value chain (see Figure 1) which began with the training of new scientists and ended with the sustainable supply of improved seed at village level.

The PASS program transformed the seed systems in Africa with greatly increased numbers of active plant breeders in the national agricultural research systems (NARS), the development and release of hundreds of improved varieties of priority African crops, and establishment of local growing seed companies and a distribution network for the improved seeds to reach farmers.

The PASS Education for Africa's Crop Improvement (EACI) subprogram funded university programs to train postgraduate students in plant breeding with universities admitting cohorts of 8 to 10 students for MSc and/or PhD programs. Most of the universities did not have postgraduate degree programs in plant breeding or other crop improvement disciplines, apart from a few with MSc in Crop Science and less than 5 students conducting research in crop improvement. This was mainly because they had 1-2 plant breeders in the faculty except for the PhD funded programs that had at least 5 PhD plant breeders on staff. AGRA funded 2 PhD programs and 14 MSc programs on plant breeding and other crop improvement disciplines.



Education for African Crop Improvement	Breeding and Promotion of Varieties	Seed Production	Delivery
Identify strongest universities	Identify breeding teams	Identify seed enterprises	Identify service providers
Establish grant support	Develop breeding strategy	Establish production and market strategy	Establish grant support
Recruit top-level fellows	Establish grant support	Establish grant support	Oversee training
Curriculum oversight	Breeding oversight	Coordinate Business Development Services and training of seed company	Oversee credit guarantee
Thesis research oversight	Link breeders to SC's.	Monitor production and marketing	Link Agrodealers (AD) to seed companies
Re-integrate students	Assist commercialization	Link to investment funds	Create AD links to farmers

Figure 1: The AGRA Program for Africa's Seed System (PASS) value chain

The PhD training programs were initially conducted over 5 years with 2 years of coursework and 3 years thesis research in the home countries but later reduced to 4 years with 1 year of coursework and the same duration of thesis research after a thorough review. The MSc training programs were of 2 years duration comprised of 1-year coursework and 1-year thesis research at the university, NARS, or other research centers within the countries. In general, the students worked on topics of national priority research supervised by an in-country plant breeder with the university supervisor(s) offering distance supervision and occasional visits. The initial EACI training of plant breeders targeted researchers working in NARS as most of the breeding work on the continent was done by these institutions. In 2013 the PASS program was funded by BMGF to further improve the efficiency of the training of plant breeders at universities in a program called the Improved MSc in Cultivar Development (IMCDA).

The IMCDA program was designed to increase and optimize plant breeders' competencies in the management and development of plant varieties using state-of-the-art technologies. The target of this program was trained scientists who could work in the emerging and growing private seed companies. The program included molecular techniques applied in Africa's plant breeding programs that include DNA fingerprinting and genetic diversity analysis, quantitative trait loci (QTL) analysis of important biotic and abiotic stresses, marker-assisted selection (MAS) and genomic prediction of breeding values as well as plant genetics and plant breeding methods (techniques). The MSc Plant Breeding programs were offered at KNUST to cover West Africa, and at UKZN and Makerere University for Southern and Eastern Africa respectively. The students were attached to private seed companies or public breeding programs with a breeding pipeline for internships of 6 months during their training. The IMCDA program in partnership with other organizations such as the University of California-Davis's African Plant Breeding Academy, supported the training of mid-career plant breeders on use of modern technologies in breeding and data analysis. This training enabled the active plant breeders to learn efficiently and targeted product development.

All the curricula in the training programs were developed at the universities using their normal processes of stakeholder engagement. The PhD training programs worked with Cornell University, International Agriculture (funded by AGRA) to support development and delivery of relevant cutting-edge curricula. The IMCDA program worked with the Plant Breeding E-learning for Africa (PBEA) program of ISU to develop modern curricula. The one weakness in all the good quality curricula developed whether in Africa or in partnership with Cornell University and PBEA was that there were no local African case studies that could be used to train students. This book brings together some case studies of work done by several plant breeders in Africa that was included in the curricula and can be used in teaching plant breeders in Africa and beyond. It can be a useful tool to use even in projections of what other conventional and molecular tools can be used to increase genetic gains in the current programs.

1.1 Africa's Staples and Priority Crops

Table 1 shows the priority crops for the selected countries in East, Southern, and West Africa.

Table 1: Priority crops in selected countries in East, Southern, and West African countries

Country	Cereal crops	Legume crops	Root and tuber crops	Other
Burkina Faso	Maize Rice Sorghum Pearl millet	Cow pea Groundnuts	Sweet potato	
Ethiopia	Maize Sorghum Rice Finger millet Pearl millet Wheat and barley Teff	Beans Cowpeas Groundnuts Pigeon peas Chickpeas Soya bean	Cassava Sweet potato Irish potato	
Ghana	Rice Maize	Groundnut Cowpea	Cassava Yam Sweet Potato	

Country	Cereal crops	Legume crops	Root and tuber crops	Other
Kenya	Maize Sorghum Rice Finger millet Pearl millet Wheat	Beans Cowpeas Groundnuts Pigeon peas Chickpeas Soya bean	Cassava Sweet potato Irish potato	Banana/plantain
Malawi	Maize Sorghum Rice Finger millet Pearl millet Wheat	Beans Cowpeas Groundnuts Pigeon peas Chickpeas Soya bean	Cassava Sweet potato Irish potato	
Mali	Maize Rice Sorghum Millet	Cowpea Groundnuts		
Mozambique	Maize Sorghum Rice Finger millet Pearl millet Wheat	Beans Cowpeas Groundnuts Pigeon peas Chickpeas Soya bean	Cassava Sweet potato Irish potato	
Niger	Sorghum Millet			
Nigeria	Rice Maize Sorghum Pearl millet	Cowpea Groundnut	Sweet potato Cassava Yam	
Rwanda	Maize Sorghum Rice Finger millet Pearl millet Wheat	Beans Cowpeas Groundnuts Pigeon peas Chickpeas Soya bean	Cassava Sweet potato Irish potato Yams	Banana/plantain
Tanzania	Maize Sorghum Rice Finger millet Pearl millet Wheat	Beans Cowpeas Groundnuts Pigeon peas Chickpeas soya bean	Cassava Sweet potato Irish potato	Banana/plantain
Uganda	Maize Sorghum Rice Finger millet Pearl millet Wheat	Beans Cowpeas Groundnuts Pigeon peas Chickpeas Soya bean	Cassava Sweet potato Irish potato	Banana/plantain
Zambia	Maize Sorghum Rice Finger millet Pearl millet Wheat	Beans Cowpeas Groundnuts Pigeon peas Chickpeas Soya bean	Cassava Sweet potato Irish potato	

1.1.1 Documentation of breeding programs and general trends

In Africa, most of the crop breeding work is done by public institutions that include NARS, CG centers, and universities. A few regional and international organizations have robust breeding programs and develop their own products. Various breeding programs in mostly NARS were engaged to facilitate selection and their possible inclusion as case studies into the IMCDA curriculum. In West Africa all 5 countries (Ghana, Burkina Faso, Mali, Niger, and Nigeria) and discussions were held with a total of 26 plant breeders carrying out breeding activities on 8 crops (maize, sorghum, millet, rice, cowpea, groundnut, sweet potato, and cassava). For the plant breeders, two sets of questionnaires were sent ahead of the visits; one on inventory and outcomes/impacts of their plant breeding research, and the other on their breeding project proposed for use as a case study in the training of African plant breeders. The responses in the questionnaire complemented the information obtained from discussions with the plant breeders during the visits. A similar methodology was used in East and Southern Africa and countries visited included Kenya, Uganda, Malawi, Zambia, Mozambique, and Tanzania. Discussions were held with 29 breeders. The plant breeders engaged in the study are shown in Table 2.

Table 2: Plant breeders engaged in the documentation process of the breeding programs and the crops they worked on in the 12 countries in sub–Saharan Africa

Country	Name of Plant breeders	Crops they worked on
West Africa		
Burkina Faso	Dr. B. J. Bationo (INERA Kamboinse) Dr. Koussao Some (INERA Kamboinse) Dr. Jacob Sanou (INERA Fara Kouba)	Cowpeas Sweet potato Maize
Ghana	Dr. Joe Manu-Aduening (CRI)Kumasi) Dr. K. Obeng Antwi (CRI, Kumasi) Dr. James Yaw Asibuo (CRI, Kumasi) Dr. P. K. Dartey (CRI, Kumasi) Dr. Maxwell Asante (CRI, Kumasi) Dr. Hans Adu-Dapaah (CRI, Kumasi)	Cassava Maize Groundnut Rice Rice Cowpeas
Mali	Dr. Ntji Coulibaly Dr. Mohammadu Coulibaly (IER) Dr. Fousseyni Cisse Dr. Moussa Sanogo Dr. Abocar O. Toure	Maize Maize Rice Millet Sorghum
Niger	Dr. Prakash I. Gangashetty (ICRISAT) Dr. Aissata Yahaya (INRAN) Dr. Ahamad Issaka (INRAN) Dr. Adama Mamadou Coulibaly (INRAN)	Millet Sorghum Millet Groundnut
Nigeria	Dr. Andrew Efisue (University of Port Harcourt) Dr. Lucky Omoigui (Federal University of Agriculture, Markudi) Prof. Mary Yeye (IAR, Ahmadu Bello University, Zaria) Prof. C,A. Echekwu (IAR, ABU, Zaria) Dr. Babu Motagi (ICRISAT) Dr. Ignatius I. Angarawai (ICRISAT) Solomon O. Afuape (National Roots and Tuber Crops Research, Umudike) Dr. Chidozie Egesi (National Roots and Tuber Crops Research, Umudike)	Rice Cowpea Sorghum Groundnuts Groundnut Sorghum Sweet potato Cassava

Country	Name of Plant breeders	Crops they worked on
East and Southern Africa		
Kenya	Dr. Philip Leley and Dr. Philip Kwena (KALRO) Dr. Chrispus Oduori, Dr. John Kimani Prof. Paul Kimani	Maize Finger millet Rice Beans
Malawi	Dr. Tenyson Muzengeza Dr. Justus Chintu Dr. Geoffrey Kananji (discussed with his technician)	Rice Groundnuts Beans
Mozambique	Mr. Joaquim Mutaliano (IIAM) Dr. Pedro Chauque, Dr. Pedro Fato, and Dr. David Mariote (IIAM)	Sorghum Maize
Rwanda	Mr. Augustine Musoni	Beans
Tanzania	Dr. Arnold Mushongi and Dr. Lameck Nyaligwa (TARI) Dr. Rose Mongi (TARI) Dr. Kido Mtunda (TARI) Dr. Sophia Kashenge-Killenga (TARI)	Maize Beans Cassava Rice
Uganda	Dr. Robooni Tumuhimbise (NARO) Dr. Lawrence Owere (NARO) Dr. Geoffrey Lubade (NASARI) Dr. Frank Kagoda (NARO) Dr. Stanley Nkalubo (NARO) Mr. Kallule David Okello (NASARI) Dr. Martin Orawu (NASARI) Dr. Jimmy Lamo (NARO)	Banana Finger millet Pearl millet Maize Beans Groundnut Cowpea Rice
Zambia	Dr. Francisco Miti (Seed Control and Certification Institute Dr. Mweshi Mukanga Dr. Martin Chiona Dr. Batiseba Tembo Dr. Nathan Phiri	Maize Rice Sweet Potato Wheat Beans

1.1.2 General comments in breeding programs

Common trait preferences emerged for the considered crops across the different ecologies. Trait preferences at the core of the breeding programs included high yield, early maturing varieties, drought tolerance, and resistance to diseases and pests. The prioritization of early-maturing cultivars, submergence tolerance in rice, and capability for anaerobic germination also in rice indicate that plant breeders in the sub-regions are keen to pursue climate-smart strategies to mitigate the effects of climate change that manifest through frequent droughts and/or floods. The programs also aim to enhance the nutritional quality of the selected crops to meet consumer preferences.

Increasingly, breeding programs are undertaking hybrid development to exploit heterosis in crops such as maize, sorghum, and pearl millet. They also use cytoplasmic male sterility to facilitate hybridization as an integral part of the hybrid program in pearl millet and sorghum. A positive trend is the exploitation of landraces and locally adapted improved cultivars in the development of new varieties.

The most used breeding methods include selection from introductions, mass selection, pedigree selection following crossing among desirable parents (including interspecific hybridization), backcross, mutation, and recurrent selection. Markers are also used but their use is limited to marker-assisted backcrossing, especially to achieve cowpea resistance to *Striga gesnerioides* in Nigeria and Burkina Faso, and resistance to cassava mosaic disease (CMD). However, lack of molecular resources and infrastructure to support marker-assisted breeding for important traits poses a limitation to the use of markers.

Through collaborations, the breeders obtained germplasm from other NARS, international agricultural research centers (IARCs), and several other organizations. The programs also ensured that farmers selected preferred varieties through participatory rural appraisal (PRA) and participatory plant breeding opportunities that were validated by multi-locational and on-farm trials undertaken simultaneously.

Some of the developed varieties have influenced government policies to enable mass production in the countries in which they were developed. Some examples include Bondofa maize variety in Burkina Faso, Sotubaka in Mali, and orange-fleshed sweet potato varieties in Nigeria — all of which attracted government-initiated mass distribution programs.

2 | Breeding Programs for Priority Crops in East and Southern Africa

2.1 Cereal Crops Breeding programs

2.2.1 Kenya maize program

Maize (*Zea mays* L) breeding in Kenya is mainly carried out by the Kenya Agricultural and Livestock Research Organization (KALRO). The main breeding goals are to increase yields by developing varieties that are resistant to Maize Streak Virus (MSV), Gray Leaf Spot (GLS), Northern Leaf Blight (NLB), Maize Lethal Necrosis Disease (MLND), Striga, and ear rots. Another objective is to achieve target traits, including early maturity in the dry areas and higher yielding late maturing varieties in areas with long growing season such as Kitale.

Breeding methods and varieties released

The program uses pedigree breeding (Figure 2), S1 recurrent selection, reciprocal recurrent selection, marker assisted recurrent selection, and backcross breeding. Quantitative trait loci (QTL) analysis and backcrossing are used to incorporate quantitative traits in desired genetic backgrounds. The program uses the Breeding Management System (BMS) to manage data and information. To date, 20 maize varieties have been released, 8 of which have been commercialized. Adoption rates of 60–90% have been recorded in some areas. The public sector and private seed companies, including Lagrotech, Sacred, and Faida, produce and market the commercialized varieties.

Figure 2: Striga hermonthica from finger millet plots at Alupe, western Kenya

2.2.2 Kenya finger millet program

In Kenya, finger millet, *Eleusine coracana* (L.) Gaertn., is cultivated on a small scale. Finger millet is one of the minor cereal crops that can be grown at high altitudes of 2,000 m above sea level, is drought tolerant, and the grain has a long storage life. Finger millet is a nutritious crop that has high protein, iron, calcium, a wide range of vitamins, and dietary fibre. It is also known for its health benefits that include anti-diabetic, anti-tumerogenic, and antherosclerogenic effects; antioxidants and anti-microbial properties (Devi et al., 2014). Its production is often affected by diseases such as blast caused by the fungus *Magnaporthe griseas* (*Pyricularia grisea*), and by weeds (*Striga*) (Fig 2 below), and it is susceptible to lodging. Among the breeding goals are high yield, improved nutritional quality and resistance to diseases and lodging.

Breeding methods and varieties released

Breeding methods used include germplasm introductions, hybridization, and development of pure lines using a modified bulk method or pedigree method. For hybridization, the plastic bag technique and gametocides (induce male sterility) are used. In collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), molecular markers have been used to a limited extent. Five varieties had been released at the time of the study with high adoption rates of 36.2%. Maridadi variety has the highest adoption rate at 64.3% of the market share. The released varieties are marketed by the Kenya Seed Company, Farm Africa, and the KALRO Seed Unit, which also licenses the varieties.

The new varieties have increased finger millet production in western Kenya. The land under finger millet per farmer has increased by 32.1%, resulting in a 20% increase in income. As a result of increased consumption, finger millet, an otherwise forgotten crop, has been propelled into the limelight. Finger millet is planted on over 65,000 ha in Kenya.

2.2.3 Kenya rice program

KALRO conducts rice *(Oryzae sativa)* breeding for both upland and paddy. The breeding goals are high yield with farmer preferred traits, among them high grain quality, good quality (including aroma, grain shape, shorter cooking time, fluffiness, resistance to blast, and cold tolerance.

Breeding methods

Breeding methods include pedigree, bulk population breeding, and doubled haploid technique. Temperature-sensitive genotypes are used to facilitate crossing in a temperature-controlled greenhouse of below 23°C. This causes pollen abortion in the female parent as the male parent is insensitive to low temperature. The use of the doubled haploid technique facilitates quick production of homozygous lines while the temperature-induced male sterility facilitates the easy production of hybrids. The double haploid technique is funded by Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI) and AGRA based at Africa Rice in Senegal. The team crossed Korean germplasm (high yielding, cold tolerant) with Kenyan landraces (locally adapted, preferred grain quality, including aroma). The pollen from this FI cross is cultured in media and propagated to get several plantlets. The plantlets are hardened and then just before flowering subjected to shock treatment which causes doubling of the chromosomes. The vigorous growing plants (with doubled chromosomes) are selected and subjected to normal environmental trials for selection of varieties.

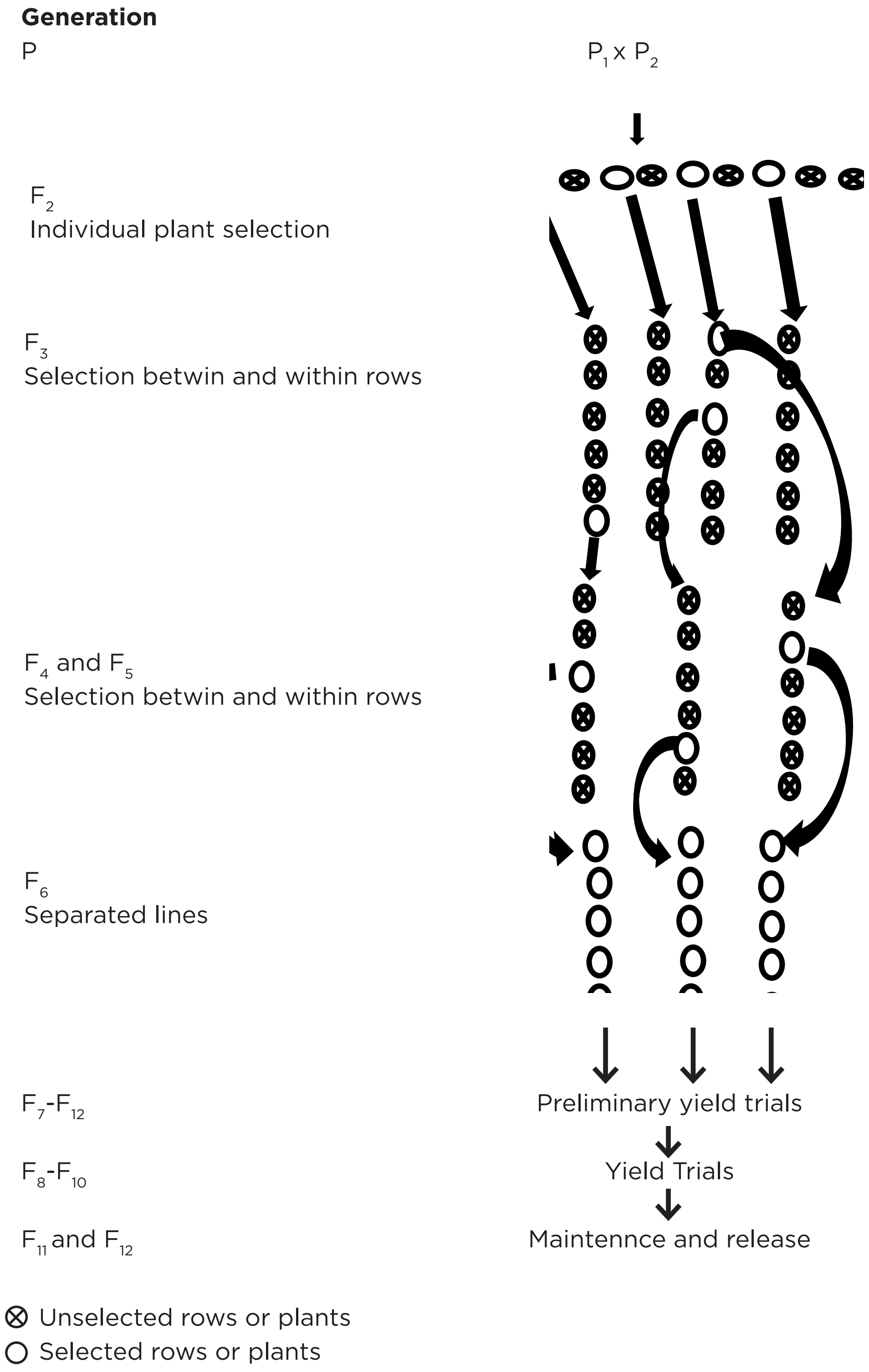


Figure 3: A pedigree breeding scheme for handling segregating population in finger millet

2.2.4 Malawi rice program

Rice (*Oryza sativa* and/or *Oryza glaberrima*) breeding in Malawi is undertaken by Agricultural Research Services at Lifuwu Research Station. The breeding goals include the development of improved rice varieties that are high-yielding, stable, and capable of resisting environmental stresses and responding well to nutrient inputs.

The target traits include improved quality, aroma, long and slender grain, early maturity, and resistance to rice yellow mottle virus. Breeding methods include pedigree, bulk methods, and haploid breeding using anther culture techniques. Due to the unavailability of facilities, the program uses facilities at Rural Development Administration (RDA) in South Korea. Three varieties had been released at the time of the study, commercialized, and were being multiplied by farmer seed multiplication groups. The list of varieties that are widely grown is shown in Table 3.

Table 3: Malawian rice varieties released and their traits and yields

Name of variety	Ecology	Traits	Yields (tons per ha)
Kayanjamalo	Lowland (rainfed and irrigated; 50–2250 masl)	Long grain, aromatic	6.5
Mpatsa	Lowland (rainfed and irrigated; 50–2250 masl)	Long grain	6
Katete	Lowland (rainfed and irrigated; 50–2250 masl)	Drought tolerant	6

2.2.5 Mozambique Sorghum

Crop breeding in Mozambique is conducted by Agricultural Research Institute of Mozambique (IIAM). The breeding program seeks to develop drought tolerant, disease resistant, high quality, and open-pollinated and hybrid sorghum, *Sorghum bicolor* (L.) Moench, varieties.

The breeding methods used are pedigree method and backcross (mainly used in the development of male sterile and maintainer (A and B) lines). For crossing and hybridization, the program makes use of the cytoplasmic male sterility approach. Eight varieties had been released, three of which had been commercialized. In rural areas, sorghum is more of a staple food crop and rarely traded. Although adoption is relatively low, consumption is likely to increase as sorghum is now used in poultry feed, soft drinks and the beer industry. The breeding program supplies seed to Unidade de Semente Basica (USEBA) and directly to other seed companies, and the new varieties are more productive than the landraces. Due to lack of funding from internal sources in Mozambique, the program is dependent on donor funding.

2.2.6 Mozambique maize program

The IIAM breeding goals for maize include drought tolerance, improved nutritional content, and resistance to Downey mildew, MSV and maize lethal necrosis (MLN). The program also encompasses improved maize varieties for both small-scale and commercial farmers. The program uses conventional means to enhance drought tolerance in maize. Doubled haploids (DH) procedure is used for fast inbred line development and genotyping is done for quality control (purity).

Seven varieties have been released so far; they include three hybrids and four open pollinated varieties (OPVs) with superior targeted traits. For instance, SP-1 is drought tolerant while Gema and Dimba are early maturing. ZM421, 521 and 621, all OPVs, have been commercialized. The adoption rate for the released varieties is 11–12%. Seed production and marketing is done by Oruwera, a local seed company based in Nampula, and Nzarayapera based in Manica. Dengo, SEMOC and IAP are some of the seed companies producing and marketing the seed. There is scope for more awareness to facilitate higher adoption of the improved varieties.

2.2.7 Tanzania maize program

Selian and Uyole Agricultural Research Institute's (ARI) breeding goals include increased incomes and improved food security through the development of stress tolerant maize (*Zea mays* L.) varieties. The program targets traits such as high grain yield, early maturity, drought tolerance, and resistance to biotic and abiotic stresses.

Breeding methods

The breeding methods include conventional breeding and marker assisted selection. Data analysis is done using the BMS program. Although over 13 varieties have been released, not all have been commercialized. Adoption rates are estimated to be 40%. Marketing of the seeds is undertaken by private seed companies including Namburi Seed Company, IFFA Seed Company, and ASA. Farmers have reported double their usual yields from using improved varieties like H308. Seed production and marketing are carried out by Highland Seed Growers Ltd., Beula Seed Company, ASA, and Kipato Seed Company.

2.2.8 Tanzania rice program

Chollima Agro-scientific Research Centre's breeding goals are high productivity using improved rice *(Oryza sativa)* varieties under changing climate. The program targets traits such as high yield, good grain quality, tolerance of salinity, and resistance to diseases such as rice yellow mottle virus (RYMV). The program uses conventional bulking and pedigree breeding methods. Three varieties had been released at the time of the study namely SATO1, 6, and 9.

2.2.9 Uganda finger and pearl millets program

Finger millet breeding in Uganda is undertaken by the National Agricultural Research Organization (NARO). The program targets high-yielding, early maturing cultivars that are resistant to major biotic and abiotic stresses. Breeding methods include modified pedigree method and bulk method, which are both conventional breeding methods. No varieties had been released yet at the time of the study since this was a new breeding program.

The NARO breeding goals for pearl millet (*Pennisetum glaucum* L.) include developing new varieties and improving productivity in semi-arid environments. The program targets the improvement of traits such as resistance to ergot, rust, and striga. It uses conventional breeding (pedigree selection and recurrent selection) methods and the BMS program. Cytoplasmic male sterility is used to facilitate crossing.

2.2.10 Uganda maize program

Maize breeding by NARO targets the development of high yielding, drought tolerant varieties that are resistant to Maize Lethal Necrosis Disease and adapted different agro-ecologies . Breeding methods use various forms of recurrent selection. This work was funded by various donors including CG centers. Some varieties that have been released in this program are listed in Table 4.

Table 4: Maize varieties released in Uganda

Country	Crop	Variety Name (Variety Code)	Variety Type	Class	Year of Release	Breeder responsible
Uganda	Maize	Longe 11H (NML97A)	Three Way Cross	Hybrid	2009	Godfrey Asea
Uganda	Maize	Longe 9H(NML85B)	Three Way Cross	Hybrid	2009	Godfrey Asea
Uganda	Maize	Longe 10H (NML88B)	Three Way Cross	Hybrid	2009	Godfrey Asea
Uganda	Maize	Muwezitatu(MM3)	Open Pollinated Variety	OPV	2010	Godfrey Asea
Uganda	Maize	YARA41(MU03-014)	Hybrid	Hybrid	2008	Grace Abalo
Uganda	Maize	YARA42(MU03-017)	Hybrid	Hybrid	2008	Grace Abalo
Uganda	Maize	Longe 5D	Improved OPV	OPV	2012	Godfrey Asea
Uganda	Maize	UH5051	Varietal hybrid	Hybrid	2012	Godfrey Asea
Uganda	Maize	UH5052	Varietal hybrid	Hybrid	2012	Godfrey Asea
Uganda	Maize	UH5053	Varietal hybrid	Hybrid	2012	Godfrey Asea
Uganda	Maize	UH5301		Hybrid	2013	Godfrey Asea
Uganda	Maize	UH5503 (Naro Maize-O3)		Hybrid	2017	Godfrey Asea
Uganda	Maize	UH5402		Hybrid	2017	Godfrey Asea
Uganda	Maize	UH5401		Hybrid	2017	Godfrey Asea
Uganda	Maize	NAROMAIZE731		Hybrid	2017	Frank Kagoda
Uganda	Maize	NAROMAIZE733		Hybrid	2017	Frank Kagoda

2.2.11 Zambia maize program

Maize breeding in Zambia is carried out by the Zambia Agricultural Research Institute (ZARI) and the Seed Control and Certification Institute (SCCI) is responsible for certification. The program aims to increase yield, improve nitrogen content, and increase drought tolerance. The breeding method used at the time was S1 recurrent selection

Six varieties had been released and five of them commercialized (Table 8). The seeds are licensed by the Zambia Agricultural Research Institute (ZARI). They are produced and marketed by Agrichandi Seed Company and smallholder seed associations in Sinazongwe, Siavonga, Chikankata, Kafue, Chongwe, Rufunsa, Kapiri Mposhi, and Mkushi districts.

Table 5: Maize varieties released from program in Zambia

Name of variety	Type of improved crop	Days to maturity (days)	Yield (t/ha)
AGP 4 (MMV 415)	Open pollinated variety (OPV)	119	5
AGP 12 (MMV 530)	OPV	127	5
AGP 27 (MMV 420)	OPV	117	5
AGP 32 (MMV 405)	OPV	110.5	4
MMV 508	Single cross hybrid	129	11.3

2.2.12 Zambia rice program

Rice breeding in Zambia aims to achieve high yield, better quality, aroma, and resistance to pests and diseases as well as tolerance of drought and acidity. The program uses pedigree breeding, and bulk methods. Three varieties had been released, as shown in Table 9.

Table 9: Rice varieties released in Zambia

Name of variety	Duration (days)	Yield (t/ha)
Longe 1	110-115	4.1
Longe 2	108-117	3.7
Longe 3	125-130	5.4

2.3 Legume Crops Breeding programs

2.3.1 Kenya bean program

Bean (*Phaseolus vulgaris* L.) breeding goals by the University of Nairobi's Plant Breeding and Biotechnology Program seek to improve yield, enhance nutrition, improve quality, and increase resistance to biotic and abiotic stresses. The breeding targets traits including gene pyramiding, resistance to Angular Leaf Spot (ALS), anthracnose (Anth), Root Rots (RR), Bacterial Blight (BB), and Bean Curl Mosaic Virus (BCMV). A wide cross is used for introgression of traits from runner bean (*Phaseolus cocchineus*) to *P. vulgaris*, which is tolerant of and resistant to diseases. Molecular breeding is used to make beans adapt to short-day tropical conditions and increase its resistance to diseases.

Breeding methods

Breeding methods include pedigree, bulk (Figure 4), single seed descent (SSD), marker-assisted breeding and gamete selection. The method involves complex crossing of several lines with different desired traits. Thereafter, gamete selection is done for plants with combinations of the different traits. Due to limited facilities, the program collaborates with the International Center for Tropical Agriculture (CIAT) for some of the genotyping services. Stakeholders are involved in the selection process, such as preliminary yield trial (PYT), advanced yield trials (AYT) and National Performance Trials (NPT). A total of 18 varieties have been released in Kenya with an adoption rate of 28%. Nine of these varieties have been commercialized. Among them, and in high demand are Miezi Mbili, Kenya Early, Mavuno, Kenya Safi, and Kenya Tamu varieties (Fig 5).

Other than in Kenya, these varieties have also been released in other countries including Democratic Republic of Congo, Cameroon, Togo, Uganda, Burundi, and Malawi. The seeds are marketed by several organizations including the Seed Enterprise Management Institute (SEMI) of the University of Nairobi, UNISEED Ltd., other private seed companies, and farmer groups. Although the demand is high for released bean varieties, there are challenges with producing and disseminating adequate seeds.

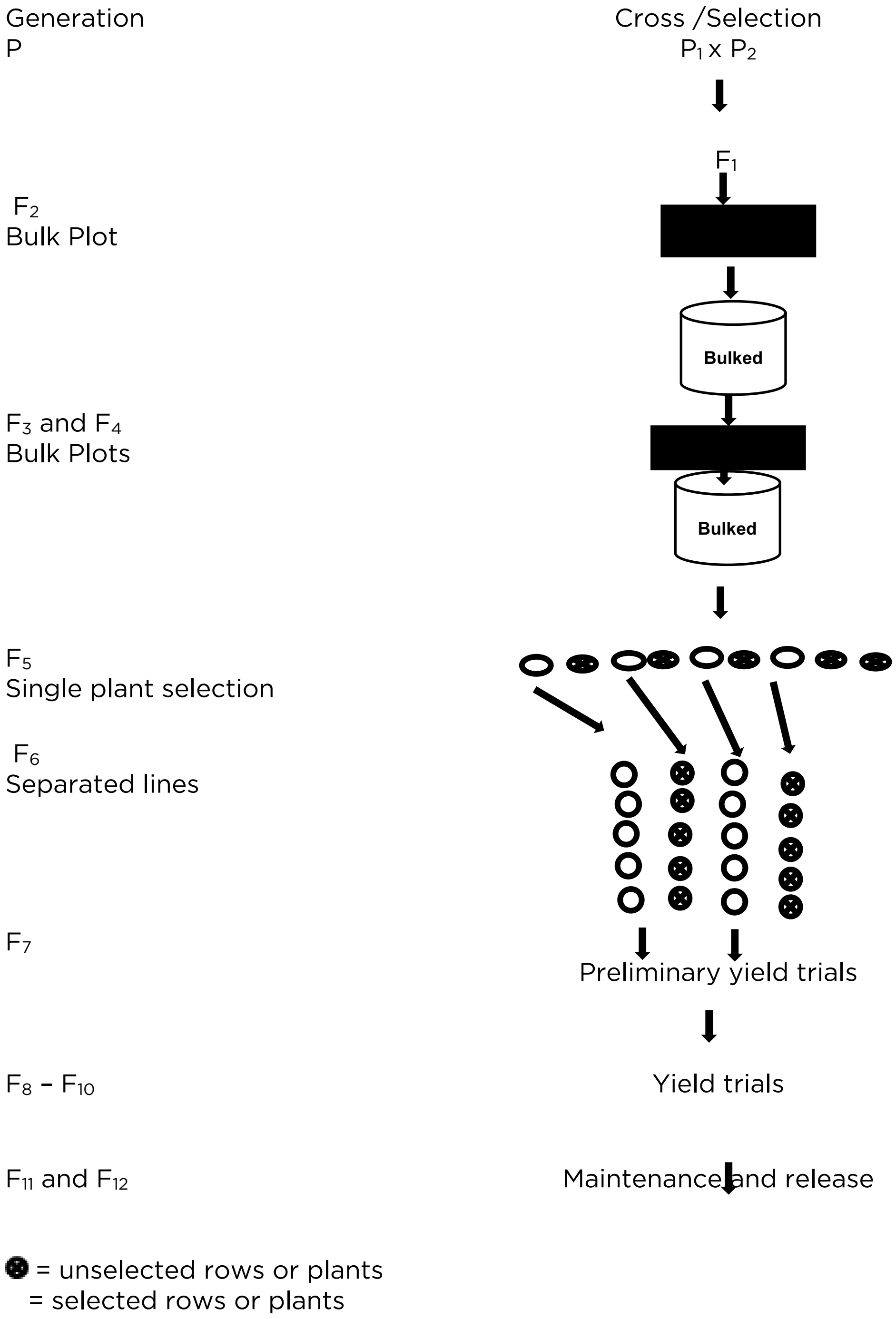


Figure 4: Scheme of bulk method of handling segregating population

Figure 5: Some of the released bean varieties from the University of Nairobi's Plant Breeding and Biotechnology Program

2.3.2 Malawi Groundnut program

Groundnut (*Arachis hypogea* L.) breeding by the Agricultural Research Services of the Ministry of Agriculture targets the development of varieties that have high oleic acid content, are resistant to rosette, leafspots and rust, drought, and aflatoxin. The breeding method includes bulk population breeding. The program does not use BMS and other modern breeding techniques. The last variety was released in 2014 but has not yet been commercialized because the Agricultural Technical Clearing Committee requires breeders to have a minimum of 50 kg of seeds. Although no adoption studies have been carried out on the varieties on the market, CG7 is the most common variety grown by farmers. Private seed companies are increasingly interested in marketing the seeds, a function that was previously carried out by the Department of Agricultural Research.

2.3.3 Rwanda bean program

The Rwanda Agricultural Board (RAB) breeding objectives for beans include higher productivity, better nutrition, and higher incomes for smallholder farmers. It targets traits such as resistance to diseases and early maturity. Breeding methods are largely conventional with some molecular techniques. Marker assisted selection (MAS) is used to select for disease resistance. The molecular and biotechnology laboratories in Rwanda collaborate with AGRA, Kirk House Trust, CIAT, and the Belgian Technical Services (BTC) on molecular breeding. The BMS program is used to manage data and information during the breeding process.

Twenty-five varieties including bush, climbing, and/or snap, have been released over the last 20 years. Some of the varieties have been commercialized. Adoption rates are higher (65%) for climbing beans and lower for snap beans.

Seeds are mostly produced and marketed by informal farmer organizations, cooperatives, government projects, and seed companies. The new varieties have increased incomes and enhanced food security for smallholder farmers. Bean productivity has doubled in the last 20 years and is twice the mean productivity for sub-Saharan Africa of 0.5 t/ha. Rwanda is now a net exporter of beans despite population increases on limited land. The Rwandan bean breeding program is probably the most successful one for grain legumes/pulses in Africa. Varieties from this program have been introduced and adopted in many countries in Eastern, Southern and Central Africa. Although it specializes in high yielding climbing beans, the program recently incorporated micro-nutrient traits.

2.3.4 Tanzania bean program

Uyole Agricultural Research Institute's breeding program targets improved yields, disease resistance, and higher quality. It uses conventional breeding methods such as bulk population breeding and pedigree breeding (scheme showed on Fig 3 earlier). Seven varieties have been released and one of these is commercialized. The seeds are produced and marketed by ASA Agency and farmers have reported doubling their yields after growing the improved varieties.

2.3.5 Uganda bean program

The NARO breeding goals seek to develop, conserve, and disseminate technology and knowledge on legume genetic resources and product quality. Breeding targets include achieving resistance to biotic stresses, ALS, Anthracnose, Root Rot, BCMV, and rust. The program also targets resistance to pests, such as stem maggot, bruchids, and bean leaf beetle. Also targeted is resistance to abiotic stresses caused by heat, drought, and soil fertility issues.

Breeding methods

Breeding methods include backcross, recurrent selection (Figure 6) and single seed descent. The program uses MAS to achieve resistance to anthracnose. To date, 14 varieties have been released and commercialized. They are multiplied and marketed by private seed companies, non-governmental organizations (NGOs) and community-based farmer organizations. Although the varieties are in high demand, no adoption studies have been conducted.

2.3.6 Uganda groundnut program

NARO is a leading player in plant breeding in Uganda. Groundnut breeding targets high yield, resistance to drought, heat, and diseases such as rosette, leafspots, leaf miners, and thrips. Also sought are high oleic acid and oil content, resistance to aflatoxin, and to pests such as aphids.

Breeding methods

The program uses the following breeding methods: pedigree, mass selection, single seed descent, MABC, and tissue culture techniques. Molecular genotyping services are outsourced from Bioneer and Inqaba. Ten varieties have been released and commercialized with high adoption rates of 40–60%. The commercialized varieties are produced and marketed by seed companies and farmers' groups. Adoption of the improved varieties has improved farmer yields and increased household incomes.

2.3.7 Uganda cowpea program

Cowpea [*Vigna unguiculata* (L.) Walp] breeding in Uganda contributes to increased crop productivity and improved incomes and livelihoods of smallholder farmers. It targets increased yield, resistance to pests and diseases, drought tolerance, and palatability. The program uses breeding methods including conventional breeding (pedigree and bulk methods). Three cowpea varieties have been commercialized. The seeds are marketed by 3 different companies namely NASECO, Equator and Victoria Seed Company.

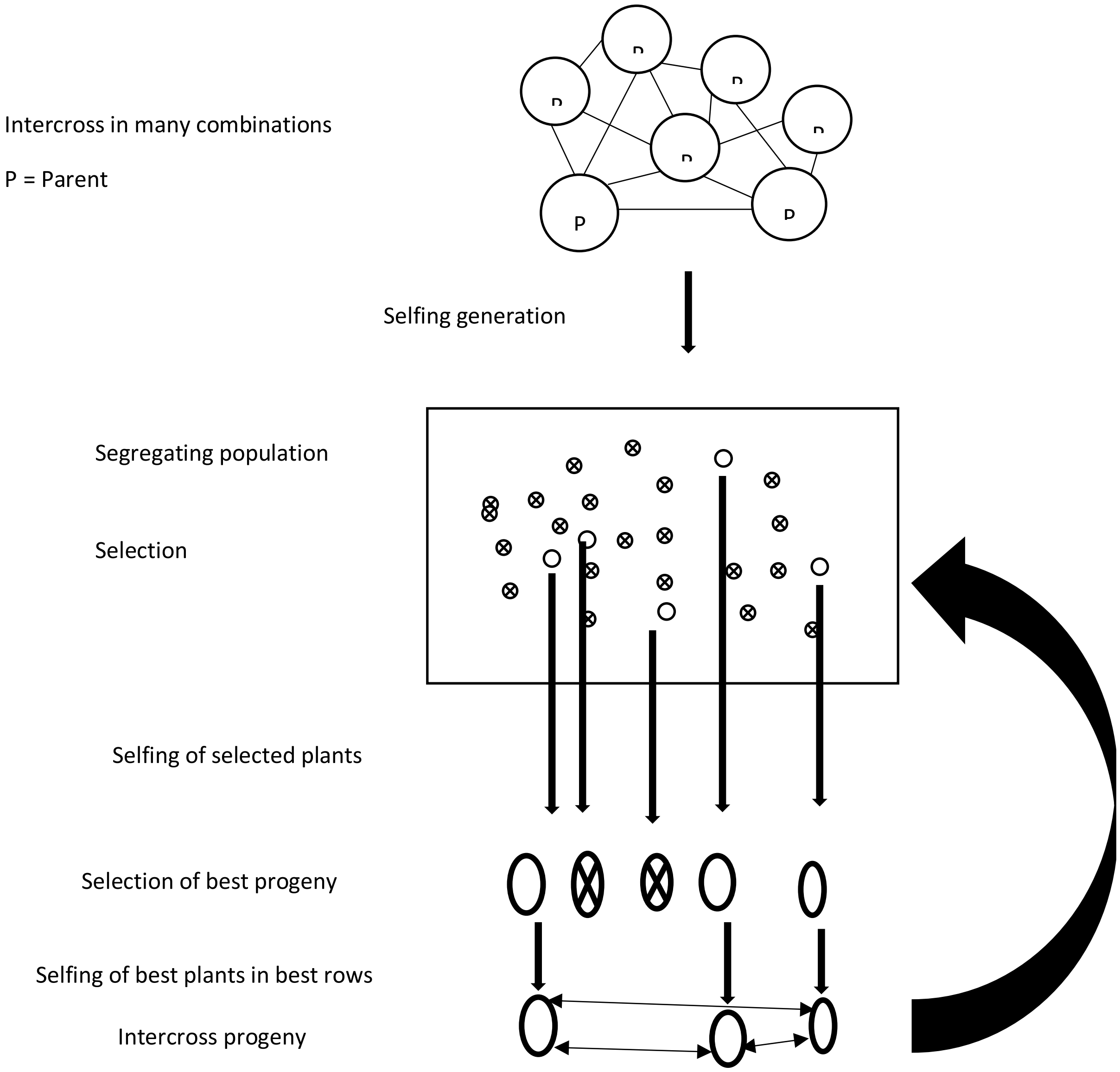


Figure 6: Simplified outline of recurrent selection

2.4 Clonal crops

2.4.1 Tanzania cassava and sweet potato programs

Tanzania's Agricultural Research Institute's (ARI) breeding goals for cassava (*Manihot esculenta*, Crantz) include high yield, high dry matter content, and resistance to diseases [mainly Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD)].

ARI's sweet potato, *Ipomea batatas* (L.) Lam, breeding program aims to achieve high yield, resistance to diseases (viruses), and high beta-carotene. The program uses conventional breeding, mainly progenies from diallel crosses and polycross progeny.

It uses a novel technique to bulk the new cassava varieties released. This involves planting two-node cuttings from 6-week-old seedlings to produce several plants. Five varieties have been released.

2.4.2 Zambia sweet potato and cassava

The Zambia Agricultural Research Institute conducts breeding for these root and tuber crops to achieve high dry root yields, early maturity, high protein content, drought tolerance, leaf palatability, disease and pest tolerance. Additional breeding goals for sweet potato *(Ipomoea batata)* include high beta-carotene content, vine persistence and leaf palatability.

Breeding uses conventional methods that involve hybridization, evaluation and selection of progeny. Seven cassava *(Manihot esculenta)* varieties and 12 sweet potato varieties have been released. The released varieties have been highly adopted. Adoption rates for Mweru cassava variety stands at 90% and 50% for Chila. That of Olympia sweet potato is 60%. Olympia is now found in supermarkets in Lusaka. Mweru is used as starch in the processing of copper and cobalt in Kalumbila Mine.

2.4.3 Uganda banana program

Banana (*Musa* species) breeding in Uganda is carried out NARO. The program targets increase in bunch yield, improved fruit quality, and resistance to pests such as banana weevils and nematodes. It also aims to achieve early maturity, drought tolerance, and resistance to diseases such as Black Sigatoka caused by the ascomycete fungus *Mycosphaerella fijiensis (Morelet)*, Fusarium wilt caused by *Fusarium oxysporum*, and banana bacterial wilt caused by *Xanthomonas* bacterial species.

Breeding Methods

Breeding methods comprise both conventional and modern techniques. Conventional methods involve crossing among desired parents (4x and 2x) to generate progeny with mixed ploidy levels: 2x, 3x, and 4x. The 3x genotypes are selected for advancement as potential new varieties. Modern techniques used to multiply clones include embryo rescue techniques, tissue culture, genomic selection and genetic modification.

Two varieties Kabana 6H (M9) and Kabana 7H (M2) have been released and commercialized. The adoption rate for Kabana 6H (M9) is 70% while that of Kabana 7H (M2) is 35%. The varieties are marketed by private tissue culture laboratories, including Biocrops (U) Ltd., Nsigotech (U) Ltd., and AGT (U) Ltd. In addition to being resistant to pests and diseases, Kabana 6H has greatly increased yields of 30–65 t/ha.

3 | Selected Case Studies for Inclusion in the MSc. Curriculum from East and Southern Africa

As a result of the breeding program, the following are good case studies that have been selected for possible inclusion into the MSc curriculum. Banana, beans, finger millet, sorghum, and cassava represent priority African staples.

3.1 Banana breeding in Uganda

Banana, also known as plantain, is a giant herbaceous plant which originated from the South Pacific. Bananas are a major food crop in over 100 countries throughout the tropics and subtropics (INIBAB, 2000). There are over 1,000 banana varieties or landraces around the world. (Heslop-Harrison and Schwarzacher, 2007). For a long time, banana has been cultivated in East and West Africa (FAO, 2005).

There are two types of banana species, the seedless bananas (triploid species) and the wild bananas (diploid species). Seedless banana species are eaten by humans as opposed to the wild, seeded species which are inedible to humans (Banana Wikipedia accessed 2016). The seedless bananas produce suckers by which the plant is vegetatively propagated.

Although the names banana and plantain have been used interchangeably, banana mostly refers to the table or dessert bananas while plantain refers to the starchier fruits often cooked or roasted before eating.

Figure 7: Banana bunches being transported to the market, Uganda

Cultivated bananas evolved from two diploid progenitors, *Musa acuminata* (A genome) and *M. balbisiana* (B genome) both with $2n = 2x = 22$ chromosomes. There are many other diploid species in this group but these two are the most important in the evolution of cultivated bananas.

About 50 recognized species of banana exist all under the genus *Musa*. Homogenomic (autotriploid) types were formed within *M. acuminata* leading to sweet bananas (Pillay et al., 2004). These have the AAA genotype with 33 chromosomes. Plantains (allotriploids) of AAB genotype and other cooking types of ABB genotype were formed through crosses of diploid *M. balbisiana* and triploid *M. acuminata* (Pillay et al., 2004).

Bananas are susceptible to various diseases such as Panama disease, Black Sigatoka, Banana Bunchy Top virus, weevils, and Bacterial Wilt. A combination of the two species helps to contribute different desired resistance traits. *M. acuminata* contributes sterility and parthenocarpy traits while *M. balbisiana* contributes hardiness, drought tolerance, disease resistance, and starchiness (Pillay et al., 2002).

Reproduction in the banana is complex. Pollen viability varies between different types of bananas species (Fortescue and Turner, 2004). Most cultivated bananas (triploids) are propagated vegetatively by suckers. The ability of some triploids to produce viable pollen has been used in breeding involving triploid × diploid crosses to generate more triploid genotypes as follows:

$AAB \times A^1A^1 = AA^1B + AA^1$ or

$AAB \times B^1B^1 = ABB^1 + AB^1$ or

$AAA \times BB = AAB + AB$

The resulting triploids can express desired traits inherited from the diploid parent. AAB and ABB triploids show higher levels of bivalent formation due to higher homology within the A and B genomes compared to the AAA or BBB triploids. Triploids can also be generated through crossing tetraploids with diploids as illustrated:

$AABB \times AA = AAB$ or

$AABB \times BB = ABB$

The tetraploid can be generated by diploid × diploid crosses followed by chromosome doubling using colchicine as in the following scheme:

AA × BB = AB followed by chromosome doubling to give AABB. They can also be produced by combining an unreduced gamete from a triploid with a haploid gamete from a diploid as:

Cross: AAB × BB

Gametes: AAB and B (AAB is the unreduced gamete)

Progeny: AABB (after the gametes combine)

All the above types of germplasm are used in Uganda's banana breeding program. Desired diploid (2X) and tetraploid (4X) parents are crossed to generate populations with mixed ploidy levels: 2X, 3X, and 4X. The mixed ploidy levels result from the different types of gametes produced by the tetraploid female parent which gives haploid, diploid and triploid gametes. For example, an AABB genotype can give the following combinations of gametes A & ABB; AB & AB; B & AAB. The AB & AB combination is the highest frequency of the gametes due to normal bivalent formation within the A and B genomes. The 3X genotypes have been selected for evaluations as potential varieties.

The program also crosses diploid (2X) and triploid (3X) to generate more 3X genotypes. This results in a mixture of ploidy levels: 2X, 3X and 4X but with the 2X and 3X in greater proportions because the triploid individual gives 1X and 2X gametes in higher frequency than the 3X gametes. The 3X individuals from the two crossing schemes above are identified using cytometry based on the DNA content of the individual. For example, DNA content of *M. balbisiana, M. acuminate*, and the AAA triploid are: 1.14, 1.26 and 1.81 respectively. According to Dr. Tumuhimbise, a breeder in Uganda, the female part of the flower is covered with specialized bags to prevent contamination with unwanted pollen. Pollen is collected from the selected male parent by covering the male part of the flower with a bag as shown in Figure 8.

The breeder applies pollen on to the covered female portion of the flower (Figure 9) after which the pollinated bunch continues to be covered until the fingers (fruits) are fully developed. When the seeds are mature, they are harvested, dried, and germinated to give banana seedlings. Banana seeds take between 3 and 6 weeks to germinate. The seedlings go into trials, followed by clonal trials, then preliminary variety trials, followed by intermediate variety trials, and advanced variety trials. Top performing varieties that produce big bunches of bananas with other desirable traits are released.

Figure 8: Banana bunch with the male flowers covered with white cloth bag. Dr. Tumuhimbise holds the top part of the male flowers on the bunch

Figure 9: During crossing, the female part of the flower is covered with specialized bags to prevent contamination with unwanted pollen

3.2 Bean breeding in Kenya

Bean, *Phaseolus vulgaris* (L.), is a legume crop which is cultivated worldwide. Some of the major producers in Africa are Tanzania, Uganda, and Kenya which produce 0.95, 0.46 and 0.39 million tons of dry beans per annum respectively (FAOSTAT, 2014). The bean flower is a typically leguminous flower showing the standard petal, the wing petals, the keel petals, the stamens with the anthers surrounding the pistil and the pistil itself. It is highly self-pollinated with less than 1% cross-pollination.

Beans belong to the family Leguminosae. It has a diploid chromosome number of 2n = 2x = 22. Cultivated forms are herbaceous annuals which are either determinate or indeterminate in growth habit. It is a C3 crop which is poorly adapted to extremes of temperatures.

Two bean gene pools have been identified: Mesoamerican and Andean (Gepts et al., 1986). Mesoamerican beans are divided into three races, Mesoamerica, Durango, and Jalisco types. The Andean gene pool is further divided into three races, Peru, Nueva Granada, and Chile (Kwak and Gepts, 2009).

Which of the germplasm is used in the breeding program in Kenya?

Bean breeding in Kenya involves conventional breeding methods including pedigree, bulk, and Single Seed Descent (SSD). It also uses marker assisted breeding which includes gamete selection, especially for bean diseases. Complex crosses are conducted, involving several lines with different desired traits. This is followed by gamete selection (Singh et al., 2005) to select segregants with combinations of the desired traits as illustrated in Figure 10:

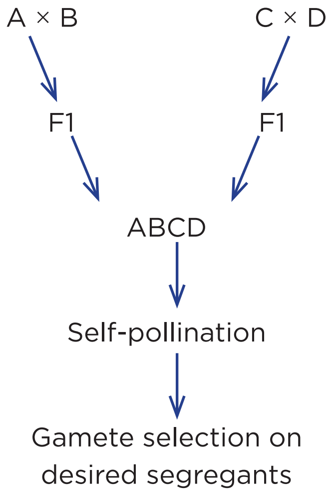


Figure 10: Crossing scheme for the selection of individuals with multiple traits from targeted parents

Bean breeding targets traits such as resistance to common diseases like Angular Leaf Spot, Anthracnose, Root Rot, Bacterial Blight, and Bean Common Mosaic Virus. To achieve tolerance of and resistance to diseases, wide crossing is done for the introgression of traits from the runner bean (*Phaseolus coccineous*) to *P. vulgaris.* An example of a wide cross is when a cross is made between a *Phaseolus vulgaris* and its wild relatives.

Due to limited facilities for genotyping at the University of Nairobi, the breeding program collaborated with CIAT to obtain some of the genotyping requirements. Stakeholders (farmers, traders, processors, and consumers) are involved at the preliminary yield trials (PYT), advanced yield trials (AYT) and national performance trials (NPT) stages. The involvement of stakeholders enhances adoption of the varieties once they are released. In all, 18 varieties had been released in the program, and 8 of them have been commercialized. Some of the varieties have been adopted in many other countries in East, Central, West, and Southern Africa.

3.3 Bean breeding in Rwanda

Rwanda has a strong bean breeding program which is headed by Mr. Augustine Musoni. The program uses a combination of conventional breeding and molecular techniques. The conventional methods used include the bulk population breeding and pedigree methods. MAS is used to achieve disease resistance. The breeding program uses the BMS program in molecular and biotechnology laboratories in Rwanda, in collaboration with AGEA, Kirk House Trust, CIAT, and the Belgian Technical Services (BTC) for additional genotyping services.

The program has yielded +25 varieties including bush and climbing/snap bean varieties. Some of the varieties have been commercialized. Adoption rates for climbing beans, range between 65% - 90%. The seeds are mostly produced and marketed by informal farmers' organizations, cooperatives, and government projects. To a lesser extent seed companies are also involved. Released varieties have increased the incomes of smallholder farmers.

Bean productivity has doubled in the last 20 years and is twice the mean productivity for sub-Saharan Africa of 0.5 t/ha. Rwanda is now a net exporter of beans despite population increases on limited land. The Rwandan bean breeding program is probably the most successful one for grain legumes/pulses in Africa. The new varieties have been introduced and adopted in many countries in Eastern, Southern, and Central Africa. The program specializes in high yielding climbing beans that have lately incorporated micro-nutrient (iron and zinc) traits.

Figure 11: Climbing bean variety, Pyiramide (ISA SB-10-1) with a local name of Mavuta released by Dr Augustine Musoni

2.4 Finger millet breeding in Kenya

Finger millet, *Eleusine coracana* (L.), 2n = 4x = 36, is a cereal crop which originated from the highlands in East Africa. It is nutritious and contains high levels of methionine, calcium, and iron, and is gluten free. It is an annual crop which comprises a 20–200 cm long stem, glumes, lemmas, stamens, pistil, and a flower which is composed of 2–11 digitate or slightly curved spikes.

India is the world's largest producer of finger millet. In Africa, it is grown in Ethiopia, Kenya, Uganda, Tanzania, Zambia, Zimbabwe, and Namibia. Production is labor intensive, especially during weeding, harvesting, and milling.

Finger millet is a self-pollinating crop with less than 1% outcrossing. The flower opens after pollination (it is cleistogamous — automatic self-pollination of plants that can be propagated by using non-opening self-pollinating flowers). It can be crossed by hot water treatment, a process in which the flower is dipped in water at 52°C for about 4 minutes. This kills the pollen, but the pistil remains viable (causes male sterility), thereby allowing cross pollination if pollinators are available.

Another crossing method is the plastic bag technique in which a plastic bag is used to cover the inflorescence before self-pollination takes place. Wet cotton wool is tied at the bottom of the bag to keep it moist. This prevents the anthers from shedding pollen grains as they clump together inside the bag without opening. The clumped anthers can be shaken off and the stigmas pollinated by rubbing them with the anthers of a flower that is shedding pollen. This makes it possible to manipulate the crossing process within the 20 minutes that the pollen remains viable and the 5 hours that the stigma remains receptive.

Cross pollination can also be achieved by using gametocides to induce male sterility. A solution of a chemical called ethrel has been used effectively as a gametocide. This chemical produce ethylene which causes the male sterility. This can be described as chemical emasculation of the flower.

Dr. Oduori, a breeder in Kenya, has successfully combined the plastic bag technique and gametocides in his hybridization program. He advances the segregating materials by use of a modified bulk method of breeding. He applies selection in early generations then allows the materials to become homozygous at about F5 or F6 stage. He then plants a row from a plant (plant-to-row) in plots and begins to select lines with desirable attributes. A row from a single plant is considered as a line. Desirable lines are then included into preliminary variety trials (PVT). Selected lines from PVT are included in intermediate variety trials (IVT) and then advanced variety trials (AVT). After the AVT the selected few varieties are recommended for release.

The PVT is conducted in a few sites but includes many entries, for instance, 500 entries. This is not replicated. The IVT includes fewer entries of about 25 but is done at more sites than the PVT (4 sites in larger plots of about 4 rows) and replicated 2 or 3 times. The AVT includes between 5 and 10 entries, in at least 5 sites and replicated 3 times. During the PVT, IVT, and AVT standard check varieties are included for comparison. Check varieties are chosen from the current high yielding varieties already released and widely grown by farmers. Dr. Oduori invites farmers and other stakeholders during the PVT, IVT, and AVT evaluations. This helps in increasing adoption since released varieties will incorporate inputs from the stakeholders.

Figure 12: Dr Oduori hand-emasculating finger millet. Natural and chemically induced male sterility

Dr. Oduori's program had released five varieties and two more had been recommended for release at the time of the study. These have been widely adopted. The impact on farmers has been high, especially in western Kenya where 36.2% adoption has been recorded and 64.3% of the farmers grow Mardadi, one of the varieties from the program. Income from sales has increased by about 20%. "This is a program that has uplifted the almost forgotten finger millet to the limelight in agriculture and consumption in Kenya," concludes Dr. Oduori.

3.5 Sorghum breeding in Mozambique

Sorghum is the fifth most important cereal crop in the world after wheat, rice, maize, and barley. Nutritionally, it contains high levels of antioxidants and minerals and is gluten free. It belongs to the family Poaceae or Graminae (Grass family); genus, *Sorghum*, and species *bicolor*, with 2n = 2x = 20 chromosomes. It has a C4 photosynthetic pathway.

Sorghum originated from north eastern Africa (Ethiopia and Sudan). Currently, it is grown throughout Africa, the Americas, Europe, Australia, and Asia. It is widely adapted and requires less water than maize, making it an ideal crop in the semi-arid regions. In Mozambique, it is mostly grown by smallholder farmers but makes an important contribution to the country's GDP. In 2014 the production was about 160,000 tons with an average yield of over 500 kg/ha (FAOSTAT, 2015).

Figure 13: Mature sorghum panicles and a breeder with one of his sorghum varieties, Otela

The sorghum plant contains a determinate panicle which can be compact or loose. The shape and color of the panicle varies from variety to variety. Each panicle contains 800–3,000 seeds which are partly covered by the glumes. Sorghum is self-pollinated but cross-pollination of up to 15% can occur in certain environments. The flower opens (anthesis) at night or early in the morning starting from the top to the bottom.

The plastic bag technique is the most commonly used technique in sorghum crossing. The discovery of Cytoplasmic-genetic male sterility system (CMS) in combination with the restorer genes has made large-scale hybridization of sorghum possible. CMS is a condition in which individuals with a certain type of cytoplasm do not produce viable pollen. Such individuals do not also have the restorer genes, usually found in the nucleus of the cell, which would make them fertile. In the CMS system used, the male sterile parent is maintained by a genotype which has normal cytoplasm for fertile pollen production but does not carry the restorer genes. The maintainer is isogenic to the male sterile line except for the differences in the cytoplasm. The CMS line is normally called the A line; the maintainer is called the B line; and the restorer is called the R line. In a breeding program, the A line is maintained by continually crossing it with the B line; the B and R lines are maintained by selfing; and the hybrid is generated by crossing the A line to the R line.

Mr. Joaquim Americo Mutaliano, a breeder in Mozambique, uses the backcross method to develop male sterile lines (A lines). He crosses a line carrying the male sterile cytoplasm (female donor parent) to a desirable line with normal fertile cytoplasm (recipient) with no restorer gene. The F1 is male sterile because it gets its cytoplasm from the female CMS line. The male sterile F1 is crossed to the desirable line with normal cytoplasm to generate a male sterile backcross 1 (BC1) generation. The BC1 is again crossed to the male fertile parent and the process is continued until BC8 or 9.

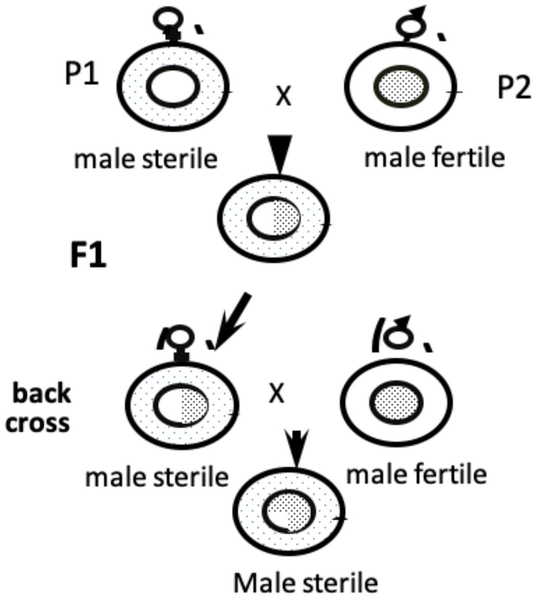


Figure 14: Transfer of cytoplasmic male sterility from a donor (P_1) parent to a recipient genotype (P_2)

At this stage of backcrossing (8th to 9th BC) the genotype of the male fertile parent has been transferred into a male sterile cytoplasm. This is a new A line (male sterile) and the original male fertile line (male parent) becomes the new B line to the A line. The new A line can be crossed to a chosen R line to generate a sorghum hybrid. Mr. Mutaliano has also used the pedigree method of breeding to develop eight varieties which have been released; all of them are OPVs. He is about to release new sorghum hybrids generated using male sterile A lines crossed to restorer R lines.

3.6 Cassava breeding in Tanzania

Cassava is an herbaceous plant in the Euphorbiaceae family, grown for its edible starchy roots. It originated from South America and is now grown in tropical and subtropical areas worldwide. Cassava was first domesticated in 5000 to 7000 BC (Lathrap, 1970) and introduced into Africa in the 16th century (Hershey, 1993). Tanzania is the fourth largest producer of cassava in Africa with an annual production of 5 million tons at a yield of 8 t/ha (FAOSTAT, 2014).

The cassava plant is highly heterozygous making it difficult to identify parents with good breeding values. The flower is complete with both male and female parts. Cassava is propagated vegetatively through cuttings. This makes it possible to indefinitely perpetuate a good variety without changing its genetic make-up.

During hybridization, crosses can be made between selected parents leading to the generation of progenies (families) that are different from each other. Seeds generated after crossing are then germinated to produce seedlings. The seeds can take up to 8 weeks to germinate. Each seedling needs to be bulked to generate enough plants to conduct evaluation trials.

Dr. Kiddo Mtunda, a cassava breeder in Tanzania, uses an innovative bulking method to generate several plants from a seedling. She does this by making two-node cuttings of the seedlings at 6 weeks then plants them in pots in a screen house. This allows her to generate three to four more plants of the same seedling. In this way she can multiply the genotype much quicker than normal. This is important because one of the major problems in cassava breeding is the generation of adequate planting materials quickly to have enough plants for evaluation. This technique can also be used on cassava plants from the tissue culture facility.

A typical cassava breeding program involves hybridization, followed by germinating the seeds to generate the seedlings. Dr. Mtunda generates up to 18,000 seedlings from which she selects 15% of the entries after 12 months. Selection is based on resistance to Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD). At this stage, the aim is to quickly reduce the number of materials to a manageable number.

The selected materials go into the clonal evaluation stage where a plant generates enough cuttings to plant in a row or plant-to-row evaluation. Data is recorded on yield, disease resistance, root characteristics (bitter or sweet), and shoot weight. Ten percent of the materials are advanced to the preliminary yield trial. At this stage two rows at two sites with replications are planted.

The selected genotypes are included in the advanced variety trials. This can have 15–20 varieties each with 42 plants. The trials are conducted on at least five sites over two years; farmers are introduced to the materials to assist with selection. Culinary tests (involving cooking and tasting of products) are done, followed by NPTs and on-farm trials. In the on-farm trials, the mother and baby trial design is used. Each participating farmer is given a subset of the mother trial and each farmer is used as a replication. When the variety is released it is cleaned of viruses through tissue culture. Figure 15 shows Dr Mtunda holding a seedling that is ready for generating more plants through two node cuttings.

Figure 15: Dr Mtuda holding cassava cuttings

Figure 16: Chereko variety released by Dr Mtunda — with high dry matter content of 27–32%, matures in 9–12 months, and is resistant to CMD and CBSD.

3.7 Wheat breeding in Zimbabwe

3.7.1 Background

The national wheat breeding program was started in 1954 at Harare Research Station. Priority was given to the development of improved bread wheat cultivars suitable for Highveld (above 1500 masl) and Middleveld (1100–1499 masl) areas. Exotic germplasm was evaluated for its adaptability for production under local winter conditions using irrigation. The material was found suitable and several irrigated wheat varieties were released over the years.

Collaborative effort was made after independence (mid-1980s to early 1990s) by the Crop Breeding Institute (CBI) and the Agronomy Research Institute to develop wheat varieties which were suitable for rainfed conditions, since wheat is also grown by small-scale farmers under vleis (wetlands) during summer. Summer wheat research was discontinued after the realization that it was not economical to grow the crop in summer. The yield was low (about 50% less than winter yields). The production costs were considerably higher in summer than in winter because of high input costs (for instance high fertilizer costs and high weed pressure) and high disease pressure. Summer wheat could not compete with alternative summer crops, such as soybean and tobacco, which were high paying. In addition, wheat grown in summer had poor grain quality.

However, CBI resuscitated the rainfed wheat breeding program with the long-term objective of complementing wheat stocks produced during winter. The summer wheat breeding program was resuscitated in 2013 through support from the Support to Agricultural Research for Development of Strategic Crops (SARD-SC) wheat project funded by the African Development Bank. The project was implemented by Department of Research and Specialist Service (DR&SS) through the International Centre for Agricultural Research in the Dry Areas (ICARDA) as the implementing agency internationally.

3.7.2 Wheat Breeding Objectives

High yield potential and quality

The main objective is to develop improved bread wheat cultivars with a good combination of high grain yield potential and quality suitable for production under irrigation during winter conditions (May to October) in all areas of the country. This is done in order to ensure that tonnage (as required by the farmer); high flour output (as required by the miller); and good quality bread (as required by both the baker and consumer) are satisfied. The yield potentials expected from a wheat variety in Zimbabwe are 8–10 t/ha in the Highveld, 6–8 t/ha in the Middleveld and 4–5 t/ha in the Lowveld. Wheat varieties with capacities to sustain high yield potential over a broad range of growing environments are the most preferred. They are selected after conducting Genotype by Environment (G×E) evaluations of genotypes in yield trials to identify those with yield stability to fulfill the breeding objectives. The discovery and use of dwarfing genes dramatically increased yield potential in wheat.

Quality

Market, baking, and milling qualities: These are as specified in the Grain Marketing Board (GMB) wheat intake standards and prescribed by the milling companies (National Foods, Blue Ribbon, and Victoria Foods). The minimum requirements for the various quality characteristics are:

- **High grain protein content (>11%)**; Protein determination is done by milling companies such as Blue Ribbon Foods, Cairns Foods, National Foods, etc.
- **High Falling number (>230 seconds)**; Indicates the soundness of the grain based on measuring the activity of alpha-amylase enzyme in the grain. It indicates whether the grain has sprouted or not. Sprouted grains have low falling numbers and usually the grain is not fit for human consumption.
- **High test density (>75 kg/hl) and plump grain**; Test density is the mass of wheat per unit volume and is measured in kilograms per hectoliter. It gives a rough estimate of the amount of flour that can be obtained. Unripe grains or shriveled grains as a result of drought (water stress) or diseases are usually low in test density and accordingly give low flour yields.

- **High sedimentation value (relative to the best quality check variety);** This test gives an indication on the baking and milling quality potential of a line. Together with test density it is used to select good quality F6 progenies for further evaluation in replicated trials. Selection is based on line performance compared to the best quality check (e.g., Kana).

Other important characteristics required by milling companies:

- high loaf volume
- long mixing time
- high flour protein (>11%)
- high water absorption capacity (70%)

Resistance to major diseases

There are four diseases of economic importance that affect wheat worldwide but the most prevalent one in Zimbabwe is leaf rust. This is followed by stem rust. However, stem rust is not common every season unlike leaf rust but is more devastating to wheat production.

a) Stripe/Yellow rust — caused by the fungus, *Puccinia striiformis*. It is easily distinguished from other wheat rusts by the orange-yellow spores, which produce small, closely packed pustules developing into stripes along the length of the leaf.

b) Leaf/brown rusts — Leaf rust is caused by the fungus *Puccinia triticinia* (previously called *Puccinia recondite* f. sp. *tritici*). It affects leaf blades, sheaths (under favorable conditions, high inoculum densities, and extremely susceptible lines). Leaf rust produces reddish orange to reddish brown spores which occur in small, 1.5 mm, oval pustules.

c) Stem/Black/Summer rust — Stem rust is a fungal rust disease caused by the pathogen *Puccinia graminis tritici* and this disease has been a problem of late in Zimbabwe as most commercial varieties are susceptible to the disease

d) Powdery mildew *(Erysiphe graminis)* — This is another wheat disease of economic importance. The symptoms include white or gray-brown powdery or cottony patches of mycelium (fungal threads) on the upper surface of lower leaves.

Good agronomic characteristics

a) Dwarf cultivars with resilient straw (<95 cm) — Short-statured cultivars have high tillering capacity and also increased grain yield per spike.

b) Early maturity (<135 days in the Highveld).

c) Resistance to sprouting in the ear.

d) Vigorous growth with high tillering capacity

e) Resistance to lodging

Varieties widely adapted to all wheat growing areas

The variety must be adapted to all wheat growing areas showing stability over locations and seasons.

Varieties that can be grown under rain-fed conditions

Identify varieties that can be grown during the rainy season (October–April). These varieties must be high yielding, of good quality, have good agronomic characteristics, and be tolerant of diseases. This objective is particularly for summer wheat evaluations.

Germplasm resource base

The International Center for Maize and Wheat Improvement (CIMMYT) in Mexico is the main source of introduced germplasm through the annual international seed nursery disbursements to international collaborators. Germplasm from this network (CIMMYT) usually comes in as nurseries or yield trials for various biotic and abiotic constraints. Germplasm, which comes in as yield trials, is usually stable (genes would have been fixed) and those in nurseries are segregating populations ranging from F2 to F7 generations. The breeding program also gets its germplasm from ICARDA.

Breeding Procedures and Methodologies

Generation of Genetic Variability

Controlled hybridization is conducted at Harare Research Station outside the glasshouses (in clay pots) during the winter season. The major objective is to have a broad-based crossing program in order to attain large amounts of variability thereby increasing the probability of encountering desirable plants. The primary objective is that of increasing yield potential. The other objective of crosses is to broaden the genetic base of resistance to disease such as rusts, fusarium, and mildew. Recently, much attention has been given to incorporate the objective of wheat quality in wheat crosses. To achieve this proper mating designs are followed. The wheat breeding uses the North Carolina design 2 (NC2). The design consists of male lines which are the source of desired traits and female lines which are usually released varieties or promising lines which need improvement in certain traits. Each male will pollinate all the females included in the crossing program.

Generation Advancement

At CBI, the number of wheat crosses made annually has been increasing and the total number of segregating populations (F_2 to F_6) has been growing. Similarly, the number of yield trials has been increasing. To accommodate this increase in breeding populations, thus a selected bulk selection method is used to evaluate recombinants from F1 to F6. The new method allows the breeder to evaluate all segregating populations, in a timely fashion. It is called selected bulk method because at each level of segregation population, uniform ears are selected in each recombinant by visual assessment to constitute a variety to be planted in the following season as a plot. This is done from F2 up to F4 when the lines are fixed (uniform). Thereafter, whole plot selections are done up to usually F6. This method usually saves on land limitation since it helps to screen large populations as undesirable ones can be discarded even at early stages of development.

Normally at least 12 years are required from line development to release of a variety and ***shuttle breeding*** is utilized so as to reduce the breeding period. The shuttle system takes advantage of favorable climatic conditions (cool) at Nyanga and Gwebi Variety Testing Center during the summer period. The system enables the program to plant two generations per season (one during winter and the next in summer) and reduces the period required for variety development. Planting of generations during summer also exposes lines to high disease pressure thereby creating a conducive natural environment for selecting varieties showing resistance to diseases.

In Table 10 and 11 below are some of the cultivars released in the last 20 yrs and some companies that are selling the seed. Fig 17 to 20b show pictures of various activities in wheat breeding.

Table 6: Cultivars developed by Crop Breeding Institute since 1999

CULTIVAR	YEAR OF RELEASE
Runde	2016
Ncema	2013
Kame	2005
Dande	2002
Shangwa	2001
Insiza	1999
Kana	1999

Table 7: Seed companies marketing CBI commercial varieties

Company Name	Variety
ARDA Seeds	Dande Ncema Kame
Zadzamatura	Dande
National tested seeds	Insiza

Figure 17: Wheat crossing block at Harare Research

Figure 18a and 18b: Characterization of new introduction lines

Figure 19: Harvesting of wheat trials

Figure 20a and 20b: Field monitoring of wheat trials

4 | Selected Breeding Case Studies in West Africa

4.1 Maize breeding in Burkina Faso

Maize is an important crop in Burkina Faso; its cultivation and consumption have continued to grow over the years. For instance, maize cultivation increased to 749,935 ha in 2014 from 276,668 ha in 1988 (FAOSTAT, 2016). The national average yield of maize increased to (1.91 t/ha) in 2014 from 0.81 t/ha in 1988. About 30% of the total land area in Burkina Faso is suitable for maize cultivation. The Maize Breeding Programme in Burkina Faso is based at INERA Fara Kouba near Bobo Diolasse. It is farmer-participatory, with PRA routinely conducted to obtain information on farmers' preferred varieties and traits.

Maize streak virus (MSV), spread by *Cicadulina* leaf hoppers, was a major problem in Burkina Faso in the 1980s. Many International Institute of Tropical Agriculture (IITA) and CIMMYT materials were evaluated in regional trials to assess the yield under MSV prevalence. Following these evaluations, EV8422SR, an open-pollinated variety, and EV8444SR, a streak-resistant open-pollinated variety were released, each with a potential yield of 4.0 t/ha. However, the farmers recorded low yields of less than 1 t/ha during this period. There was further need to improve the yields of EV8422SR and EV8444SR maize varieties through improved adaptability to local conditions.

4.1.1 Breeding methodology

Five hundred (500) plants of EV8422SR were selfed to generate S1 seeds which were sown ear-to-row. *(Puccinia polysora*) and Curvularia Leaf spot resistant/tolerant lines were advanced to S6, with two generations grown per year. Eighteen (18) outstanding S6 lines were recombined to produce SR22 variety, which was released for cultivation in 1989. Similarly, 500 S1 lines were generated from EV8444SR. Using the same criteria, S1 lines were advanced to S6; good performing lines were recombined to produce eEV8444SR, an improved version of the variety.

A total of 30 open-pollinated varieties, including SR 22 and eEV8444SR from diverse sources (including IITA), were crossed to a single cross hybrid tester — M164WxM162 — obtained from South Africa through collaboration with l'Institute de Recherche d'Agronomique Tropical, France. Top crosses were evaluated at six stations in INERA and six partner institutions including the Ministry of Agriculture and the extension services. Varieties SR22 and eEV8422SR showed good performance across locations in crosses to the tester.

SR22 and eEV8422 were crossed in the dry season of 1997/1998 to produce a varietal cross. The cross was evaluated together with other varieties from diverse sources during the rainy season of 1998. The highest yield was obtained from a three-way cross called FBH1 (which was the result of an IITA hybrid with the tester).

However, this material exhibited a long maturity cycle (120 days), which made it undesirable, given the short growing seasons sometimes observed in Burkina Faso. Bondofa (FBH34 SR) was the next highest yielding hybrid. Bondofa (meaning filled barns), a cross between SR22 and eEV8422SR, was released in 2014. It has a maturity cycle of 97 days and yields between 6.5 and 9t/ha. Bondofa was a successful hybrid between two parent varieties, originally released in Burkina Faso.

4.1.2 Release of developed varieties and dissemination

The seeds of Bondofa were first commercially produced in the dry season of 1998 with eEV88444SR as female and SR22 as male. Both varieties flower in 57 days. With eEV88444SR as female, seed producers are able to obtain at least 4 t/ha.

Bondofa is tolerant of drought and resistant to common maize diseases in Burkina Faso. On-farm demonstration of Bondofa continued from 1998 to 2003. Demonstrations involved 250 on-farm trials per year. In farmers' fields, Bondofa was evaluated with eEV8422SR as a check. By 2003, more than 95% of farmers preferred Bondofa over EV8422SR. The highest yield obtained by farmers in these trials was 7.43 t/ha. Farmers who save and use their harvests as seeds for the next season are still able to obtain a grain yield of not less than 4 t/ha.

In 2010, Bondofa gained prominence when at the annual Forum de la Recherche Scientific et de L'Inovvation Technoloque(FRIST) when it won both the first prize of the President's innovation award and the first prize of the innovation award of the Ministry of Agriculture. The promotion of Bondofa gained impetus in 2010 with funding from AGRA.

In addition to Burkina Faso, the variety is currently marketed in Côte d'Ivoire, Mali, Niger, and Democratic Republic of Congo. The success achieved with Bondofa encouraged the Government of Burkina Faso to implement a program called "Operation Bondofa". This was a maize sufficiency program, aimed at solving the hunger problem in the country. Under this initiative, the government purchased Bondofa from seed producers and distributed it to farmers at subsidized prices of CFA1,000 for 20 kg of seed whose actual value is CFA30,000. To ensure maximum yield, the government reduced the cost of fertilizer by half to encourage its use in maize production.

4.1.3 Quest for more improved maize varieties

Stakeholders in the maize value chain saw the need to develop new maize varieties that would complement Bondofa. Based on participatory rural appraisal, the desired traits for the new varieties were early maturity, higher yields, yellow color, suitability both for the manufacture of poultry feed and for human consumption. The use of existing yellow maize varieties in poultry feed required supplementation with lysine and tryptophan, leading to increased cost of production. This necessitated a breeding program to produce high-yielding yellow maize varieties which are early maturing, with high lysine and tryptophan content.

Two varieties were chosen as parents, quality protein maize (QPM), each with a grain yield of at least 6.5 t/ha. These two parents are eEspoir (male) and eWari (female). Development of the new varieties targeted to achieve early maturing, high yielding yellow maize variety with high lysine and tryptophan. The development of eEspoir and eWarri is described in the following paragraphs.

Development of eEspoireEspoir (meaning hope) was derived from Pop 66 SR — a population with a 95–110-day maturity cycle that was developed by CIMMYT/IITA. It was improved for adaptability in Burkina Faso. Five hundred (500) S1 lines were generated from the population and advanced to S7 with two selfing cycles produced per year (dry season and rainy season) during which selected plants were planted ear-to-row. Evaluation was done for drought tolerance important agronomic traits and resistance to local diseases. At S7, 18 lines with good *per se* performance were recombined to produce Espoir which has a maturity cycle of 97 days. Espoir variety was released in Burkina Faso.

Five hundred (500) S1 lines produced from Espoir were crossed to Warri (tester), another variety developed from FBC 6. FBC 6 is an early maturing population which is tolerant to drought, has stay-green characteristics, is tolerant to local diseases and excellent for fresh consumption. The top crosses were evaluated in many locations. Six S1 parental lines of the top crosses with the desired traits were recombined to produce eEspoir, which matures in 95 days.

4.1.4 Development of eWari

eWari was derived from Wari. Like that of Espoir, eWari was develop from Pop 66 SR. 500 S1 lines produced from FBC 6 were advanced to S7 using the ear-to-row method. Lines were selected based on traits such as early maturity, drought tolerance and resistance to diseases. Evaluation was done in several locations. Six S7 lines with the best performance were recombined to produce Wari variety which matures in 88–91days. It was released for cultivation in Burkina Faso.

Five hundred (500) S1 lines were produced from Wari. The lines were crossed to Espoir tester and top crosses evaluated for combining ability in multi-locational trials. The six best top crosses were selected and recombined to produce eWarri. In effect, Espoir was used as tester for Warri to produce eWarri while Wari was used as tester for Espoir to produce eEspoir as required in reciprocal recurrent selection. eWarri matures in 84 days. Following its development eWarri was released as a cultivated variety.

Figure 21: Dr. Jacob Sanou proudly showing off cobs of Komsaya

4.1.5 Release of developed varieties and dissemination

eEspoir (male) and eWarri (female) were crossed to produce Komsaya variety, which was released in 2011. Komsaya is a yellow QPM variety with stay-green qualities, drought tolerance, and resistance to local diseases. It matures in 88–91 days and yields between 8–12 t/ha. Since it is a product of the first cycle of a recurrent selection, farmers are able to save seeds from their harvest to use as planting materials without a considerable reduction in yield. Although Komsaya has been released as the product of the first cycle of a recurrent selection breeding scheme, additional cycles of recurrent selection are ongoing with the objective of developing varieties that are superior to Komsaya.

4.2 Cowpea breeding in Burkina Faso

Cowpea (*Vigna unguiculata*) is an important grain legume in West Africa. It contains 25% protein, making it a good supplement for animal protein. In addition to its food value, cowpea is an important component of farming systems due to its drought resistance and ability to fix nitrogen to the soil thus, reducing fertilizer costs.

In Africa, cowpea is mainly cultivated in Burkina Faso-Sahel, North Sudan, and South Sudan. Cowpea production is affected by several biotic and abiotic constraints. One of the major biotic constraints is susceptibility to the parasitic weed *Striga gesnerioides*. Seeds of *Striga gesneriodes* (and other species of striga), can remain in the soil for up to 20 years without losing viability. They then germinate in response to stimulants (mostly strigolactone) which is present in cowpea (and other host plants).

After germination, striga seedlings produce a specialized structure known as "haustorium" with which it connects to cowpea roots depriving it of carbon and nutrients. The parasitic association of striga with the host crop makes it more difficult to control compared to other pests and diseases. Up to 70% of striga-related damage happens before the parasite emerges from the soil. The magnitude of damage depends on the age of crop at time of infection and presence of other stress factors. Extreme yield losses often ranging from 80–100% have led farmers to abandon striga-infested cowpea farms.

Irrespective of improvements in specific traits, it is imperative that all cowpea varieties in Burkina Faso be resistant to *Striga gesnerioides*. This has become complicated due to the existence of different races of the parasite *Striga generioides* in West Africa. Whereas resistance is controlled by a single dominant gene, eight races of the parasite have been identified. These are: KP and Race 1 in Burkina Faso (SG1); SG3 in Nigeria and Niger; SG4 in Benin; SG4z in Benin; SG5 in Cameroon; SG6 in Senegal; and SG4i found on a legume *Indigofera hirsuta*.

Prior to the commencement of this breeding project, the most widely cultivated cowpea variety in Burkina Faso was KVX396-4-5-2D. The variety is white seeded, averaging 16.0g grain weight but is susceptible to *Striga gesnerioides*.

4.2.1 Breeding objectives

A PRA was undertaken in 2008 and 2009 in the three cowpea growing areas in Burkina Faso. The PRA educated farmers on different topics, including the fact that *Striga gesnerioidesis* is a parasitic weed and not part of the cowpea root system as they earlier believed. In addition, it revealed the traits that cowpea farmers and consumers were looking for as follows:

i. Large grains

ii. White grain color

iii. Rough testa-requires less time and energy to cook

iv. High yield

v. Tolerance to post-maturity field deterioration

vi. Resistance to Striga gesnerioides

vii. Resistance to cowpea aphid-borne mosaic disease

viii. Resistance to brown blotch disease caused by Colletotrichum capsici fungus

ix. Resistance to pests at storage

The breeding's main objective was therefore to develop large grain *Striga gesnerioides*-resistant, cowpea varieties with rough testa.

4.2.2 Breeding methodology

A backcross breeding program was initiated in 2008. The recurrent parent was KVX640, a local line in Burkina Faso. It comprised of white grain color and rough seed coat with a maturity cycle of 70 days. The donor parent (for resistance to *Striga gesnerioides*) was the F_1 between B301 (small seeded, *S. gesnerioides*-resistant) and IT81D-994, a white line with big seeds which has a maturity cycle of 80 days.

The F_1 between the recurrent and donor parents was back crossed to the recurrent parent to produce BC_1.Three additional back crosses were made to produce BC_4F_1 and the resulting plants were taken through two generations of selfing (cowpea is naturally self-pollinating) to produce BC4F3. Backcrossing ensured that the desirable traits of the recurrent parents were recovered in the progenies.

At every stage of the breeding process, selection was carried out among 64–120 individuals for plants with resistance to *Striga gesnerioides*. The plants were infested with seeds of *Striga gesnerioides* using striga seed-sand mixture at a rate that ensured at least 1,000 germinable seeds per pot. Infested pots were conditioned for one week before sowing cowpea seeds.

Plants free of striga in the infested pots indicated resistance and were selected. Three to four generations were grown per year. Materials selected at the BC4F3 were evaluated in Preliminary Yield Trials in 2010 in naturally infested farmers' fields in 8 locations in the three cowpea-growing zones in Burkina Faso. Advanced yield trials continued in 2011 alongside on-farm trials. The lines were assessed independently by both breeders and farmers. Using artificial epiphytotics, trials were also conducted for resistance to diseases such as cowpea aphid borne mosaic virus and brown blotch diseases.

4.2.3 Release of developed varieties and dissemination

Dr. J.B. Tignegre released four varieties that were all resistant to Striga race 1 and are commercialized and sold by Nafaso seed company among others. The varieties released are shown in Table 8 below

Table 8: Cowpea varieties released from this breeding program

Name of variety	Characteristics	Important traits	Days to maturity	Yield (t/ha)
Tiligre (KVX 775-33-2G)	Large-sized, white-colored grain with rough grain texture	Striga race 1 — resistant varieties, white color grain, with wrinkled texture, hilum color brown,	60	2
Kom-Calle (KVX 442-3-25 SH)	Large-sized, white-colored grain with rough grain texture	Striga race 1 — resistant varieties, white color grain, with wrinkled texture, hilum color black	70	1.8
Gourgou(TZ1 GOURGOU)	Large-sized, white-colored grain with rough grain texture	Striga race 1 — resistant varieties, white color grain, with wrinkled texture, hilum color black	67	2
Nafi (KVX 771-10G)	Large-sized, white-colored grain with rough grain texture	Striga race 1 — resistant varieties, white color grain, with wrinkled texture, hilum color black	75 days	2

A new simple storage technique that eliminates pest infestation was developed through the collaborative effort of INERA and Purdue University. This involves keeping cowpea grains in hermetically sealed polythene bags before transferring into jute bags. Grains are now effectively preserved using this method.

4.3 Sweet potato breeding in Burkina Faso

Sweet potato is an important source of carbohydrate and micronutrients. Until 2006/2007, the crop was neglected in Burkina Faso. The recent years have witnessed an increased production of sweet potatoes. In 2014 its production was relatively higher (area cultivated was 6,427 ha compared to that of yams (6,275 ha) and cassava (3,230 ha), FAO (2014).

Landraces of white-fleshed sweet potatoes were cultivated in Burkina Faso mainly as a cash crop. The variety is low yielding (about 9 t/ha) with low levels of Vitamin A. Orange-fleshed sweet potato (OFSP) is high in beta-carotene. Its cultivation could potentially address Vitamin A deficiency, which is widespread in Burkina Faso.

This prompted the introduction of OFSP from the International Potato Centre (CIP), Nairobi, in 2005. The 15 OFSP varieties introduced were first multiplied on-station to generate adequate planting materials. In 2006 and 2007, the materials were evaluated in four locations in Burkina Faso, namely: Kamboinse, Leo, Fada, and Kombissiri.

Notably, the sweet potato weevil (*Cylas puncticolis*) was a major constraint. The weevils gain access to sweet potato roots through cracks that appear in the soil during drought. The eggs of the sweet potato weevil can remain in the soil for 3 years while continuing to affect subsequent sweet potato crops. Farmers dealt with this by practicing crop rotation with rice and sweet potato. This was also effective in controlling the rice yellow mottle virus (RYMV). They also sprayed pesticides immediately after rainfall as a way of getting weevils out of the soil.

Farmers require high dry matter content in their sweet potato. The OFSP varieties are known to have lower dry matter content (32%) compared to the white flesh varieties which have slightly higher dry matter content of (40–42%). The good performance of the OFSP varieties recorded in 2006 deteriorated in 2007. In addition to being susceptible to virus infection and root rot, the introduced varieties are poorly adapted to the environmental conditions in Burkina Faso.

4.3.1 Breeding objectives

The above-mentioned challenges prompted the breeding of high yielding OFSP varieties which are adapted to local environmental conditions, contain high dry matter, and are resistant to common diseases. The breeding aimed to develop varieties which would continue to serve as a cash crop, provide food, and address high Vitamin A deficiency, especially among children and women in Burkina Faso.

4.3.2 Breeding methodology

A total of 148 accessions of sweet potato (including 35 OFSP accessions) were collected from sweet potato growing regions of Burkina Faso in 2008 and 2009. The accessions were characterized using 30SSR markers and morphological descriptors of sweet potato. Data generated from the characterization reduced the redundancy to 87, among which were 8 OFSP accessions. Results of the evaluation assisted in identifying local sweet potato accessions to use as parents in the breeding program.

Sweet potato is a cross-pollinating, heterozygous hexaploid. Twenty local accessions which flowered in previous evaluations and 15 OFSP were selected for use as parents. Local materials were used as female to exploit possible maternal effects for the important traits. The accessions were established in pots in a crossing block. In addition to natural crosses, controlled crosses were done among all parents in the crossing block. Given the incompatibility among clones, seeds were generated from crosses between five local varieties and three introduced crosses.

Figure 22: Sweetpotato seeds from crossing block in Kamboinse.
Photo Credit: Victor Adetimirin

From the 15 families, 498 seeds were obtained. The seeds were scarified by soaking in 96% H_2SO_4 for 20 minutes. Given that sweet potato is vegetatively propagated, every seed is a potential variety. Some seeds were destroyed by the scarification treatment. Seedlings were observed for performance and reaction to diseases in 2009, providing the first opportunity for selection. In 2010, 271 plants were advanced for observation yield trial (OYT) at three locations, Kamboinse, Fada, and Farakoba.

Cuttings were established for evaluation in three replications in each of these three locations at the rate of five cuttings per replication.

On the basis of yield, dry matter content, flesh color and resistance to diseases, 28 entries (10% of the entries evaluated in the OYT) were advanced for preliminary yield trial (PYT) in three locations in 2011. Using the same criteria, 12 entries were selected and evaluated in advanced yield trials (AYT) in 2012 and 2013 in Kamboinse, Fada, Farakoba, Koupela, Leo, and Orodara in four replications per year. To shorten the duration of the breeding, the AYT was carried out in conjunction with farmers and extension agents. Of the 12 varieties evaluated, 3 with the following characteristics Table 9 were selected for release:

Table 9: Orange flesh sweet potato varieties selected for release

S/N	Pedigree	Yield (t/ha)	Color	DM Cont. (%)	B-carotene (mg/100g of fresh root)	Reaction to SPVD
1	BF 59 X CIP 199062.1-4	20–25	**Flesh**: Deep Orange **Skin**: Yellow	29	8.32	Good resistance to potato virus disease (SPVD)
2	BF 59 X CIP 199062.1-1	15–20	**Flesh**: Orange **Skin**: Pink	27	4.00	Moderate resistance to SPVD
3	BF13 X CIP 199062.1-3	15–20	**Flesh**: Light Orange **Skin**: Light Pink	26	1.76	Moderate resistance to SPVD

A negative correlation was obtained between B-Carotene and dry matter content. As a result, a recurrent selection breeding scheme was implemented to increase both dry matter and B-carotene content.

4.3.3 Release of developed varieties and dissemination

Out of the breeding program, five local accessions were released in 2014. These varieties are:

(i) BF51 (Baglre)

(ii) BF 138 (Nanyounondou-1)

(iii) BF139 (Nanyounondou-2)

(iv) Jewel (Joel) and

(v) (v)Tiebele-2.

The varieties are multiplied and distributed by NAFASO, Hellen Keller International (HKI), Catholic Relief Service (CRS), the Food and Agricultural Organization of the United Nations (FAO), the United States Agency for International Development (USAID) (under the Resilience and Economic Growth in The Sahel – Enhanced Resilience (REGIS-ER) program and the Ministry of Agriculture. After multiplication, seed growers distribute planting materials to root growers using a subsidized voucher system over a 3-year period. HKI purchases planting materials from INERA and distributes to seed growers free of charge.

Fig 23 below are some sweet potato breeding activities

Figure 23: Dr Koussao Some sweet potato breeder in a screen house in Kamboinse-Burkina Faso, with improved sweet potato cultivars and multiplied sweet potato planting materials being packaged for distribution. Photo Credit: Victor Adetimirin

4.3.4 The future of sweet potato

Non-flowering and cross incompatibility are the major challenges faced in sweet potato breeding. The absence of a tissue culture facility in Burkina Faso compels breeders to send materials to Crops Research Institute (CRI), in Kumasi, Ghana for cleaning before they are returned to INERA for multiplication. Research aimed at the development of flowering varieties and the achievement of cross compatibility will lead to the development of improved sweet potato varieties. A tissue culture cleaning facility in INERA will facilitate the multiplication and dissemination of improved varieties.

4.4 Rice breeding in Ghana

Rice is an important food crop in Ghana. The country imports 60% of its rice at a value of US$700 million annually. Farmers mostly grow traditional varieties, such as Asante Mo, whose quality is acceptable to the consumers. However, it is late maturing. Previous rice breeding programs have not adequately produced varieties with the desired qualities. Other rice varieties are Jasmine 85, Japonicas and Nerica, among others. Nerica, for instance, was introduced in Ghana in 1997. Although it is early maturing, consumers consider it to be of low quality. Jasmine 85 was released by Savanna Agricultural Research Institute, Nyankpala, Ghana in 2009. It is susceptible to drought and a number of diseases.

The development of rice varieties with acceptable agronomic characteristics and quality traits preferred by farmers can potentially increase farmers' incomes by 40%. Arising from this, a breeding project was initiated in 2010. The project's objectives were different and unique to each of the rice ecologies. The program aimed to develop farmer and consumer- acceptable high-yielding lowland rice varieties with traits such as high amylose content, and desired appearance with regards to grain length, grain size and shape, taste, aroma and colour (white preferred).

4.4.1 Breeding methodology

Seventy-one lowland varieties from different sources were planted in 2 m × 2 m plots in 2 replications in Nobewam-Ghana. In 2011, a total of 30 varieties were selected and evaluated under irrigation in plots that measured 5m x 2m in three replications. Four of the evaluations were carried out in southern Ghana and one in Northern Ghana. The evaluated traits were the milling property of 'brown rice' (rice weight after husk is removed), "white rice" (rice weight after bran is removed/ polished, and 'head rice' (weight of unbroken rice). The evaluation which involved farmers and scientists obtained yields of 1.42 to 9.42 t/ha for different varieties. IR841, an aromatic variety, obtained a yield of 6.11 t/ha and Jasmine 85 obtained 3.81 t/ha. Fig 23 to 25 below show some of the activities and rice line traits in the breeding program.

Twenty-four varieties were further evaluated during the dry season of 2011 in Nobewam, followed by advanced yield trials in 4 locations in 2012.

Figure 24: Nobewam (5-9-10) and sensory evaluation of 30 varieties in the dry season of 2010.

Figure 25: Evaluation by farmers in 2012 and lodging rice. Photos Credit: P.K. Dartey

Figure 26: Advanced yield trials during rainy season of 2012 in Aframso and IR 841 variety (left) and Jasmine 85 (right). Photo Credit: P.K. Dartey.

4.4.2 Release of developed varieties and dissemination

IR841 performed well. This prompted Premium Foods Limited to engage 12 farmers in Tono-Ghana to plant 17.66 ha under irrigation in the dry season of 2012. The same company also engaged 94 farmers to cultivate 122.56 ha during the rainy season of 2013. These served as on-farm trials. IR841 was released in 2013.

4.5 Groundnut breeding in Ghana

Groundnut is cultivated in all ecological zones in Ghana, with the greatest potential in the Northern region, where it is mostly cultivated. Production is affected by rosette virus, which sometimes leads to total yield loss. As a result, some farmers have abandoned its cultivation. This prompted stakeholders including seed companies, researchers, extension agents and policymakers to request for the breeding of better adapted groundnut varieties in 2000.

The breeding program aimed to develop early maturing, high oil content, rosette-resistant groundnut varieties. To begin with, 40 groundnut varieties from ICRISAT were screened in 2005 in 5 locations for resistance to diseases and pests as well as increased yield. Out of this, four varieties were released in 2005. However, the varieties had a long maturity duration of 120 days, leading to low adoption. Additional materials from ICRISAT were screened between 2007 and 2011. Subsequently, four early varieties were released in 2012. Two of them were for local consumption and production of groundnut paste; one had a high oil content while the fourth was resistant to the rosette virus.

4.5.1 Breeding methodology

Two of the four previously released varieties were used as donor parents to provide genes for resistance to rosette virus. Three landraces (Aprewa, Nkatepa, and Shitaochi), mostly cultivated by the farmers; were used as recurrent parents in a backcrossing breeding scheme. Seven backcrosses were used to introgress rosette virus resistance genes in the landraces. To facilitate the spread of the aphids-transmitted virus, border rows of susceptible varieties were planted one to 2 weeks before planting the backcross progeny. This ensured the aphid availability in the nursery. Plants that were resistant to the rosette virus were selected for backcrossing. This ensured that the desirable characteristics of the recurrent parents were recovered in the progeny. At the 7th backcross generation, aphids were reared in special structures (Fig 27), fed with diseased plant tissues and introduced to progenies of the 7th backcross generation being screened.

Figure 27: Cages for rearing aphids.
Photo Credit: James Yaw Asibuo.

Thereafter, 49 lines were selected and evaluated in Kumasi and 3 other locations. Based on the results, 23 lines were grouped according to maturity periods as follows: early maturity (85–90 days) and medium maturing lines (95–100 days). The two groups were evaluated in four major agro-ecological zones: forest, derived savanna, savanna and coastal savanna. Multi-locational trials were conducted in 2014, 2015, and 2016.

A post-harvest strategy involving the use of a solar dryer was used to dry the harvested groundnuts. This is useful in reducing levels of aflatoxin, a chemical substance that is produced in improperly dried grains. The solar dryer is regulated to dry groundnuts at temperatures not higher than 35°C so as not to destroy the fatty acid content. The developed groundnut lines were screened for oil content, fatty acid, and aflatoxin. Groundnuts contain 80% oleic and linoleic acid; high oleic acid content facilitates better storage and is therefore preferable. Three varieties were released in 2017.

Fig 28 to 30 below highlight the participatory selection of groundnut varieties carried out in the program

Figure 28: Evaluation of varieties in on-farm trials/evaluation of varieties; Farmer displays local and improved groundnut varieties
Photo Credit: James Yaw Asibuo.

Figure 29: Farmers examine improved groundnut variety in Ejura.
Photo Credit: James Yaw Asibuo.

Figure 30: Farmer's field devastated by rosette disease in 2015 at Ejura; improved variety not affected by the disease. Photo Credit: James Yaw Asibuo

Figure 31: Farmers examine improved groundnut variety in Ejura. Photo Credit: James Yaw Asibuo.

4.5.2 Release and dissemination of developed varieties

Groundnut is self-pollinated, making it possible for farmers to save their seeds for planting in the next season without any reduction in yield. As such, seed companies do not produce groundnut seeds for sale to farmers. A strategy to distribute groundnut seeds to farmers involves demonstration of improved varieties. Six willing farmers were trained on seed production in Atebubu-Amatin District. Among other things, the farmers were trained on isolation distance, timely planting and proper post-harvest handling. These farmers produce and sell seeds in small quantities which are affordable to most farmers and profitable to the seed sellers.

A USAID project being implemented by ICRISAT from 2015–2019 targeted the distribution of improved groundnut varieties to 170, 000 households. Three tons of the early maturing and high oil content varieties were distributed to the Ministry of Food and Agriculture, three seed companies and farmer groups. The success of these varieties triggered the interest of seed companies. One of them, Heritage Seeds, requested one ton of Foundation seed in 2016.

4.6 Cassava breeding in Ghana

Cassava is a staple tuber crop that is widely grown in West Africa. It originated from South America in the 18th century. It contributes about 22% of the agricultural GDP and accounts for 30% of daily calorie intake in Ghana. Tubers are used as human food, as livestock feed, and as raw materials in industries.

Cassava is consumed in varying forms in different countries. In Nigeria, it is processed into "garri", flour which is used for baking different confectionaries. In Ghana, it is pounded and consumed as "fufu" — a widely consumed food. A cassava cultivar, TMS 30572 (locally known as Afisiafi — meaning "everywhere") that is mostly suitable for the production of "garri" has since been developed. It is widely distributed and cultivated in Ghana. However, different products require different cassava characteristics. For instance, "fufu" would require a cassava variety that is different from that of "garri". This underscores the need to prioritize consumer/end–user preferences in breeding programs. Cassava is vegetatively propagated, with a low multiplication rate. This allows for selection of desirable traits in breeding programs.

Although CMD-resistant varieties have been developed at the IITA, Kumasi, Ghana, the selection mostly focused on use for 'garri' as opposed to other cassava dishes. The most common cassava landraces that have been cultivated by farmers in Ghana are low-yielding and susceptible to CMD. To address these challenges, a cassava breeding program was initiated in 2008 with the aim of developing high yielding CMD resistant cassava varieties that are consumer-acceptable and suitable for local dishes.

4.6.1 Breeding methodology

Thirty cassava landraces were selected from different ecological zones in Ghana. They were crossed with TME 11, a high yielding CMD resistant variety which was developed by the IITA. The landraces were used as the recurrent parents while the CMD-resistant variety was the donor parent. The following landraces showed resistance to CMD: AW18, Nyamebekyere 273, NK43, AW3, NK26, K25, Dabodabo; Ahwengyankwa, 674, Debor, Degarti, AgricBankye, and NK57.

The resistant progeny was backcrossed to the recurrent parents. Two hundred and twenty-four backcrossed progenies (BC1) were screened with three molecular markers, SSR 28, NS 158 (SSR markers), and RME1 (SCAR marker), all of which are associated with the CMD 2 gene. DNA was extracted from leaves of the 224 BC1 progenies; F1 progeny showed resistance to CMD. The genotypes were screened with the 3 markers; 82% of the genotypes contained at least 1 marker for the CMD 2 gene and 95 progeny that combined the marker for CMD with farmer/consumer-preferred characteristics were selected (Fig 32). These were evaluated during on-farm trials.

Based on the performance in multi-locational, on-farm, and on-station trials in the Forest, Forest-Savanna, and Coastal Savanna zones respectively, the following six genotypes were released in November 2015 (Table 10 and Fig 32)

Figure 32: Plots of 95 cassava clones with CMD markers during on-farm evaluation Photo Credit: Joe Manu-Aduening.

Figure 33: Different cassava varieties. Photo Credit: Joe Manu-Aduening

Table 10: Released Cassava Cultivars

S/N	Cultivar	Name
1	12/019	Duadakpakpa
2	12/0236	Amansanbankye
3	12/0245	AGRA bankye
4	AW3/10/011	Dudjie
5	AW3/10/008	Abrabipa
6	ANKA/10/003	Lamesese

4.6.2 Release of developed varieties and dissemination

Following release, multiplication of the varieties commenced in May 2015. With support from AGRA, two seed producers, JOSMA and OHUMPONG produce and disseminate the varieties. In addition to project funding and training by AGRA, the program has given breeding efforts a boost through the construction of a laboratory which is used for molecular analysis. Through the project, a cassava variety has been discovered with fine starch which is suitable for brewers and or industrial use.

4.7 Maize breeding in Mali

Mali is one of the countries with the highest potential for maize in West and Central Africa. Maize production holds much promise in eradicating poverty and securing the livelihoods of smallholder farmers in Mali. In 1980, production was estimated at 115,747 t/ha with a mean grain yield of 0.9 t/ha (FAOSTAT, 2016). There have been attempts to improve maize varieties with an objective to increase yields. For instance, IITA, Ibadan, Nigeria, organized a three-year Regional Uniformity Variety Trial (RUVT) in 1989, 1990 and 1991. The trial which consisted of 20 entries was done in 4 replications in Sotuba, Longorola, Sougoula, and Farako. The trial identified Suwan-1 SR as suitable for the environmental conditions in Mali.

Subsequently, Suwan-1 was included in the National Elite Variety Trials (NEVT) in 1992. However, this open-pollinated variety displayed poor husk cover which predisposed it to insect and bird damage. This posed a challenge to its release, necessitating an improvement of the variety for this trait. As a result, a breeding program was established with an objective of improving the husk cover of Suwan-1 SR.

4.7.1 Breeding methodology

A population of Suwan-1 SR was grown in1992 in Sotuba. Out of this, 500 plants with good husk cover were selected. The seeds were composited, and a sample was used to grow another large population of Suwan-1 SR. Five hundred plants with good husk cover were selected in a second cycle of mass selection. Seeds of selected plants were again composited, and 10 on-farm trials were carried out in Sikaso, Kouchala, Bourgouni, and Kangab in 1993 and 1994.The trials involved four varieties, including the old and new versions of Suwan-1 SR. Farmers' field days were conducted both on-station and on-farm.

4.7.2 Release and dissemination of developed varieties

Based on the results, Sotubaka (the improved version of Suwan-1 SR with good husk cover) was released in 1995. Sotubaka is open pollinated and is resistant to lodging, streak and other foliar diseases. It produces excellent flour, is good for bread and beer and excellent for the preparation of local dishes and for use in the production of poultry feed and silage. As a result of the new variety, maize production increased from 212,493 tons in 1995 to 1,433,085 tons in 2014. (FAOSTAT, 2016).

Today, Sotubaka is the leading maize variety in Mali. Its production has spread to Togo, Burkina Faso, Sierra Leone, Liberia, Senegal and Congo Brazaville. Its proliferation has been catalyzed by the efforts of AGRA which purchased 50 tons of Sotubaka seeds in 2014 for cultivation in Liberia.

One hundred cooperatives and four seed companies in Mali (Faso kaba, Comptoire 2000, Soprosa, and Nakushi) produce certified Sotubaka seeds. The successes of this variety led to Dr. NTji Coulibaly's recognition and State commendation in 1995 when he received the Presidential Award during Independence Day Celebrations. The first of its kind, the award was in recognition for his efforts in the development and release of Sotubaka.

4.7.3 Quest for yellow hybrids for poultry feeds industry

Although Sotubaka was widely used for flour, bread and in the manufacture of beer, poultry feed and silage, there was a growing need for yellow hybrids which are suited for the growing poultry industry in Mali. Interventions by AGRA hastened the breeding process for the hybrids in 2007. Using hybrids from IITA and CIMMYT hybrids Regional Uniformity Variety Trials (RUVT) were performed in 2009. Subsequently, outstanding yellow and white hybrids were selected for inclusion in the NEVT.

Hybrids, including three-way crosses, were identified for on-farm trials. However, the seed companies that were previously involved in the various stages of the evaluation were not able to produce seeds of the hybrids, given the technicality of hybrid seed production. Consequently, a breeding program was established to produce affordable, top cross hybrids, which is faster to develop in a less complicated seed production process. The breeding objective was to develop high-yielding top cross hybrids adapted to the environmental conditions in Mali.

Figure 34: Dr. N'Tji Coulibaly after receiving a national award.
Photo Credit: Victor Adetimirin

4.7.4 Breeding methodology

Ten yellow parents of hybrids that were identified in the previously conducted RUVT were crossed with Sotubaka in 2012. Sotubaka was used as the female parent while the inbred lines were the male parents. The top crosses were tested in 2013 at three locations; Sikasou, Kebila and Sotuba. On-farm demonstration was carried out in collaboration with L'European Cooperative Pour le Development (EUCORD) and Societe de Production de Semence at each of the three locations. Farmers' Field Days and on-station trials were carried out. Subsequently, the following three top crosses were identified:

1. Sotubaka × CLRCY034 (named Farako). Its yield potential is 7–8 t/ha
2. Sotubaka × CLO2420 (named Filani). Its yield potential is 7–8 t/ha
3. Sotubaka × KU1409 with a yield potential of 8–8.5 t/ha.

Further, on-station and on-farm trials were conducted in the same locations in 2014. Before the releases, verification of the characteristics was done by the Comite National de Semence PourL'Obtention Varietale (CNSOV).

4.7.5 Release and dissemination of developed varieties

The three varieties were released in 2014. Seed companies commenced marketing of Farako and Filani varieties in 2015. Inadequate quantities of foundation seeds of the parental male lines and Sotubaka poses a challenge to the breeding program. However, seed companies, including SOPROSA are interested in the production of seeds of Farako seed.

4.8 Rice breeding in Mali

Rice is an important crop in Mali. After maize and sorghum, rice is the third-most cultivated crop on 700,000 ha across all ecologies. Irrigation accounts for 18% while upland, lowland and deep-water rice accounts for 82%. The upland, lowland and deep-water rice are rainfed.

Rice production is affected by different constraints from one ecology to another. The major constraints for lowland rice include blast, Rice Yellow Mottle Virus (RYMV), African Rice Gall Midge (ARGM) and stem borer. The Institut d'Economie Rurale (IER), in partnership with AfricaRice, and CIRAD (Centre de Cooperation Internationale en Recherche Agronomique pour le Dévelopement) are pursuing breeding for new rice varieties that are resistant to most of these biotic constraints. *Oryza glaberrima,* widely cultivated in northern Mali, is mostly sold in the markets or used for local consumption. The community believes that *O. glaberrima* has good stomach filling abilities, making it ideal for fighting hunger. However, it also faces challenges that necessitates breeding to improve its traits. For instance, its selling price is low (100 CFA) due to its red color; it is susceptible to shattering and is low yielding, often at less than 1 t/ha.

Another wild variety, *O. longistaminata* which is resistant to diseases has displayed undesirable traits. It has high panicle sterility, a trait which results in few grains (18 grains per panicle or less). However, mutation breeding could potentially improve undesirable traits and develop it into a cultivated variety or as a genetic resource in rice improvement programs. Subsequently, breeding programs were initiated to exploit the different desirable traits in the varieties.

4.8.1 Breeding to exploit disease resistance from Oryza longistaminata

A breeding program was initiated in 2005 to exploit disease resistance from the wild variety, *Oryza longistaminata* and develop it into a cultivated variety.

4.8.2 Breeding methodology

Mutation breeding for the improvement of Oryza longistaminata

One hundred-gram seeds of *Oryza longistaminata,* were exposed to gamma rays at 20 kilorads. M1 seeds were planted, to give M1 plants with low survival traits and high levels of sterility. The fertile plants were advanced to M2 in 2006. Five fertile M2, plants were observed (one fertile plant with red grains, and four partially fertile plants, also with red grains). The fully fertile M2 plants were advanced to M3. Crosses were made between the four partially sterile M2 plants and interspecific (*Oryza glaberrima* and *Oryza sativa*) rice varieties. M3 progenies of the crosses were evaluated in 2007.

Figure 35: Oryza longistaminata, original parent of mutants. Photo Credit: Fousseyni Cisse the breeder

M3 progeny from the fully fertile M1 plants displayed uniform grain color - an indication of fixation. Progenies of crosses between the partially fertile M2 plants and the interspecific hybrids displayed segregation, specifically for grain color (red/white), grain shape, grain length, presence of awn, plant height, short maturity period, response to shattering and presence of anthocyanin.

By M4, no variation was observed for the M4 progeny derived from the fully fertile M1 plant. One line was selected at the M4 and compared with selections made from progeny between the crosses in preliminary yield trial in 2008. The selected materials were evaluated in advanced yield trials in 2009, 2010 and 2011. Multi-locational trials were carried out in Sikassou and Mopti (2012 and 2013) as well as Segou (2014 and 2015). The selection derived from the fully fertile M1 mutant plants showed superior performance in all the trials. The root system changed from rhizomatous to fascicular (a trait obtained from *Oryza longistaminata*). The resulting variety was named DKA-M7 and a Distinctive, Uniformity, and Stable (DUS) trial was conducted in Sikassou.

4.8.3 Release and dissemination of developed varieties

DKA-M7 variety was released in 2016. The variety is adapted to lowland, has good grain quality (white grain) and a high yield potential of 7 t/ha. DKA-M7 presents an opportunity for mutation induction in the development of varieties. It is a unique direct contribution of wild relatives into the diversity of cultivated crops.

4.8.4 Breeding to combine filling ability of O. glaberrima with high yield of O. sativa

The second breeding objective of rice in Mali was to develop an upland drought-tolerant variety that combines the good filling ability of *Oryza glaberrima* with the high yielding trait of *Oryza sativa*. To achieve this, a breeding program was initiated in 2002.

4.8.5 Methodology

One hundred and sixty accessions of *Oryza glaberrima,* were collected from northern Mali. The accessions were screened for drought tolerance, in 2003 at Longorola station. After 45 days, the planted seeds were subjected to moisture stress for 30 days. After that, the plants were irrigated until maturity. Data was collected on plant recovery, plant height, tillering ability and days to maturity.

Figure 36: Grain and root systems of *Oryza Longistaminata* and mutants. Photo Credit: Fousseyni Cisse.

Figure 37: Panicles of *Oryza longistaminata* (left) and mutants (right). Photo Credit: Fousseyni Cisse.

Three *Oryza glaberrima* accessions (RAM3, RAM55 and RAM120), which showed tolerance to drought were crossed with elite upland varieties: NERICA 4 and WAB 181-18, mutants of *O. glaberrima* (SIK353-A10, SIK350-A150), and *O. sativa* varieties (Gambiaka Kokum, Kogoni 91-1, BG90-2). The F1 resulting from the sterile crosses,were back crossed one to four times, depending on the compatibility of the parents to the recurrent parents (*O. sativa* mutants and NERICA 4) to improve their fertility. Fertile plants were advanced. Plants with desirable characteristics in segregating generations were selected in each generation until fixed lines were obtained in BC4F7. Backcrossing and development of fixed lines was done by growing two generations per year.

A preliminary yield trial was conducted for 43 lines under upland conditions and 36 lines under rainfed lowland conditions in 2007. This was replicated thrice. In 2008 and 2009, a total of 15 of the promising lines were evaluated in advanced yield trials. On-farm multi-locational trials were carried out in 2010 in 21 locations in Sikasso. Each trial consisted of four of the selected lines and one check variety, totaling five entries. The Distinctive, Uniformity and Stable (DUS) trial was conducted in 2011, on DKA-P16, DKA-P17, DKA-P27 for upland ecology, and DKA1 and DKA11 for rainfed lowland ecology.

4.8.6 Release and dissemination of developed varieties

DKA 1, DKA 11, DKA-P17 and DKA-P27 were released in 2011. DKA-P27 is white grain, early maturing (three months), tolerant to blast and drought. It is superior to Nerica 4 and yields 4 t/ha. The breeder and foundation seeds of these varieties are produced by IER while certified seeds are produced by Faso Kaba, SOPROSA, and other seed companies.

Figure 38: ML6-1-1 (DKA-M11) under shallow depth conditions in Longorola station. Photo Credit: Fousseyni Cisse

4.8.7 Breeding for disease-resistant rice varieties

Another breeding program was initiated with the objective of developing rice cultivars which are resistant to diseases including blast, RYMV, ARGM and stem borer.

4.8.8 Breeding methodology

One hundred and fifty varieties from several partnering institutions were evaluated in Longorola (lowland) between 1990 and 1993, and 20% of the varieties were evaluated in preliminary yield trials in 1994. The varieties were further evaluated in advanced yield trials in 1995 and 1996. The four best varieties were selected and evaluated between 1997 and 1999, under rain-fed lowland ecology, using SIK350-A150 variety as a check.

The varieties were further evaluated in 2000 and 2001, in multi-locational trials under shallow water conditions in Segou and Mopti regions. Although slightly susceptible to rice yellow mottle virus, Shwetasoké variety was selected for release because it is high yielding at 5t/ha, has a heavy panicle and is tolerant to submergence.

4.8.9 Release and dissemination of developed varieties

Shwetasoké was released in 2002. It is the best performing variety in lowland areas, and the first variety to be released for shallow water conditions of Segou and Mopti. Breeder and foundation seeds are produced by IER, Service Semencier National (SSN) and SOPROSA.

4.9 Sorghum breeding in Mali

Sorghum is a basic staple food in Mali. It is consumed as porridge and in many other forms. Mali is one of the major producers of sorghum in West and Central Africa with an average grain yield of 1.056 kg/ha (FAO, 2014). It is grown in three agro-ecological zones, Sahel, Sudan, and Northern Guinea.

Open-pollinated local varieties are mostly cultivated for subsistence use. The smallholder farmers also engage in low scale intra-rural grain marketing. They use income from sorghum sales to purchase food and other consumables. However, sorghum yields are usually low. Previous attempts to introduce hybrids from India failed because they were not adapted to the climatic conditions in Mali. The materials flowered early, were susceptible to downy mildew and were insensitive to photo period. Photo period sensitivity is an important trait which ensures that flowering occurs only towards the end of the rains. This enables heads to mature in dry conditions, reducing the incidence of molds.

The use of low-yield cultivars, drought, low soil fertility, insects (head bug) and diseases (molds) are some of the constraints that lead to low sorghum yields in Mali. Head bugs and molds adversely affect grain quality, sometimes rendering it unfit for human consumption.

The predominant sorghum variety in Mali is the Guinea-race sorghum, which originated from West Africa. It possesses several adaptive traits that it suitable to the ecological situations in Mali.

Although the variety shows excellent yield stability, it gives limited yield. As a result, increasing productivity of the Guinea-race sorghums is a key priority of farmers. The development of these hybrids can potentially increase the productivity of sorghum while retaining the desirable adaptive characteristics.

4.9.1 Breeding objectives

AGRA funded the initiation of a research program in 2007 to establish the development of commercially viable, farmer-preferred, Guinea-inter racial sorghum hybrids for West Africa. The breeding objectives and methodology were varied based on the specific trait being explored.

4.9.2 Breeding to achieve improved sorghum varieties

Guinea genetic materials were obtained from diverse sources between 2000 and 2004. The materials were crossed to an A1 source of cytoplasmic male-sterility. To develop Guinea male-sterile lines, back crossing was done using A/B pairs backcrossing and artificial control of the day length. Thus, the first female parents (A-lines) of inter-racial, dwarf-Guinea genetic background were developed. Three of them (97-SB-F5DT-150A, 97-SB-F5DT-154A and 97-SB-F5DT-160A) showed sterility. Thereafter, 97-SB-F5DT-150A was used as a female parent.

Male-parents with good pollen production and restoration ability were identified based on pollen shedding traits (abundance, timing and panicle architecture) and fertility restoration. More than 10 inter-racial (Guinea x Caudatum-race) sterile parents (A lines) with complete sterility and diverse plant height, maturity, grain quality, and panicle length, were developed.

The Guinea × Caudatum male-sterile A/B pairs were used to produce the first experimental hybrids in 2004 and 2005. More than 200 hybrids were developed and evaluated in Sotuba, Samanko, Cinzana, and Kita, in 2006 in a preliminary yield trial in two replications. The best 50 hybrids were selected and evaluated in Advanced Yield Trial (AYT) on station in Sotuba, Cinzana, Kolombada, and Sikasso; and on-farms in Kafara, Ouelessegougou, and Marako, in 2007 and 2008. Three to four replications of AYT were done (depending on the quantity of seeds available). Eighteen (18) hybrids out yielded the local variety check by 4 to 60%. On-farm tests involving the four best hybrids were conducted, after which Sewa, Sigui-Kumbe, and Fadda were identified as potential hybrids.

4.9.3 Release and dissemination of developed varieties

Sewa, Sigui-Kumbe and Fadda were released in 2008. Sewa is the highest yielding variety with 4.0t/ha. It attains a height of 2.0 m and matures in 125 days. Due to its high stover quality, it is used both for human consumption and in livestock feed. Hybrid seed production and dissemination of the released hybrids began in 2009 by NakoSi and Comptoir 2000 seed companies, and by farmer seed producer associations (ULPC, USCPMD, Cooprosem) and NGOs (EUCORD, AEDMD). In 2013, 24 tons of certified hybrid seeds were produced, with Sewa accounting for more than 70%.

Different partners including: Malimark, EUCORD, ULPC, Cooprosem, USCPMD, Faso Kaba, Comptoir 2000, Nahkosi, Amassa, CMDT, DRA, and rural radio and TV stations used both traditional and novel communication techniques to create awareness on the benefits of the newly developed hybrids. Some of the techniques included field, on-station and on-farm demonstrations, inter-village visits, radio programs, and farmer organization meetings.

Figure 39: A field of Sewa. Photo Credit: Abocar Oumar Toure.

4.9.4 Breeding to develop millet hybrids

Hybrids are generally higher yielding than open-pollinated varieties because they are the best materials for the exploitation of heterosis. To develop hybrids from local materials, a breeding program was carried out using the following steps:

(i) Development of dwarf varieties was done by introgression of genes for dwarfness. Dwarf genotypes are more suitable for use as female parents in a hybrid breeding program because hybrid seeds are more easily produced in seed production fields with taller male parents.

(ii) Introgression of photoperiod-sensitivity traits was done to adapted dwarf populations.

(iii) The dwarf photoperiod-sensitive female parents were converted to male-sterile. This is an effective method of emasculation.

(iv) Fertility restorer populations/lines were developed to show heterosis with the female.

4.9.5 Breeding to develop high-yielding disease resistant millet varieties

The program's main objective was to develop high-yielding, dual purpose photoperiod sensitive, millet varieties with resistance to diseases (downy mildew) and bird damage.

4.9.6 Methodology

The program tapped the desirable traits in Civarex 06-05, a variety that was previously converted to dwarf. Pedigree breeding method was used to cross CIVAREX-90-1 and aneco type millet with bristles, following six generations of selfing. Civarex 06-05 is photo period sensitive, high tillering, tolerant to stem borer and resistant to downy mildew.

Back crossing was done to convert Civarex-06-05 to male-sterile (A). Male sterile LCICMA7 was used as female while CIVAREX 06-05 was used as male recurrent parent. After three backcrosses, 50 millet varieties from Mali, Niger, Burkina Faso, and Nigeria were crossed (male) to the male-sterile version of CIVAREX 06-05 (female). The test crosses were evaluated to identify genotypes which show heterosis with CIVAREXA406-05 (carrying the LCICMA7 cytoplasm). Thirty plants were used as female for each cross while the pollen of 30 plants were used to represent the male parent.

Evaluation of the testcrosses was done in 2010 in Sudan and Sahel agro-ecological zones. Data was collected on plant height, days to flowering, reaction to downy mildew, panicle length and circumference, yield, and panicle seed set. Panicles were examined and classified based on seed set (full, partially full or without grains). Nine male parents with superior combining ability with CIVAREX 06-05 were identified in LCICMA7 cytoplasm as follows: Toroniou C1, Sanioba 03, Boboni and Maiwa from Nigeria; HKP, Niosinio, Benkadinio, Synthetique 00-06 and Synthétique04-03 from Niger.

Plants of the BC3 were crossed to Civarex 06-05 to generate BC4 in 2010. At BC4, the selected population were crossed to the identified nine of the male parents that showed good combining ability at the BC3 and 13 others. In 2011, evaluation of the 22 testcrosses were done in the same 2 locations as with the testcrosses for the BC3. BC4 plants were crossed to Civarex 06-05 to obtain the BC5 generation. Testcross seeds were produced by crossing the BC5 generation to the nine testers (male), and testcrosses evaluated in 2012, also at the two locations as with BC4 and BC5 generations. The 3-year testcrosses evaluation provided information on performance in multiple environments.

Nine on-farm trials were carried out in 2012 and 2013. On-farm evaluations were done for five top crosses and a local variety was used as a check. To promote the varieties, demonstration trials were conducted at the rate of up to 50 trials per year from 2012 to 2014 in three locations. The original Civarex 06-05 population was used as the maintainer variety (B). Plantings were done twice a year; during the dry season and rainy season.

4.9.7 Breeding to develop the restorer version of Torioniou

Some open-pollinated varieties possess the ability to restore fertility. Toroniou variety was studied from 2013 to 2015 in a study aimed at identifying individuals that carry genes for fertility restoration. Three hundred and fifty-five plants of Torionìou were crossed to male-sterile dwarf plants of Civarex 06-05.

The 355 Torioniou plants were then selfed to generate seeds of 355 S1 families. All the 355 F1 crosses (between Civarex 06-05 and Torioniou) were evaluated for pollen shed (an indication of fertility restoration). Seeds of 20 S1 families of the male parents (Toroniou) that restored fertility of F1 plants were bulked and grown in isolation to create Toroniou-R (Restorer).

4.9.8 Release and dissemination of developed varieties

Toroniou Hybrid Top Cross (HTC) was released in 2015. It is high yielding (3.5 t/ha). Although farmers are willing to purchase the seeds of Toroniou HTC, they are unavailable. This is because seed production remains a challenge; There is no good synchronization of flowering of the male sterile, maintainer and restorer populations. This results in low seed set which is not viable for commercial production by seed companies. Consequently, there are attempts to improve the flowering synchronization of these populations.

4.9.9 Breeding to improve flowering synchronization of Toroniou Hybrid

Ten plants each of the A, B, and R populations were selfed, and the S1 seeds from each population bulked. The synchrony of the A B, and R populations were assessed for effectiveness in 2016.

4.10 Sorghum and Millet breeding in Niger

Niger has very few PhD plant breeders generating improved varieties of the crops adapted for the country. New varieties of pearl millet and legumes have been identified that give farmers advantages in terms of yield, crop yield stability, resistance to major pests and diseases, and grain micro-nutrient density (ICRISAT Seed Systems in Niger). The quantities of seed produced are still very low when compared to the quantities required to sow at least 25% of the country's cropped areas with improved variety seeds. More widespread adoption by pearl millet and legume producers requires a focused effort on outreach accompanied by dynamic breeding programs to achieve the measurable gains in food security that are urgently required.

4.10.1 Sorghum breeding

Sorghum is the second most important staple food in Niger, after pearl millet. It is largely cultivated for subsistence use. Although the landraces are adapted to local conditions, they are low yielding. Generally, Niger has recorded a decline in sorghum production. For instance, production reduced from 0.6 t/ha in 1961 to 0.39 t/ha in 2010. This can be attributed to poor soils, poor varieties, low use of inputs (fertilizers) diseases (grain mold. *Gibberellathapsia*; long smut, *Ustilagotritici*; and anthracnose, *Colletotrichum* spp.), pests (*Striga hermonthica),* and insects (sorghum midge, *Contariniasorghicola*; and head bugs, *Eurystylusoldi*).

Although there are improved local varieties, the yields are often less than half the yields of experimental hybrids on-station. There have been efforts to develop better yielding hybrids, NAD-1 in 1999 and more recently F1-223 which has better grain quality. Breeding has relied on the use of exotic male-sterile female parents, which are susceptible to pests and diseases. Therefore, there is need to develop male-sterile female parents (to facilitate hybridization) from adapted landraces. This is to ensure adaptation to changing rain patterns, resistance to drought as well as pests and diseases.

4.10.2 Breeding to develop improved sorghum varieties

A breeding program was initiated with the objective of developing high-yielding, early maturing sorghum hybrids from locally adapted landraces.

4.10.3 Methodology

Crossing was done in 2008 and 2009, for 200 sorghum accessions of four A lines, N223 (from Nebraska), ATX623 (from Texas), M150 and M23 (both from Mali). The crosses were evaluated in 2009 and 2010, in three locations with different rainfall amounts, Maradi and Koni (500 mm) and Gaya (800 mm). The seeds of 225 high performing hybrids were multiplied in 2011. Evaluation was done in 2011 in Maradi after which the best varieties were selected.

Seeds of selected 51 crosses were produced and evaluated on-station at Maradi and Bengou during the rainy season of 2013. Eleven hybrids were selected, and their seeds produced in the dry season of 2014. The hybrids were evaluated on-station in Doso, Dogondouchi, Maradi and Kolo. They were also evaluated on-farm in eight villages - Madaoua, Soumarana, Danja, Hadamna, Galami, Dogueraoua, Kassama and Falki. Two best performing hybrids were selected. The two hybrids have a yield of 3–4 t/ha, are of medium height, have long panicle and good grain quality and a short maturity period of 80–85 days.

The parents of the 11 hybrids were evaluated for synchronization of flowering in 2014 at Maradi. Those which showed flowering synchrony were further evaluated for synchrony in 2015. This is important as it enhanced the success of hybrid seed production by seed companies. Two hybrid parent combinations, AN223A × 90SN1 and AN223A × Sepon 82 (also the parents of the selected varieties) showed synchronized flowering. Seeds of the two hybrids were produced during the dry season of 2015 and 2016. The seeds were used for multi-locational on-station and on-farm trials in 2016.The hybrids were characterized in Distinctive, Uniformity and Stable (DUS) trials in 2017 and submitted to the National Varietal Release Committee, for release.

4.10.4 Millet breeding in Niger

Pearl millet is the major staple crop in Niger. Millet grains are high in protein (11%) and lysine. Millet is adaptable to dry conditions which are predominant in the country. Annual rainfall in Niger can be classified into three, regions receiving 600–800 mm per annum, 300–600 mm and less than 300 mm.

The most widely cultivated millet varieties in Niger are: HKB — an improved variety developed from a landrace, and ZATIB — a population cross released in 1996. Despite its nutrition and economic potential for the country, Niger has the lowest millet yield in the world. Its production is 400–500 kg/ha against a potential yield of 2 t/ha.

Cultivation of early maturing varieties presents opportunities for smallholder farmers to escape the accumulation of phytate-associated with late maturity; and end-of-season drought experienced in northern Niger.

A PRA conducted in 2009 identified traits that farmers desire from the millet varieties. These include long heads, resistance to diseases (downy mildew and striga), big-size grains of white to yellow color and high yield. Farmers in the drier northern Niger prefer short panicle (farmers believe that millet varieties with long panicles require more rainfall), good tillering ability — good to withstand storm, resistance to lodging, drought tolerance, big size grains of white to yellow color, and high yield. The development of high yield hybrids holds potential for increasing millet yield in Niger.

4.10.5 Breeding to develop adapted high-yielding disease resistant hybrids

To achieve this, a breeding program was initiated to develop adapted high-yielding millet hybrids with farmer-acceptable traits and resistance to downy mildew.

4.10.6 Methodology

Four varieties with good yield potential were selected from western and eastern Niger. Previous research established that millet varieties from eastern and western Niger belong to different heterotic groups. The varieties from eastern Niger were: Moro, Ankoutess, Gamoji and Ex-Borno, while the four varieties from western Niger were: HKB, HKP, H80-10GR and Sounna 3. Varieties from eastern Niger (used as female) were crossed to those from western Niger (used as male) during the dry season of 2009-2010 in Kollo. The 16 hybrids, their 8 parents and 2 check varieties, (26 entries in total) were evaluated in 2010 and 2011 in Kolo. The hybrids were screened for reaction to downy mildew (DM) using four isolates collected from Maradi, Gaya, Kollo, and Sadore (Table 11). The screening included resistant and susceptible DM checks. Eight hybrids showed higher yields than Souna3, the parent with the highest grain yield of 1,869 kg/ha. The eight hybrids and their DM incidence are as follows:

Efforts are ongoing to develop top cross hybrids from the hybrid populations identified to have potential in Mali. This involves backcrossing to convert the cytoplasm of two female parents of the hybrid populations to male sterile using known male sterile sources. The crosses for which these activities were initiated are Gamoji × HKB and Moro × HKP-GMS.

Millet is protogynous (the stigma is receptive before the pollen is shed). Pollen shed takes place 2-3 days after exertion of the stigma, with 80–85% pollen dispersal by wind. Although conversion to male sterile was initially planned for Moro, its earlier flowering (57 days) compared to HKP-GMS (60 days) necessitated that HKP-GMS to be female and Moro to be male for good nicking.

Table 11: Eight hybrids and their DM incidence

S/N	Hybrid	Downy Mildew Incidence (%)
1	Gamoji × HKB	6.2
2	Ex Borno × H80-10 Gr	11.3
3	Moro × HKP GMS	9.1
4	Ankoutess × HKB	6.6
5	Ankoutess × HPP GMS	16.8
6	Ankoutess × Souna 3	4.1
7	Gamoja × Souna 3	6.1
8	Ex Borno × HKB	6.8

By 2013, the conversion of Gamoji to CMS was at BC2. The CMS employed the A4 system using ICMA 0088 from ICRISAT. The A4 system has been found to be the most stable in Sahel. Exotic CMS sources are susceptible to downy mildew and not adapted to the environmental conditions in Niger.

Ankoutess, a widely adapted improved millet landrace with loose panicle and big grey kernels, was converted to CMS. The conversion was at BC3 by 2013. The backcrosses were advanced to BC3 for Gamoji and BC4 for Ankoutess. CMS of Ankoutess BC3 and Gamoji BC2 were assessed in 2014.

A breeding activity was initiated in 2014 to broaden the population base of the CMS conversion program. The number of plants used for the broadening of the genetic base was increased to 172 for Gamoji and 114 for HKP-GMS. The development of fertility restorer lines in the male parental populations, HKB and Moro was pursued.

F1 between plants derived from a cross between the CMS conversions and each of HKB and Moro were evaluated for fertility by checking spikes for seed set. The rationale for this is that F1 plants for which had fertility restored under such harsh conditions would also have their fertility restored under more favorable growing conditions. On-farm testing of seeds of the two hybrids, Gamoji × HKB and Moro × HKP-GMS were done in 2015 and 2016 in 11 sites. Lodging was observed in some locations, suggesting that future hybrids should be shorter. Acoutess was advanced to BC5 while Gamoji was advanced to BC4 in 2015.

4.10.7 Breeding to improve nutrition and disease resistance

A breeding program was initiated to develop a micronutrient-rich, dual-purpose, downy mildew resistant variety that is adapted to local conditions.

4.10.8 Methodology

To exploit the available diversity in millet in WCA for adaptability to the widely distributed soil conditions and nutritional quality, especially micronutrients, about 300 millet accessions collected from the WCA sub-region were evaluated during the rainy season of 2009 in Niger, Mali and Senegal. Seventy-two accessions selected from the 2009 evaluation of 2009 by plant breeders and farmers were further evaluated in 2010 in the three countries. Selection was based on high yield and high Iron and Zinc content.

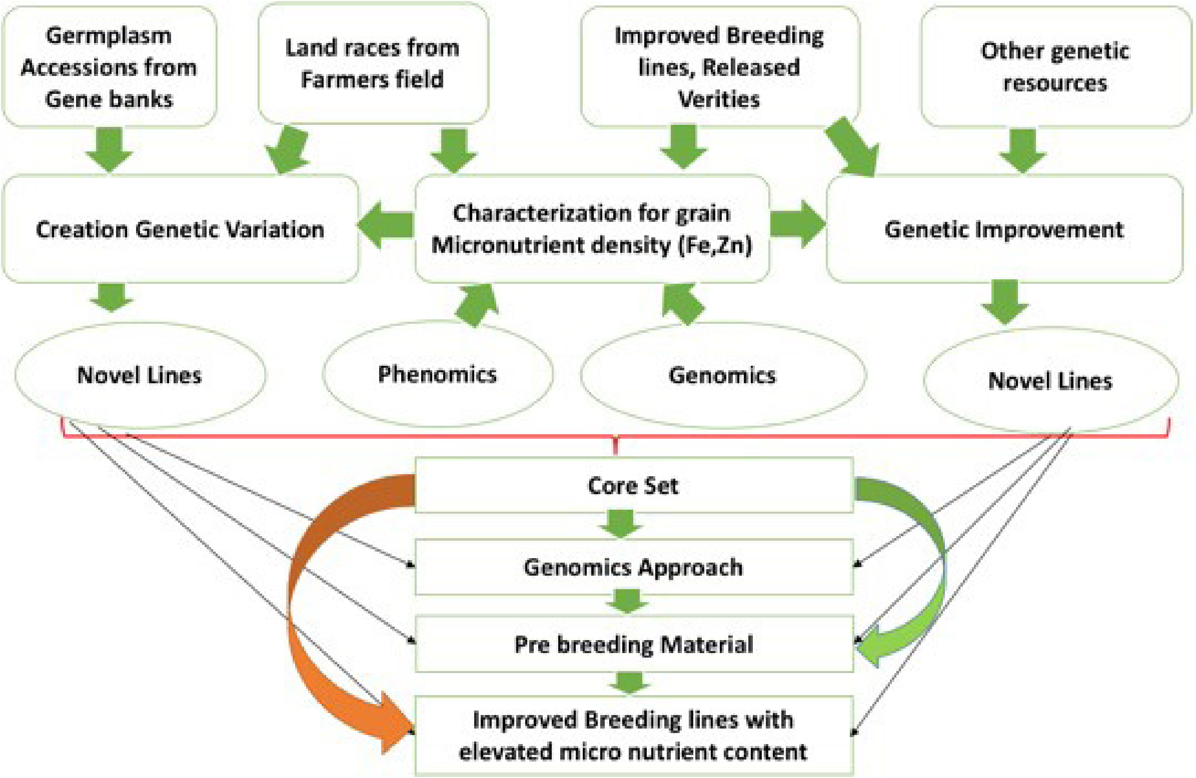


Figure 40: diagrammatic representation of the breeding scheme followed at ICRISAT, Niamey (Gangashetty et al., 2015)

On-farm demonstrations were carried out in different regions of Niger in 2010. Five most-promising entries and two checks, Sadore Local (local check) and ICMVIS89305 (improved OPV) were evaluated in on-farm demonstrations. Farmers' field days were carried out in the different locations, and results submitted to the Varietal Release Committee.

Figure 41: Heads of high-yielding OPV ICRI-Tabi pearl millet variety (Photo Credit: Prakash Gangashetty, ICRISAT)

4.10.9 Release of developed varieties and dissemination

ICMV IS 10101, named ICRI-TABI, was released in 2011. ICRI-TABI is high yielding (1 t/ha). It is dual purpose, has stay green characteristics at maturity and high tillering ability. It has a compact head, grey-colored grains and is resistant to downy mildew. It contains Iron content of 40 ppm and Zinc content of 35 ppm. It matures within 90 days from the date of sowing. Farmers have grown the seeds of the variety since 2011.

ICMV IS 99001 and Mil De Siaka (ICMP IS 13151) were released in 2013. Yield potential of these varieties are 1.1 t/ha and 1.2 t/ha respectively.

4.10.10 Activities Towards Future Improvement of Millet in Niger and the Sub-Region

One hundred S1 lines from the accessions selected at the end of the rainy season of 2009, together with downy mildew-resistant and susceptible checks, were screened for their reaction to downy mildew. The best 10 S1 progenies with high resistance to downy mildew, DM, and whose parental accessions had superior agronomic traits and high micronutrient content were planted in isolation under irrigation in February 2010.

Random mating was done using bulked pollen. The objective was to produce a population with high level resistance to DM, higher micronutrient content, and higher yield. The derived population was evaluated in 2010 in five locations in Nigeria, and three locations in each of Mali, Burkina Faso, and Senegal. Ten of best millet accessions were crossed to three A (male fertility system) lines, A1, A4, and A5 in 2015. F1 from these crosses were assessed for fertility in 2015.

4.10.11 Breeding to develop high yielding disease resistance varieties

A BMZ-funded project was initiated with the aim of developing high-yielding, downy mildew-resistant, dual purpose and nutritious millet hybrids for sub-Saharan Africa.

4.10.12 Methodology

Three hundred landraces of millet were collected from West and Central Africa in 2008. Plants of these accessions were selfed to generate S1 lines in 2009. From these, 300 S4 lines were generated for the Pearl Millet Genome Wide Association Mapping Population for West and Central Africa (PMIGAP-WCA).

The 300 S4 lines were crossed to four A (male sterility system) lines, 4-2A, SDEA 4L-160, LCICMA1 and LCICMA7. The 1,200 crosses were evaluated in ICRISAT Sadore Research Station, Sadore, in Niger for fertility (seed set and pollen fertility study) and 15 fertile hybrids were produced in 2015. They were evaluated in three replications in Niger and Senegal. Several hybrids with great potential were identified, with the following important characteristics shown in Table 12

Table 12: Characteristics of selected hybrids

S/N	Name	Potential Yield (t/ha)	Days to Maturity	Type and other important characteristics
1	ICMH IS 14006	2.5–3.0	70	Dual purpose
2	ICMH IS 14003	2.5–2.6	65	Grain millet
3	ICMH IS 14002	2.0–2.4	70	Dual purpose, higher fodder yield, branching at every node
4	ICMH IS 14012	2.5–3.0	80–85	Dual purpose, white grain, High Fe (45 ppm)
5	ICMH IS 14011	3.0	75	Long heads
6	ICMH IS 14009	3.0	75	Long heads

Figure 42: Pearl millet hybrid ICMH IS 14006 at ICRISAT Sahelian Center- Niamey, Niger. Photo Credit: Prakash Gangashetty, ICRISAT

Figure 43: Head length of pearl millet hybrid ICMH IS 14006 (Photo Credit: Prakash Gangashetty, ICRISAT)

Above (Fig 42 and 43) are characteristics of the pearl millet hybrids developed by the program at ICRISAT Niger.

4.11 Rice breeding in Nigeria

Rice is an important food security crop in Nigeria that is grown both for subsistence and commercial use. Its consumption has continued to increase from 0.5–2.0 kg/person per year in the 1960s to 33.5 kg/person per year in 2015. Farmers' incomes from rice have risen with increased production. Lowland rice has a higher yield that is 2–2.5 times higher than upland rice, even though their costs of production are similar. Rice production in Nigeria is affected by two abiotic constraints, namely drought and iron-toxicity. While drought has become a recurring feature in crop production in West Africa as a result of climate change, the latter is largely predominant in Abakaliki and Edozigi, two major rice-producing areas in Nigeria.

4.11.1 Breeding Objectives

A rice breeding program was initiated in 2004 to develop drought-tolerant, early maturing and high-yielding rice varieties. The program was collaboratively implemented by the International Rice Research Institute (IRRI), The Philippines, IITA, Nigeria and National Cereal Research Institute (NCRI), Badeggi, Nigeria.

4.11.2 Methodology

Crosses were made among several elite varieties and IR68, a high tillering, drought-tolerant variety. Evaluation of the populations was done at IITA, Ibadan in two seasons, one of which was under irrigation. In the same year, the materials were evaluated in Abakaliki in one season. Individual plant selection was carried out based on phenotypic characteristics. Seeds from 50 selected plants were bulked per population.

Selected individual plants were advanced to F5 at which a high level of homozygosity was observed based on the uniformity of F5 plants derived from each selected F4 plant. Lines that showed

Figure 44: Preliminary Yield Trials in Abakaliki in 2010. Photo Credit: Andrew Efisue

desirable characteristics and a high level of homozygosity were evaluated. Preliminary yield trials involving 30 lines were carried out in replications in Ibadan and Abakaliki in 2010 (Fig 43).

Seeds of 11 lines that were identified as superior were multiplied and subjected to Participatory Varietal Selection (PVS). The varieties were again multiplied in the second season of 2011 at IITA. Multi-locational, on-farm and on-station trials were carried out in 2012 in Oyo, Lafia, Yola, Makurdi and Abakaliki. Based on good performance, five varieties, IWA 1, IWA 2, IWA 3, IWA 4 and IWA5 were submitted to the Variety Release Committee.

4.11.3 Release and dissemination of developed varieties

Three varieties, UPIA1, UPIA2 and UPIA3 were released. They are high-tillering and photo period-insensitive with long slender grains. The parents of the three varieties are provided in Table 13 below

Table 13: Released rice varieties

Released Varieties	IRRI Code	Parental Crosses
IWA 1	IR 68	IR 19660-73-4/IR 2415-90-4-3-2//IR 54
IWA 2	IR 69513-21-SRN 2-UBN 1-B-7-2	IR 57514-SRN-299-3-2-4/IRRI 119//IR 43524-55-1-3-2
IWA 3	IR 74371-54-1-1	IR 55419-4*2/WAY RAREM

UPIA1 is early maturing (matures in 90–100 days), has tolerance to iron toxicity and a high yield potential of 7–8 t/ha. UPIA 2 is medium maturing (110–120 days), with a high yield potential of 8–9 t/ha. UPIA3 is early maturing (100–110 days), is drought-tolerant, with a high yield potential of 7–8 t/ha.

Farmers purchase their seeds from seed companies to avoid contamination associated with use of rice from previous harvest. AGRA has stepped in the gap by offering a grant award for the multiplication of foundation seeds of the three varieties.

4.12 Cowpea breeding in Nigeria

Cowpea (*Cowpea unguiculata*) is an important grain legume in West Africa. Nigeria accounts for 61% of world cowpea production. The grain, which contains 25% protein, is a good supplement for animal protein. Cowpea production suffers many biotic and abiotic constraints, the major one being the parasitic weed *Striga gesnerioides*. The most grown variety is Borno Brown, largely grown in Borno State, one of the states in Western Nigeria with the highest hectarage under cowpea. It has large grains that are brown in color and a yield of about 300kg/ha. Although it is preferred because of its size and color, it is susceptible to *Striga generioides.*

There are other cowpea cultivars that are resistant to *Striga generioides* but they are not cultivated because their other traits (such as yield, color and size) are not desirable to farmers. For instance, B301, the first striga resistant cowpea cultivar from Botswana has very small grains which are undesirable to farmers. Breeding efforts have introgressed the resistance gene in B301 into several cowpea varieties with bigger grains. One of such varieties is the IT97K499-35 which was developed by the IITA. It has a white grain with a yield potential of 1.3–1.7 t/ha. Cultivar development continues to pursue striga-resistant cowpea varieties with farmer-preferred traits.

4.12.1 Breeding methodology

In a breeding program to improve Borno Brown, farmers identified the following traits to be desirable: resistance to *Striga gesnerioides*, high yield, big seed size, brown grain color, and suitability for intercropping with cereal crops. The program, which commenced in 2010, used Borno Brown as the female parent and IT97K-499-35 (with gene for resistance to SG3 from B301) as the male parent. Borno Brown was the female parent while IT97LK-499- 35 (with gene for resistance to SG3 from B301) was used as male parent. The F1 was back crossed to Borno Brown to generate BC1F1. In BC1F1, eight plants were genotyped to identify those with the gene for resistance to *Striga gesnerioides*. These were advanced to BC1F2. Twenty-four plants of the BC1F2 generation were raised in 30-cm diameter (atrim) pots infested with 5,000 germinable seeds of *Striga gesnerioides* with 95% germinability. The infested seeds were conditioned for 7 days before planting cowpeas seeds.

In addition to SSR 1 marker locus, cowpea plants were genotyped using SSRC42B marker locus. The cowpea plants were phenotyped for their reaction to *Striga gesnerioides*. Resistant plants were advanced to BC1F3. Nine plants were raised from each plant selected at the BC1F2. Families at the BC1F3 were screened *Striga gesnerioides* in pots. Families that showed uniform resistance to *Striga gesnerioides,* had (implying homozygosity of parental plants of the BC1F2) and which had big, red grains, were selected and advanced to BC1F4 which were evaluated on the field.

Figure 45: First row (from left to right): B 301, the original source of resistance gene to SG 3 (very small grain), cowpea variety with resistance gene of B301 from which resistance gene was introgressed into Borno Brown. Second row (from left to right): Improved varieties developed from Borno Brown (female) and IT97K499-35 (male) viz. UAM091016-6-2 (redgrain), UAM091051-1 (red grain) and UAM09 1055-6 (white grain). Photo Credit: Victor Adetimirin

Lines showing uniformity at the BC1F4 for all considered traits were bulked to increase the amount of seeds for multi-locational trials which were carried out in 2011 and 2012 in five locations, *viz*. Mijinbir in Kano State, Biu, in Borno State, Zaria, in Kaduna State, Malamaduri, in Jigawa State and Makurdi in Benue State. On-farm trials and multi-locational trials were conducted in these States (except Borno) in 2013 and 2014.

Three varieties, UAM 091046-6-1, UAM 091051-1, both red in color, and UAM09 1055-6, white in color, were submitted for release in 2016.

They performed well in a non-striga environment, Makurdi, under drought conditions, and in Maradi, Nigeria, as well as under *Alectra vogelli* (in the screen house). The varieties have potential for cultivation in both Niger and Cameroon.

4.13 Groundnut breeding in Nigeria

Groundnut is one of the world's principal oil seed crops. The world production stands at 22.2 million ha with an average yield of 1,554 kg/ha. Out of the worldwide production, the developing world accounts for 95.5% of total production. In Africa, groundnut production is mostly done in the Sahel, Sudan and Guinea. More than 60% of production is done in West Africa, with Nigeria producing 51% of the groundnuts in the sub-region.

In Nigeria, the crop is largely grown by smallholder farmers under rainfed conditions. It is a major source of protein and dietary oil for both subsistence and commercial use. Groundnut can be consumed raw, boiled, roasted or crushed to obtain vegetable oil used for cooking. It can also be fed to livestock in the form of groundnut cake, a by-product of crushing, or used as an ingredient in other foods. It is rich in protein, oil, and micro-nutrients such as iron and zinc. It contains amino acids which complement those of cereals such that consuming them together raises the nutritional effectiveness of both.

Socio-economic constraints coupled with other biotic and abiotic constraints have increasingly hampered high yields in Nigeria, whose average groundnut yield stands at 1.0 t/ha compared to the world average of 1.5 t/ha; yields in China and the USA are over 3 t/ha. Groundnut haulm is very important and at the peak of the products used from the crop as on the economic cost per weight of haulm can be as much as that of the grains.

IAR, ICRISAT and other organizations have previously collaborated to develop groundnut varieties that are adapted to different ecological zones in Nigeria. Some of these varieties, possess desirable traits like high yield, and resistance to major biotic and abiotic stresses in Nigeria. The most serious among these stress factors is the rosette disease, which is transmitted by the aphid, *Aphis cracivora.* It is the most destructive groundnut disease in Nigeria and other countries in West and Central Africa. In 1975, the disease destroyed nearly one million hectares of the crop in Nigeria.

There are a few Rosette-resistant varieties that were produced by the Institute of Oil and Oil Seeds in the 1950s. They include KH 149A, 69-101, RMP12 (later released in Nigeria as Samnut 10). However, some of these varieties are of long duration, predisposing them to end-of-season drought.

The Institute of Agriculture Research (IAR) developed high yielding, short and medium-duration lines that are resistant to rosette. Three of these, Samnut 21, Samnut 22 and Samnut 23 were released in 2000. There is still a need to develop groundnut varieties with better traits such as high yield, rosette resistance, and early maturity.

4.13.1 Breeding objective

A breeding project was initiated with an objective of developing higher yielding, rosette resistant, and early maturing groundnut varieties with farmer-acceptable traits.

4.13.2 Breeding methodology

One hundred and forty advanced lines produced by ICRISAT were screened for rosette resistance in a nursery at Samaru in 2010. This was done during the rainy season which is favorable for the build-up of aphids. Seventy-nine of these lines, which showed no rosette symptoms were selected and evaluated for pod and haulm yield in 2011. Eight of the lines which displayed farmer-preferred traits were evaluated in 2012 on-station and in six other multi-locational sites in Sudano-Sahelian and northern Guinea. The highest yielding varieties across the trial locations were ICGX-SM 00018/5/P15/P2 and ICGX-SM00020/P5/P10.

From the trials, five varieties, ICGV-IS-07865, ICGV-IS-07865, ICGV-IS-07886, ICGX-SM, 00018/5/P15/P2 and ICGX-SM 00020/P5/P10 displayed high pod yields, early maturity, resistance to rosette, and high protein content. They were evaluated with checks in on-farm trials at six sites in Jigawa, Kaduna, Kano and Katsina states in 2012 and 2013.

4.13.3 Release and dissemination of developed varieties

ICGX-SM 00018/5/P15/P2 and ICGX-SM 00020/P5/P10 were released as SAMNUT 26 and SAMNUT 25, respectively.

Figure 46: Plants and nuts of SAMNUT 25. Photo Credit: C.A. Echekwu

Figure 47: Plant and nuts of SAMNUT 26. Photo Credit: C.A. Echekwu

4.14 Sweet potato breeding in Nigeria

Sweet potato is the third most popular tuber crop in Nigeria, after cassava and yam. It is preferred because:

(i) It can grow in all agro-ecological zones, including marginal soils.

(ii) It has a short maturity cycle of 3–4 months compared to 12 months for cassava and 8 months for yam. making it possible to grow two crops in one year without irrigation in the rainforest agro-ecological zone;

(iii) It has a weed suppressing ability.

(iv) It has a high nutritional content.

Over the years, sweet potato yields have been hampered by poor seeds and susceptibility to sweet potato virus disease (SPVD). The Orange-fleshed sweet potato (OFSP) variety is known to contain high beta-carotene, whose deficiency is a public health problem in Nigeria, estimated at 28.1% (Ajaiyeoba, 2012).

The CIP-SSA has demonstrated the potential of OFSP to mitigate the burdens of Vitamin A deficiency (in Kenya and Uganda). To enhance acceptability and adoption, improved sweet potato cultivars exhibit end-user (farmers, consumers and processors) preferences. The most important ones are high dry matter content, high yield, high carotenoid content, and resistance to SPVD. Previously, OFSP varieties were introduced in Nigeria by CIP. However, they were not accepted due to their low dry matter content and susceptibility to SPVD.

4.14.1 Breeding to develop high yielding sweet potato varieties

Consequently, a breeding project was initiated to develop high yielding OFSP and white-fleshed sweet potato varieties with high dry matter content, high carotenoid content, resistance to SPVD, good root conformation, and consumer acceptability.

4.14.2 Methodology

Nine sweet potato clones from the National Root Crops Research Institute, Umudike, were evaluated for agronomic characteristics and food quality in 2003 in replicated trials in Umudike and Utobi. Three of the clones showed potential for fodder as they extensively produced vines with no tubers. The other six genotypes were polycrossed in 2004 as shown in Table 14.

Table 14: Sweet potato clones established in polycross block

S/N	Genotype	Characteristics
1	TIS 87/0087	High yield, high dry matter, resistance to sweet potato virus disease, good root shape, good root size, good plant vigor, and tolerance to *Cylas* spp (sweet potato weevil)
2	TIS 8164	High yield, high dry matter, resistance to sweet potato virus disease, good root shape, good root size and good plant vigor
3	TIS 86/0086	Moderate yield, white-fleshed; high resistance to SPVD; good root shape and size
4	CIP 199004.2	Light orange, moderate yield and high dry matter
5	Ex-Igbariam	Yellow flesh, moderate to high yield (18–25 t/ha depending on ecology), good root shape and size
6	TIS 2532. OP.1.13	White flesh, high yielding, high dry matter, resistance to sweet potato virus disease, good root shape, good root size, and good plant vigor

The polycross produced 300 seeds of half-sib families, half of which were of red color

.

Figure 48: Sweet potato crossing block (right) in Umudike and seeds of half-sib families from the crossing block. Photo Credit: Solomon Afuape.

In 2005, clones of 50 elite orange and white-fleshed sweet potato varieties from CIP–Kenya, were evaluated in Umudike. The clonal evaluation, targeted traits such as reaction to SPVD, root shape and flesh color.

Preliminary yield trials, advanced yield trials and evaluation were carried out in three replications in Umudike, Otobi, and Igbariam, in 2006 and 2007. With funding from AGRA, multi-locational trials were carried out for 10 advanced breeding lines and 5 promising materials from the CIP collections. On-farm and multi-locational trials were done in 2011 and 2012.

4.14.3 Release and dissemination of developed varieties

Three varieties, UMUSPO/1 (light orange-fleshed, known as King J), UMUSPO/2 (white-fleshed), and UMUSPO/3 (deep orange-fleshed Mother's Delight), were released in 2013.

The released varieties (Table 15) have been distributed to farmers and farmer groups in selected locations in Nigeria. Some of the trained farmers now engage in the production of OFSP vines as business. Hellen Keller International, an international non-governmental organization, has been active in the distribution of high-quality vines of the released orange-fleshed varieties to pregnant women and breast-feeding mothers in Nigeria as a strategy to combat vitamin A deficiency.

Table 15: Characteristics of released varieties

S/N	Cultivar	Characteristics
1	King J (UMUSPO/1) NRSP/05/022	• Very high yielding • High resistance to sweet potato virus • Adapted to all agro-ecological zones in Nigeria • Very vigorous growth • High dry matter content (≥30%)
2	UMUSPO/2 NPSP/05/10D	• High yielding • High resistance to SPVD • Intermediate dry matter • Very white flesh color • Good taste
3	Mother's delight UMUSPO/3	• High carotenoid content • High yielding • Tolerance to SPVD • Good root shape • 3–4 months to maturity • Adapted to all ecological zones in Nigeria, especially the Guinea and Sudan savannas where SPVD pressure is low • Low dry matter

In addition, the Catholic Relief Service, another international organization, distributed 1.5 million vine cuttings to 5 states in Nigeria in 2015. The Osun State Government has included Mother's Delight in the government-sponsored feeding of elementary school children since 2014. The number of schools involved in the program increased from 8 in 2014 to 20 schools in 2015.

The Federal Government also initiated a sweet potato intervention project known as the Rainbow Project with the aim of distributing 2 million vine cuttings of Mother's Delight to 20,000 household families in Ebonyi, Benue, Kwara, Kaduna, Nassarawa, and Osun.

5 | Conclusion and recommendations

The review of some of the African plant breeding programs has shown that public breeding programs share similar or almost similar breeding objectives, methodologies, and challenges. However, despite facing many challenges, they have developed and released many crop varieties with considerable yield gains and resistance to some of the major biotic and abiotic constraints. Including some of the successful breeding programs as case studies in the e-curriculum of the Improved MSc for Cultivar Development in Africa (IMCDA) and any other plant breeding curricula can help students appreciate how to develop efficient breeding pipelines for targeted product development and adoption.

Furthermore, most breeding programs exclusively use conventional plant breeding methods such as pedigree, bulk, hybrid, and backcrossing methods. The fact that most breeding programs have achieved considerable genetic gains without or with little application of modern molecular breeding technologies should be applauded. However, embracing genomic tools by all African plant breeding programs to complement conventional breeding methods can accelerate genetic gains through improved selection accuracy and efficiency.

Lack of financial resources is the major and chronic challenge faced by breeding programs in Africa. This can be attributed to poor financial prioritization of plant breeding programs by the respective governments. Since most breeding programs share similar breeding objectives, limited financial resources can be optimized by harmonizing national breeding programs into regional programs. Harmonization of breeding programs is in line with the developments in regional seed policies such as the harmonization of seed regulations of the Southern African Development Community (SADC) (SADC, 2008), the Common Market for East and Southern Africa (COMESA) the East African Community (EAC), and the Economic Community of West African States (ECOWAS) (Kuhlmann and Zhou, 2016). Not harmonizing plant breeding programs has resulted in disjointed and multiple parallel breeding projects across Africa, which is straining the already limited financial resources.

6 | References

1. “Banana”. Banana-Wikipedia, The Free Encyclopedia. http://wikipedia.org/wik:/Banana. Accessed 26/05/2016.
2. COMESA/ACTESA. 2016: COMESA Seed Harmonisation Implementation Programme (COMSHIP). Enhancing quality seed availability to small-holder farmers. Mutual Accountability Framework Meeting Proceedings, Addis Ababa, Ethiopia. 23–24 February 2016. http://africaleadftf.org/wp-content/uploads/2016/09/COMESASeed-Harmonisation-Implementation-Plan-COM-SHIP-_JULY-2014.pdf
3. FAO. 2005. Banana statistics 2005. Food and Agriculture Organization of the United Nations, Rome.
4. FAOSTAT. 2014. Food and Agriculture Organization of the United Nations, Rome.
5. FAOSTAT. 2015. Food and Agriculture Organization of the United Nations, Rome.
6. Fortescue, J. A., Turner, D. W. 2004. Pollen fertility in Musa: Viability in cultivars grown in Southern Australia. Australian Journal of Agricultural Research 55: 1085-1091.
7. Gepts, P., Osborn, T. C., Rashka, K. and Bliss, F. A. 1986. Phaseolin protein variability in wild forms and landraces of the common bean (Phaseolus vulgaris): evidence for multiple centres of domestication. Economic Botany 40: 451-468. Crossref.
8. Hershey, C. H. 1993. Cassava, Manihot esculenta Crantz. In: G. Kalloo and B.O. Berg, eds: Genetic Improvement of Vegetable Crops. Pp 669-691. Pergamon Press NY.
9. Heslop-Harrison, J. S., Schwarzacher, T. 2007. Domestication, genomics and the future of the banana. Annals of Botany 100: 1073-1084.
10. INIBAB. 2000. Bananas. International Network of Improvement of Banana and Plantain, International Plant Genetic Resources Institute. Available online at http://bananas.biodiversityinternational.org/files/files/pdf/publications/brochure_bananas.pdf.
11. Kwak, M. and Gepts, P. 2009. Structure of genetic diversity in the two major gene pools of common bean (Phaseolus vulgaris). Theorectical and Applied Genetics 118: 979-992.
12. Kuhlmann, K., & Zhou, Y. (2016). Seed policy harmonization in ECOWAS: the case of Ghana. Syngenta Foundation for Sustainable Agriculture working paper.
13. Lathrap, D. W. 1970. The Upper Amazon. Sidalc.net.
14. Pillay, M. A., Tenkouano, A., Hartman, J. 2002. Bananas and Plantains: Future challenges in Musa Breeding. In: Crop Improvement, Challenges in 21st Century. Food Products Press, New York. Pp 223-252.
15. Pillay, M. A., Tenkouano, A., Ude, G., Ortiz, R. 2004. Molecular characterization of genomes in Musa and its applications. In: S.M. Jain, R. Swennen eds. Banana Improvement: Cellular Molecular Biology and Induced Mutations. Chapter 23.
16. SADC. 2008. Technical agreements on the harmonisation of seed regulations in the SADC region: Seed variety release, seed certification and quality assurance, quarantine and phytosanitary measures for seed. Gaborone: Botswana.http://ftf-seedtrade.com/index.php/more-info/9-sadc-technical-agreements-hsr-2008/file.

Alliance for a Green Revolution in Africa (AGRA)
West End Towers, 4th Floor
Muthangari Drive, off Waiyaki Way, Nairobi, Kenya
PO Box 66773, Westlands 00800, Nairobi, Kenya

WWW.AGRA.ORG