ROADMAP FOR A CONTINENT
Modern genetics and plant breeding for Africa

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Africa can lead the way

The Global Food Security Index, recently created by The Economist Intelligence Unit, identifies and measures the risks to food security in 105 countries, basing its analyses on the affordability, availability and quality of food. It aims not just to describe food insecurities but to provide solutions.

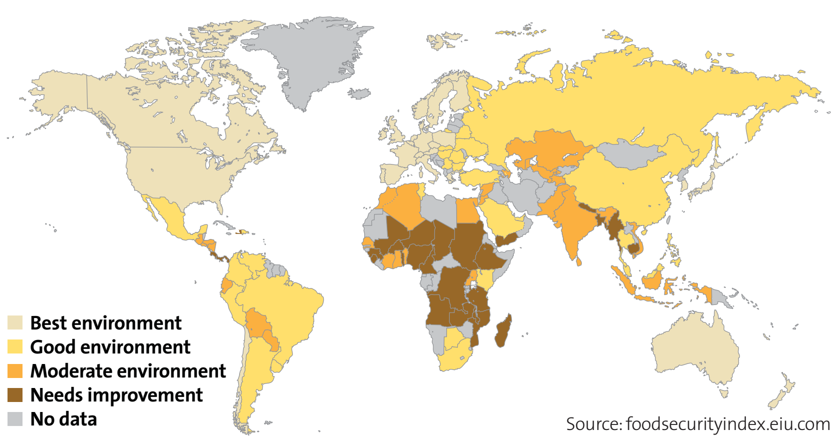
The bottom of the food security table is dominated by Sub-Saharan African countries including Mozambique, Ethiopia, Rwanda and Nigeria, where economies are forecast to grow fastest over the coming years. Africa in general – and Sub-Saharan countries in particular – could be in a position to lead the introduction of the latest agricultural technologies, especially for improving plant breeding, in order to meet their food security needs.

The key crops for solving Africa's food and income security challenges are banana, plantain, cassava, potato and sweet potato, along with other indigenous root vegetables and the staple grain crops of maize, rice and sorghum, of which the first two are being imported in large quantities. These key staples provide an excellent source of cheap calories, but there is an urgent need for new and improved cultivated varieties. How can today's advances in plant genetics help bring this about?

KEY THEMES

- Key role for African plant breeders.
- Current innovations, pros and cons.
- Blueprint for future progress.

Figure 5.1 The Global Food Security Index, 2014



Source: foodsecurityindex.eiu.com

The Global Food Security Index is based on a combination of 27 different indicators covering food affordability, availability, quality and safety, as well as background influencing factors such as literacy and economic opportunities for women.

Genetic variation is the engine that drives advances in crop breeding.

Two main drivers of innovation

Genomics research and its application to plant breeding have reached a stage where two main drivers of innovation have begun to emerge:

- Firstly, there is what could be called the growing democratisation of genomics technology, with the speed and accessibility of gene sequencing accelerating and its cost falling. With sequencing data doubling every five months, the cost per DNA base being sequenced is in free fall.
- Secondly, alongside the cheapness and accessibility of sequence information, dietary and nutritional security is now a global priority, putting agriculture centre stage. The future of farming is pivotal to a sustainable planet based on a viable green economy.

These two factors have combined to change attitudes to plant breeding by opening up the prospect of improving crops in a variety of ways. Now, if exciting new breeding programmes are to flourish, they will need support and insightful leadership.

Next-generation sequencing

Genetic variation is the engine that drives advances in crop breeding. The wider the variation, the greater the ability of a plant species to respond to, and survive in, a changing environment. Those plants that do survive will go on to transmit their favourable genes – and the traits these genes code for – to their offspring. It is this that provides the basis for the selection of plants with desirable characteristics.

A number of high-throughput, low-cost technologies known as next-generation sequencing (NGS) have made possible the completion of reference genome sequences for many important crops, including orphan species such as the pigeon pea, grown by resource-poor farmers in more than 25 tropical and subtropical countries, including in Africa.

In January 2014, the African Orphan Crops Consortium (AOCC), composed of the University of California-Davis, Mars, Inc. and other institutions, announced the 100 African crop species whose genomes will be sequenced. Having the total, detailed genetic sequence of a crop provides a platform for identifying individual genes and discovering genetic markers – short DNA sequences that are invaluable in manipulating genes for beneficial characteristics. There is currently a good deal of interest in one category of marker SNPs – single nucleotide polymorphisms, often called "snips". These vary by only one biochemical unit but can have big consequences for a plant's characteristics.

BOX 5.1 Breeding in brief

Plant breeding is essentially about identifying the best parent plants and crossing them to improve performance. Successful breeders skilfully combine elements of science, art, craft and business acumen.

The methods they deploy, whether traditional, high-tech or both – are determined by a crop's reproductive biology and breeding mechanism. Propagation – the way plants reproduce themselves – is of four kinds:

- *Vegetative* (or clonal) propagation, whereby new individuals develop from specialised structures such as bulbs or tubers on the parent plant. Potato, sweet potato, cassava and yam fall into this category.
- *Inbreeding*, in which crops self-fertilise through pollination, as with wheat, barley, rice, soybeans and cotton. Two-thirds of the world's food crops are inbreeders.
- *Outbreeders*, such as maize and forage grasses, which cross-pollinate with unrelated or distantly related plants.
- *A variable intermediate group* which can partly cross-pollinate, partly self-pollinate. The best-known example is sorghum.

Rapid developments in NGS technology do not just add detail to our understanding of the make-up of a plant's total complement of genetic material. They also open up the promise of new discoveries of genes with important effects on traits and diversity. One example is maize, where genome-wide analysis of 278 maize lines has enabled scientists to quantify the molecular changes that take place during the breeding process. This gives them a sophisticated tool for understanding better the genetic resources within any given plant and for identifying novel variants of genes that could be used in breeding.

Marker-assisted and genomic selection

With the dramatic fall in the cost of DNA-based techniques, methods such as marker-assisted selection (MAS) have taken off; MAS is already widely used in all breeding programmes by the big seed companies. This method of selecting a biochemical marker associated with a gene that codes for desirable plant characteristics has been successfully deployed in submergence-tolerant rice (see Case study on page 32) and in backcrossing programmes carrying transgenes from another species.

However, traditional MAS has limitations because it identifies only a few markers, while many of the crop traits that breeders are trying to put into their plants are complex – controlled by large numbers of regions along the genome, each one with only quite a small effect. Another drawback is that it does not always give a wholly accurate picture of the effect of stretches of DNA linked to genes of interest. A new MAS technique – genomic selection – overcomes these difficulties. Rather than seeking to identify individual markers significantly associated with a trait, genomics uses all marker data as predictors of performance and consequently delivers more accurate predictions.

Plant populations

For many key African crops, however, the bottlenecks that might impede future breeding advances are not so much genomic as population-based. Breeders have a better chance of accessing useful genetic variants if the underlying research focuses on community-based plant populations – populations of plants created from a community of parents and hence likely to contain a range of genetic variants controlling complex systems such as pest resistance, yield, stress tolerance and grain quality. This give a more finely tuned, higher-resolution picture of genetic mechanisms. One such initiative, first developed in maize and called nested association mapping, has already enabled researchers to isolate genes controlling complex plant traits such as pest resistance regulated by a number of genes, not just one. Another experimental design for plant populations – with the compelling acronym MAGIC (Multi-parent Advanced Generation InterCross) – is being deployed in wheat, rice and sorghum.

Theory and practice: closing a gap

Many of Africa's major food crops, including cassava and banana, reproduce vegetatively rather than by seed, making them ideally suited to improvement through genetic modification.

Plant breeders are genuinely excited by the dramatic advances made by research on crop genomes: information is pouring out of their laboratories at a dizzying rate, possibly faster than plant breeding practice can keep up.

Plant breeding is resource-intensive and highly dependent on collecting accurate data to support decision making. It also relies heavily on new insights from the even faster-moving fields of human genetics and evolutionary theory. This, allied to the fact that more and more is being discovered about the control of genes regulating complex traits, means that plant breeders' methods are becoming increasingly dependent on accessing new knowledge. Powerful computer simulations now make it possible to evaluate different breeding strategies or to model the way different genes work to help bridge the gap between theory and practice. Nonetheless, any simulation will ultimately need to be tested in a breeding programme.

Road map for Africa

The new crop science and technology could be of great benefit to African agriculture, but it needs to take a comprehensive strategic perspective that embraces not just technology but the biology of Africa's critically important crop species.

Education, training and skills strongly focused on crop species of relevance are essential. A new generation of African plant breeders needs to be inspired to integrate modern approaches into practical, productive breeding programmes.

Innovative partnerships between funders, breeders, policy makers, urban planners, ecologists, educational institutions and professional communicators are needed to articulate the critical role of plant breeding in agricultural productivity and environmental sustainability.

Plant breeding needs to become more compatible with the goals of African agriculture, to embrace both greater species diversity and farming systems. It is not just a matter of focusing on crops to promote food security. Breeders need also to think about farm incomes and productive employment.

Plant breeders need to focus not just on food security, but on crops that might boost incomes and productivity, such as coffee.