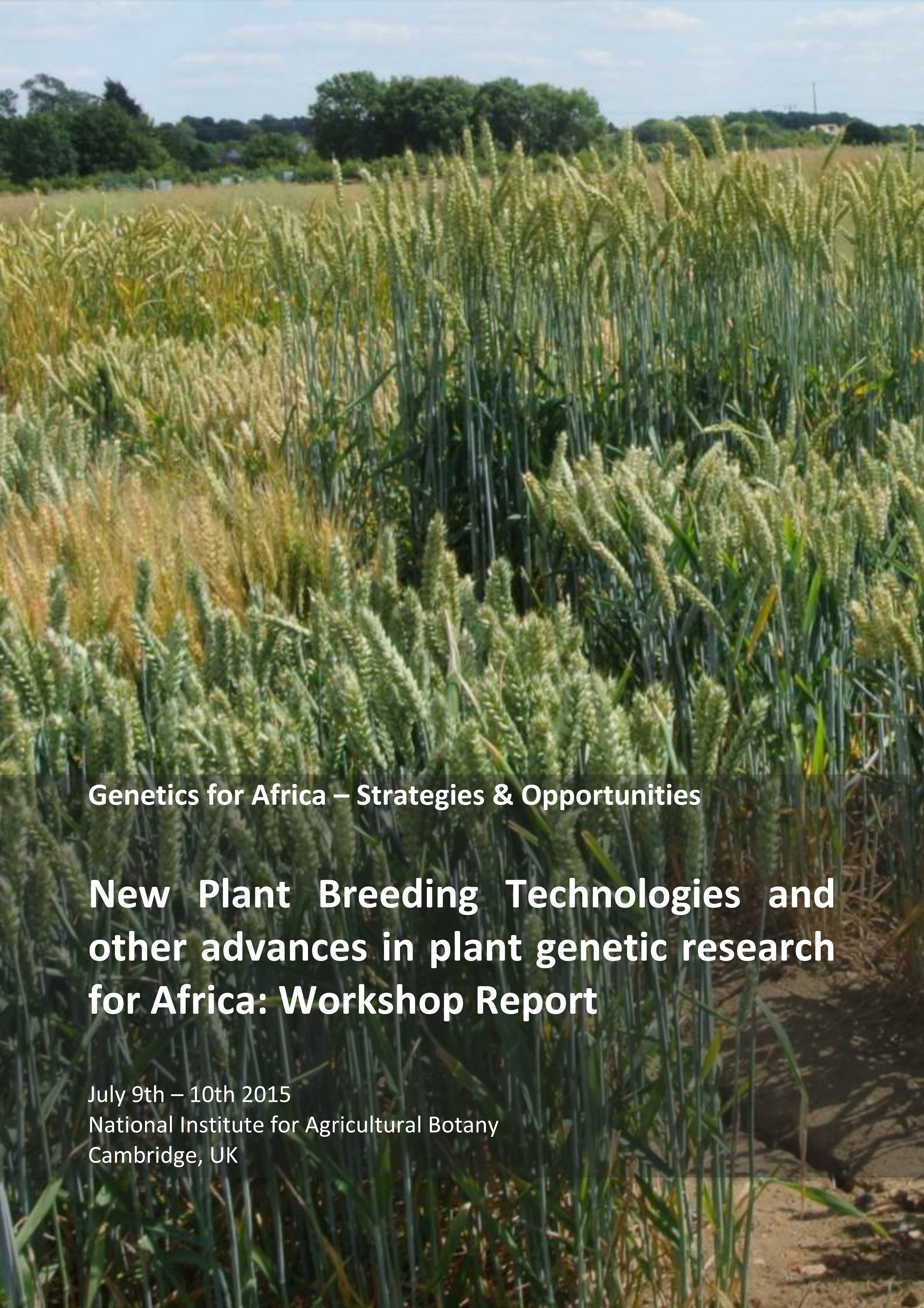

Genetics for Africa – Strategies & Opportunities

New Plant Breeding Technologies and other advances in plant genetic research for Africa: Workshop Report

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Cover photo: NIAB Innovation Farm, Dr Claudia Canales

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Executive Summary

The Genetics for Africa – Strategies and Opportunities planning grant aims to investigate the extent to which genetic research in and for Africa has a direct relevance to social and economic development, and the extent to which improved communication can assist in public understanding, acceptance and uptake of the research outcomes and to more appropriate regulation.

The project is investigating these matters through three workshops, on new plant breeding technologies, animal and human genetics research respectively.

The first workshop, on the New Plant Breeding Technologies and other advances in plant genetic research for Africa, was held on 9th - 10th July 2015 at the National Institute for Agricultural Botany in Cambridge, UK.

Whilst GM technology is still regarded by some regulators and activists as new and untested, it is over 20 years old and the first products are already coming off-patent! The cutting edge of research is now in the New Plant Breeding Technologies (NPBT's) and other areas including epigenetics.

NPBT's can be more precise and directed in manipulating DNA and may also not necessarily show recognisable "foreign" DNA inside the resulting sequences.

This has obvious consequences – both positive and negative – for regulation, acceptability and activist interest. Some technologies, which involve making fewer changes to the native genome, may be more acceptable across these communities. Others, including those which – though they use transgenic methods – have final products which contain no transgenic material, may on the face of it seem more acceptable to the public but cause more concern to regulators and activists since they will be difficult to test for. A gene-edited product which has involved a transgenic intermediate stage which is then removed from the final sequence may be indistinguishable from a product of conventional or mutation breeding.

The regulatory regime for NPBTs has not yet been decided, and is the subject of intense debate. IN the US, several new plant varieties produced by gene editing techniques have not been regulated as GMO's. In Europe, the debate continues, but unfortunately decisions to not regulate varieties have been met with activist challenges! Once again, there is a risk that adoption of an overly onerous set of regulatory burdens is encouraged, including in the developing world, as a mechanism for seeking to hinder uptake of these technologies or because the risks have been poorly understood. This is doubly important since, by their very scope and power, NPBT's are likely to have wider application – in animal and human genetics, for example – and regulations adopted in haste may have unintended and unfortunate consequences for future research.

And of course, African regulators will once again look to North American and European regulators to inform their own courses of action.

It is important to recognise some of the problems and unintended (at least, by the regulators!) consequences of current regulations adopted to deal with GM, in order to encourage adoption of a coherent international regulatory framework focusing more on traits and the scientific evidence, and where costs and complexity are more proportionate to the risks involved.

An appropriate regulatory regime might be based around:

- evidence-based focus on food/feed safety
- move towards a focus on trait or variety
- assess at a level proportional to risks
- move away from automatic pre-market regulation
- include appropriate post-market monitoring as sole process of assessment for traits already commercialised

In terms of engagement with African regulatory authorities and the African research community, the following approaches seem appropriate:

- share information on NPBTs early on with regulators and through public forums
- monitor discussions at CPB / COP-MOP and EU, and propose science-based options
- conduct regulatory consultations in Africa regarding products in the pipeline, and possible exemptions
- work with regional bodies such as COMESA on data exchange and acceptability

Although NPBT patents and publications have increased significantly in recent years, little NPBT research has been carried out on crop science challenges and varieties in the developing world. But by their very breadth and power, the technologies are likely to prove extremely useful in solving intractable Africa crop improvement problems, combat diseases, improve resilience and yield and lower costs in the face of increased demand from rapid population and GDP growth and massive urbanisation.

International collaboration will be important in research involving the NPBTs, to combine the technical expertise in the new technologies from the north with knowledge of the specific issues and challenges of African crops from researchers in the south. Awareness and expertise in the new technologies is still rare in Africa, so there is a great need for the building of local research capacity and expertise.

The importance and value of new plant breeding technologies to the general public need to be communicated by focusing on important breeding targets rather on the technologies per se. It will be important to provide real-life examples of the benefits, to highlight the potential of NPBTs to solve 'intractable' problems such as improvement of vegetatively propagated crops where traditional breeding is hard, and to promote the use of the technology in neglected and underutilised African orphan crops or multiple-use crops (eg food and energy).

Appropriate messages with suitable, non-technical vocabulary must be crafted for target audiences, with the following provisos:

- the term NPBTs should probably be avoided, as it is too technical and detached for a general audience.
- promote discussions on the use of science, and genetics as critical for agriculture, the main economic activity and the biggest generator of employment on the continent.
- promote agricultural production as an entrepreneurial exercise for wealth creation and sustainable rural economies.

- encourage thinking about genetics in an integrated way, for example, addressing farm productivity at different levels at once (crop, animal and microorganisms) and at the same time promoting human health and nutrition.
- consider the nexus between agriculture, water and energy.
- harness the open-mindedness of young people with respect to new technologies and biotechnology to promote the sector with youth
- promote use of technological advances in other areas (such as mobile telephony) to support agriculture and rural businesses for a data-driven bioeconomy

It will be important to sensitize policy makers and politicians to the importance of new technologies, including genetics and NPBT, early on, through sustained personal relationships and using stories and demonstrations rather than abstract arguments.

And biotechnology should be promoted in the school curriculum, in tertiary, and in post-graduate education through a mixture of training, capacity building, research collaboration and outreach to media.

Innovative and nuanced outreach on NPBTs is necessary at this time, to help build research linkages that will demonstrate the importance of the new technologies as well as to inform the decisions being taken in the formulation of new frameworks to regulate the use of those technologies, and to avoid the mistakes that were made during the introduction of GM technology.

"Communication is crucial. Even technologies that initially were highly controversial were rapidly accepted once the direct benefits they brought were clear to the public. The power of the media in forming public opinion about scientific advances cannot be ignored."

– Tim Radford
former Science Editor
"The Guardian"

Session 1: Introduction

Genetics for Africa – Strategies & Opportunities (G4ASO)

Dr Bernie Jones, Co-leader, G4ASO

The Genetics for Africa – Strategies & Opportunities (G4ASO) project follows suit of *Biosciences for Farming in Africa* (B4FA-described later), a three-year project that focused on communication and dialog activities on crop genetic improvement for agricultural productivity. The B4FA media fellowship, one of the main B4FA activities, received very positive feedback resulted in the training of 160 media professionals from four Sub-Saharan African countries. However, the importance of communicating to the public scientific advances in other fields of genetics, notably of livestock, fish and insects was frequently raised. These disciplines are important for promoting increases in farm productivity, and need to be considered to provide integrated solutions to complex problems such as poverty and malnutrition, and to encourage economic diversification. In addition, they are also relevant for the control of agricultural pests and diseases; biodiversity conservation (including wildlife); preservation of the environment; and critical for human health. A further common request was to widen the focus of engagement to other countries in Sub-Sahara Africa, since B4FA was active only in Ghana, Nigeria, Tanzania and Uganda.

B4FA also brought attention to the fact that despite the richness in interesting projects carried out in national research institutions addressing important national constraints to production, few are generally visible to the general public and to other members of the scientific community. The main reasons for this poor visibility of research activities are the lack of funds for science communication and outreach activities, and the general lack of comprehensive and informative institutional websites. This situation affects not only the information flow between scientists and media professionals, but is also likely to be a barrier to the development of regional scientific collaborative networks and the sharing of advances among researches working in similar or interrelated fields. Better knowledge of the range of research activities in the continent would also allow streamlining and prioritising international funding for improving productivity and welfare in the continent, and in this way maximising the impact of funding and the uptake of research initiatives.

A follow on initiative on communication and outreach activities focused on genetics in Sub-Sahara Africa would therefore have three main objectives: 1) Cover genetic research more widely, including in animals and humans; 2) Promote public outreach in more African countries; 3) Uncover and celebrate African research and researchers.

The main objectives of the G4ASO planning grant are to map African genetic research; determine key opportunities for public outreach in African genetic research; and form strong and relevant partnerships for the development of a programme and the eventual implementation of the project.

A focused two-day planning workshop will be organised for each topic (plants, animals and human genetics) reviewing recent research for and in Africa; the potential developmental impact of this research, and the opportunities for the communication and outreach activities that would increase uptake, public acceptance and promote the adequate and proportional regulation of new technologies.

In plant genetics, G4ASO focuses on genetic techniques not covered by B4FA, namely the new plant breeding technologies (NPBTs) and epigenetics and genomics. The workshop on animal genetics, which will be hosted by the International Livestock Research Institute (ILRI) in Nairobi in September 2015, will review livestock breeding, genetic modification, and the genetics underpinning diseases, biodiversity and wildlife conservation. Topics to be included in the final workshop, scheduled for the end on 2015 in South Africa, include human genetic diseases, non-communicable lifestyle diseases; heredity and origins; personalised medicines; and DNA testing. Special attention will be given to research areas that are both potentially beneficial, but also controversial, present ethical considerations and/or are of high urgency.

An introduction to the New Plant Breeding Techniques (NPBTs)

Prof Joachim Schiemann, Julius Kühn-Institut, Germany

The technologies collectively referred to as New Plant Breeding Techniques (NPBTs) are the latest additions to the 'toolkit' available to plant breeders for the development of superior crop varieties. While NPBTs share with Genetic Modification (GM) technology the ability to expand the biodiversity potential available for breeding beyond natural species barriers and effect specific alterations to the genome, they differ in two important ways.

1. NPBTs allow specific ***directed*** genome alterations, while GM does not allow for spatial control in the insertion of transgenes (*i.e.* there is no control over the position of the transgenes in the chromosomes of the modified plant).

2. The products of NPBTs may not necessarily contain recognisable 'foreign' DNA sequences, either because the genetic changes effected are very small (a point mutation or a few nucleotides) and hence undistinguishable from natural variation, or because transgenes are only needed in intermediate stages of the breeding process and are removed from the final product. Crops developed by NPBTs may therefore be undistinguishable from crops developed by conventional breeding techniques.

NPBTs can be subdivided in three broad categories:

1. The first category comprises GM technologies, distinguished by the source of the transgene. In **Cisgenesis** a native gene (and linked regulatory elements) from a sexually compatible crop species is used, while in **Intragenesis**, the transgene is a gene from the same species modified *in vitro*. Foreign sequences such as selection genes and vector-backbone sequences should be absent. Currently, intragenic and cisgenic plants are regulated as GM plants worldwide, but the de-regulation of these techniques is being considered both in the US and the EU.

2. The second category includes techniques that may have an intermediate GM stage during the breeding process, but with final products that lack a transgene or an obvious genetic signature. **RNA-dependent DNA methylation**; **grafting of**

non-GM scions in GM rootstocks; transient *Agrobacterium* infiltration; and **Reverse Breeding** fall in this group.

3. Finally, the third category comprises gene-editing tools: **Oligonucleotide Directed** Mutagenesis and techniques based on site-directed nucleases. The latter include: **Zinc Finger Nuclease (ZFN) Technology**; **Transcription Activator-Like Effector Nucleases (TALENs)**; and **Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and CRISPR-associated proteins (CAS)**.

While GM crops are subject to strict regulation, the regulatory requirements for crops developed by NPBTs are not decided in countries of the European Union, and currently the focus of intense debates.

The future regulation of new plant breeding techniques is currently the focus of intense public debate in the EU. The latest trigger was a February 2015 decision by four EU countries, including Germany, to authorise as exempted from GMO regulations field trials of oilseed rape produced by ODM by a US biotechnology company. Following a public letter from NGOs and interests groups, the European Commission subsequently reversed its position and published a letter stating that planting unapproved GM crops is illegal, and promising to resolve the current regulatory uncertainty surrounding NPBTs by the end of 2015. In June 2015 the German Federal Office of Consumer Protection and Food Safety (BVL) published a statement[1] rejecting the EU's objection to the decision on the

[1] *http://www.bvl.bund.de/DE/06_Gentechnik/04_Fachmeldungen/2015/2015_06_03_Fa_CIBUS.html*

NPBT's explained…

RNA dependent DNA methylation (RdDM)

In RdDM double-stranded RNA is expressed in target cells (or in other parts of the plant and subsequently transported to target cells) with the aim of inducing methylation of the gene or the regulatory regions that in turn lead to specific gene silencing. Since no changes are made to the underlying nucleotide sequence, and methylation changes can be stable and heritable, the final product will contain no foreign DNA sequences and will be undistinguishable from a crop produced by conventional breeding.

Grafting of non-GM scions in GM rootstocks

[Describe normal situation]. The ability of double stranded RNA to move cell to cell in a plant over long distances also opens the possibility of creating chimeric plants containing a GM rootstock expressing an effector RNA (for the control of pathogens, for example) and a non-GM scion. While the plant root would be GM, the leaves, fruits and seeds would contain no foreign DNA, so could be excluded from regulation.

Transient Agrobacterium infiltration

Agrobacterium is routinely used for the generation of GM crops, but this requires the stable incorporation of the transgene in the genome of the germcells (these are the sexual cells that will form the sperm and egg cells and hence contribute to the subsequent generation). Transient expression of Agrobacterium on somatic (non-sexual) cells is useful for the production of high value products, such as pharmaceuticals, and also the basis of the 'Spray-N-Trait' technology currently held up in the regulatory process. When the transgene is able to replicate and spread systemically to other cells and tissues of the plant this technique is referred to as Agroinfection, to distinguish it from Agrobacterium infiltration sensu strictu where the transgenic DNA is incapable of replication. The offspring (seed) of these techniques is non-GM, provided the transgene is not incorporated in sperm and egg cells.

Reverse Breeding

Reverse breeding allows the propagation of F1 hybrids in cases where the parental genotypes are not known, or to maintain beneficial gene combinations during breeding, by temporarily suppressing genetic recombination during sexual reproduction. Since no alterations are introduced in the DNA sequence the final product will be undistinguishable from the original F1 hybrid.

NPBT's explained…

Oligonucleotide Directed Mutagenesis (ODM)

An oligonucleotide (a short DNA sequence) containing the desired mutation and complementary to the template DNA around the mutation site is modified for increased binding potential. When the oligonucleotide and the target sequence hybridise (due to their complementarity) the mutation results in mismatch, which is recognised and repaired by the cell's normal repair mechanism. This technique is suitable for generating point mutations, and is useful for developing herbicide resistance or for inactivating the catalytic site of target proteins. ODM results in genetics changes that can be obtained with other forms of mutagenesis, but generates fewer unintentional changes or effects than those introduced into organisms by irradiation or chemical mutagenesis. For these reasons experts recommend the deregulation of crops produced by ODM.

Gene-editing techniques based on site-directed nucleases (SDN)

The common principles underlying techniques using site-directed nucleases are the following:

- *a DNA binding domain is either encoded or fused to a restriction domain*
- *the nuclease is stably or transiently expressed in vivo*
- *after binding of a specific DNA sequence a double strand break (DSB) is induced in the target genomic region*
- *the DSB is repaired by the cellular repair machinery*
- *during DNA repair point mutations or larger genetic modifications are fixed*

Three types of SDNs are recognised. In SDN-1 repair of the double strand break occurs via non-homologous end-joining and can result in can result in site-specific random mutations. In SDN-2 and SDN-3 a homologous donor DNA is used as a template to induce specific nucleotide sequence changes by homologous recombination HR, which results in either mutations in the gene of interest (SDN-2) or in the insertion of new genetic material (SDN-3).

Gene editing techniques include meganucleases (MNs); zinc-finger nucleases (ZFNs); transcription-activator like (TAL) effector nucleases (TALENs) and clustered regularly interspaced short palindromic repeats (CRISPR) and CRISPR associated proteins (Cas), the most commonly used of these being Cas9 (CRISPR/Cas9 system).

classification of the ODM oilseed rape variety.

The European Plant Sciences Organisation (EPSO) Working Group[2] on Agricultural Bio-technologies recommends that the following techniques are excluded from GMO legislation[3] in the EU:

- ODM
- ZFN-1 and -2 (without recombinant DNA)
- Offspring and fruits from grafting with non-GM scion
- Offspring of plants subjected to Agro-infiltration "sensu stricto"
- RdDM subjected plants without heritable change of their DNA (methylation alone is not a heritable genetic change)
- Offspring from reverse breeding

Techniques which are within the scope of GMO legislation include:

- ZFN-3
- Cis- and Intragenesis
- Grafting with GM scion
- Agro-infiltration "sensu stricto" (subjected plants) or floral dip (also offspring)
- RdDM subjected plants with integrated foreign DNA
- All intermediate organisms containing recombinant DNA

The techniques of ZFN-3 and Cisgenesis (and combination) might be excluded if the resulting organism is similar to self-cloning.

Participants to the G4ASO meeting commented during the Q&A session on the likely ambivalent impact of the Cibus request

[2] *http://www.epsoweb.org/agricultural-technologies-wogr*

[3] *Directives 2001/18/EC and 2009/41/EC*

in the EU: while the promise by the Commission to reach a decision on the regulatory status of NPBTs by the end of 2015 was considered positive, the fact that the first trait engineered under review is herbicide tolerance was believed to potentially reduce public acceptance of NPBTs. Also raised was the impossibility to distinguish by testing whether some crops were developed by NPBTs (although regulation in the EU is based on traceability rather than on testing) and the implications that this may also have on protecting intellectual property (IP) rights. The latter would have to be addressed by the Plant Breeders' Rights.

Epigenetics: potential for crop improvement

Prof Rod Scott, Bath University

Achieving global food security by 2050, with an expected global population of 9.6 billion people, will require a doubling of the current levels of grain production. The situation will be aggravated by the very high population density in some parts of the world (half of the world's population currently lives in South and South East Asia), and by the combined pressures of climate change and expected large increases in freshwater and energy demands. While conventional breeding has been very successful in developing improved crop varieties, increases in productivity are plateauing for many species, and for other crops productivity levels are even collapsing. Conventional breeding relies on genetic diversity and recombination as the source of variation. Epigenetics – changes in gene expression brought about by small modifications to the DNA and associated molecules – could contribute to the plant breeding 'toolkit' by providing new sources of variation that do not require recombination.

The molecular basis of epigenetics relies on the effect of methylation of DNA and histones (proteins that package the DNA in the cell nuclei) on the degree of condensation of the chromatin (which is the fibre composed of DNA and associated molecules). A more lose configuration (called euchromatin) is associated with higher levels of gene expression, while a more condensed state (heterochromatin) induced by methylation leads to reduced gene expression. The switch between euchromatin and heterochromatin is reversible, with two broad types of 'cellular memory': short/mid-term and mid/long-term or transgenerational.

An example of short-term epigenetic memory is vernalisation, the process by which plants acquire at the seedling stage the ability to flower after exposure to a period of low temperature, even if flowering occurs only in adult plants. Vernalisation relies on the suppression of expression of a flowering gene (called FLOWERING LOCUS C), induced by the modification (methylation) of histones.

Mid to long-term epigenetic memory (epigenetic imprinting) affects several important crop traits such as seed size (one component of yield) and hence could be used for crop improvement. In genetic imprinting (parent of origin effect) specific genes are repressed only when provided by either the maternal genome (in maternal imprinting) or the paternal genome (paternal imprinting) genome. The molecular basis of imprinting relies on methylation. In plants imprinting affects seed size because it affects the proliferation of the endosperm[4] (the nutritive tissue that surrounds the embryo). The molecular identity of the seed size genes controlled by parental imprinting is being investigated in experiments using the model plant Arabidopsis. Epigenetic imprinting also plays a role in interspecific hybridisation barriers and in apomixis (seed development without meiosis and recombination), and therefore it could potentially be used to produce wider hybrids and to fix beneficial F1 hybrids.

Another strategy to increase the epigenetic variation that can be used in breeding programmes and to quantify the impact of heritable epigenetic variation is to experimentally induce changes in genomic methylation and study the heritability of complex traits (such as seed size, root length and plant height) in plants that are similar at the DNA level but different in their methylation status.

Epimutagenesis may therefore enable exploration of allelic variation and novel combinations of alleles without relying upon recombination, which would be particularly attractive in species that are clonally propagated; have limited available genetic diversity; or in species where the target genes for improvement are located in genomic regions with low levels of recombination.

Genetic Imprinting explained…

In plants with an excess of paternal genomes the endosperm proliferates excessively and the resulting seeds are very big, while in plants with an excess of maternal genomes the endosperm fails to proliferate and the seeds are very small. In both cases an imbalance of parental genomes is lethal. The molecular basis of genetic imprinting is DNA methylation: artificially reducing the level of methylation (which de-represses gene expression) in the maternal plant has the same effect as increasing the number of paternal genomes, and conversely reducing methylation in the paternal plant results in very small seeds, mimicking a maternal genome excess phenotype. Maternal imprinting hence limits the growth of the endosperm, while paternal imprinting promotes it. An explanation for this 'parental conflict' is that the paternal genome will aim to maximise resource allocation from the maternal plant into their shared progeny, while the maternal genome will tend instead to distribute resources evenly between all her progeny (of potentially different fathers).

Session 2: Research, development benefits and outreach

Two Decades of Cowpea Research and Advocacy

Prof Idah Sithole, University of Zimbabwe

Cowpea is a hugely important crop in Africa: native to the continent it thrives in agricultural areas with low-rainfall, and millions of smallholder farmers- both men and women- grow it, often in intercropping systems. In addition to playing a very important role in the food security of many rural households, cowpea is also widely traded in local markets, and constitutes an

[4] *Seeds are the result of a double fertilization event: one sperm cell and egg cell (both haploid) fuse to generate the embryo, while another sperm cell fuses with the diploid central cell to give rise to the endosperm. Therefore seeds contain three different genotypes: the diploid seed coat has two maternal genomes; the embryo has one maternal and one paternal genome; and the endosperm two maternal and one paternal copies. Successful seed development requires coordination between all the tissues and genomes.*

important food source for the growing African urban areas. 200 million Africans consume cowpeas. While cowpea is widely grown in other parts of the world (with 21 million acres grown globally), about three-quarters of total production occurs in Africa, with Nigeria and Niger being the main producers.

Cowpea production faces however important production constraints, including pests, parasites and diseases, and environmental stresses such as drought and heat. NBPTs could play an important role as additional tools in addressing some of these constraints, in particular in developing varieties with resistance to insect pests and viral diseases.

Resistance to an important insect pest, the cowpea borer (*Maruca vitrata*), which causes severe loses to production (an average of 70 to 80% in infested fields) has already been the focus of crop international improvement initiatives using genetic modification (GM) since alternative genetic sources of resistance are not available in the cowpea germplasm. These initiatives, the oldest now in its 27th year, have been led by the public sector with the goal of increasing productivity and reducing dependency on pesticides for the benefit of low-resource producers and consumers in the continent. The Network for the Genetic Improvement of Cowpea for Africa (NGICA) was formed in 2001, and is now evolved into the Cowpea Alliance, which has increased its remit to include yard long bean, and has also expanded membership to include partners from Pakistan and Brazil.

The Pod-borer Resistant Cowpea Project aims to develop and disseminate farmer-preferred and locally adapted *Maruca*-resistant cowpea varieties in Sub-Saharan Africa. The project is arranged as a public-private partnership (PPP), with private company donating the technology. Resistant cowpea lines were first developed in the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia. Organisations in Africa involved in the introgression of the transgene into elite varieties, compliance with regulatory requirements, field testing and seed multiplication and distribution include NGICA; the African Agricultural Technology Foundation (AATF); National Agricultural Research Organisations and the International Institute for Tropical Agriculture (IITA). Currently, three West African countries are carrying out confined field trials: Nigeria, Burkina Faso and Ghana.

NIAB's African collaborations

Dr Lesley Boyd, National Institute for Agricultural Botany (NIAB), UK

Three rust diseases plague wheat: leaf (brown) rust (caused by *Puccinia triticina*); stem (black) rust (caused by *Puccinia graminis*); and stripe (yellow) rust (caused by *Puccinia striiformis*). The incidence of wheat rust is on the increase, with the disease rapidly spreading to regions of the world previously unaffected. A good example is the spread of Ug99, a particularly virulent form of rust that affects over 70 percent of spring wheat. Ug99 was first reported in Uganda in 1999, and by 2007 it had already spread to Asia threatening one of the main producing areas of the world for this crop. The severity of the situation and the risk the disease may also spread to North America have prompted the establishment in 2005 of the Borlaug Global Rust Initiative by the international research community. This initiative comprises global systems for monitoring and surveillance of the disease; research projects focused on gene discovery for new rust resistance genes; the multiplication and distribution of replacement wheat varieties; and training and capacity building in areas affected by rusts.

A number of research initiatives, part of the global effort to tackle wheat rusts have been conducted in partnerships with colleagues in African countries. In 2008, a project funded by the UK Biotechnology and Biological Sciences Research Council SARID (Sustainable Agriculture for International Development) Initiative led to the discovery of disease resistance markers, in collaboration with partners in South Africa and Mexico. This project was followed by another research grant (2012- 2016), which sought to confirm and expand on achievements of the SARID project, and importantly, to extend the partnership to colleagues in Kenya. The network of partnerships has been further extended by a new initiative seeking to address problems in the delivery pipeline for research products to farmers in Sub-Sahara Africa: Agri-Transfer. This project comprises new partners in the UK, and aims to assess the efficacy of new ICT-based extension methods to disseminate information and technologies to smallholder farmers.

Among the achievements to date:

- New sources of rust resistance that are being used by wheat breeders have been identified and characterised.
- Advanced molecular marker platforms were introduced in South Africa and Kenya, and training to PhD students and technical staff was provided, which has enabled research partners in these countries to benefit from technological advances in the field.
- Long-term North-South networks that support crop development and food production have been established

ARC Biotechnology: Genetics, Genomics, Bioinformatics, Phenomics and more….

Dr Jasper Rees, Agricultural Research Council of South Africa

Advances in sequencing technologies in the last three decades have been staggering. While in the early 1980s determining the sequence of short chromosomal regions (100bp) was an arduous team effort, current sequencing machines are able to sequence a billion of kilobases per day. Genome sequencing projects have become an integral part of crop improvement efforts, and several genomics applications require high throughput DNA sequencing: *de novo* and re-sequencing of genomes; marker development; transcriptome analysis and the development of new genetic resources (such as Amaranth and guava). Sequencing projects are also focusing on important plant pathogens, and on livestock species.

The Agricultural Research Council (ARC) Biotechnology Platform was established in 2012 with a focus on several areas: genomics; genomic selection (including mutation breeding and double haploid generation); bioinformatics; plant transformation; plant phenotyping and genetic engineering. Since 2014 the facility houses the Illumina HiSeq2500 Platform, the biggest DNA sequencer in the African continent.

The formation in 2011 of the African orphan crops consortium, a partnership between public and private organisations led by the New Partnership for Africa's Development, follows an increasing recognition of the importance of indigenous genetics resources of the continent. The 96 most important orphan crops have been identified, and sequencing work is being carried out both in the USA and at the ARC. There are also plans to establish an African Plant Breeding Academy at the University of California Davis, US, and plant breeding academy facilities at the World Agroforestry Centre and in West Africa.

Opportunities in African Crop Genetics

Prof Diran Makinde, NEPAD Agency African Biosafety Network of Expertise

The uptake and acceptance of GM crops in the African continent has improved in recent years, with a number of governments revising and strengthening biosafety laws, with both pro- and anti-GM voices being heard in the process. Three African countries currently commercialise GM crops: South Africa, Burkina Faso and Sudan. And 12 countries have enacted biosafety legislations and are leading confined field trials (CFTs), while a further 12 countries have biosafety laws but no CFTs. However, 32 African countries have yet to enact biosafety legislations, and while South Africa has 64 approved events, only one event has been approved in Burkina Faso, Sudan and Egypt (and Egypt has currently suspended the cultivation of GM crops).

CFTs include several crops important for the food security of the continent: banana, cassava, maize, sorghum, cowpea, sweet potato and rice. Traits targeted for improvement are nutritional qualities of the crop (e.g. vitamin-enriched banana, cassava and sorghum); improved tolerance to drought and soil salinity; and improved resistance to tropical pests and diseases.

Important new developments in plant genetics include the establishment in 2013 of the African Orphan Crops Consortium Genomics Lab, which will target neglected indigenous crops important for the food security of the continent. Currently whole genome sequencing is being undertaken for 12 species, and 40 accessions of common bean and African cabbage have been re-sequenced. The aim is to sequence 50 species and estimate the genome size of a further 100 species. In addition, the African Plant Breeding Academy (AfPBA) was established in 2013 at the World Agroforestry Centre (ICRAF) with the aim of training 250 plant breeders and technicians over 5 years.

Another application with large potential benefits both to human health (e.g. for malaria control) and agriculture is the use of transgenic insects. GM mosquitoes engineered for sterility may suppress natural populations transmitting diseases. Consideration will have to be given to potential risks, and social and economic aspects of this technology.

A key challenge in the continent is the fact that although many African countries have biotechnology policies, regulations and strategies they possess limited capacity within national systems in regulatory decision-making. A study using qualitative surveys and desk reviews in seven countries (Burkina Faso, Ghana, Nigeria, Kenya, Uganda Mozambique and South Africa) determined the characteristics of countries with successful biotechnology programmes. These typically have enabling regulatory and business-friendly environments; political will and commitment to implement policy; adequate legal authority; and effective regulatory oversight roles. However, risks associated with the use of biotechnology products are often over-emphasized and the process of adoption is often politicised. Since regulatory processes are commonly influenced by game changers (politicians, local government leaders, community and religious leaders and the media) these are important target groups of communications and outreach initiatives.

Molecular breeding approaches for crop improvement

Prof Ian Graham, University of York

Agricultural productivity is a function of the plant’s genotype, the influence of the environment, and the effect of the interaction of the genotype and the environment. Critical for crop improvement is the availability of genetic variation to be used in plant breeding programmes. Genetic variation may be derived from the species gene pool; from wild ancestors (since the process of domestication results in genetic bottlenecks and the loss of genetic variation); as induced variation from mutagenesis; or engineered via genetic modification. Impressive improvements in DNA sequencing technologies in the last decade have lowered the barrier for development of tools for trait improvement in any crop, facilitating the discovery of new DNA markers and genes.

Malaria is a life threatening disease that according to the World Health Organisation causes over half a million deaths yearly, mostly of children in Africa. A project set to develop improved medicinal plants for malaria adopted a combination approach: wild related species were to used derive novel genetic variation and new sequencing technologies were applied at several stages in the breeding process. These included: the identification of genes and markers; developing a genetic map; and selecting the best parents for the generation of hybrids.

The first hybrids were released in 2012 for commercial production in Africa and China. One hectare of the crop can produce 2 tonnes of dry leaf, yielding 20 kg of artemisin, which is roughly equivalent to 40,000 Artemisinin-based Combination Therapy (ACT) treatments. Currently testing is being carried out in Madagascar, Uganda, India and China, and the lead hybrid was registered in China in 2015.

Session 3: Communication and outreach for Africa's genetic research

Harnessing Genetics for Africa at the Speed of Business

Dr Emmanuel Okogbenin, AATF

Many Sub-Saharan African countries face increasing food security concerns, aggravated by the rapid population growth and changing weather patterns. The development of improved plant genetic resources to face these challenges are important, but pertinent questions include: Is the farmer contextualized as an entrepreneur? Are plant breeding initiatives intended as academic or business ventures? Why are improved crop varieties not being adopted by farmers? Where are the main yield gaps? Development of varieties adapted to conditions in farmers' fields; reducing testing times to accelerate the release of new varieties; and rewarding breeders are measures likely improve the impact of genetics research in the continent.

NPBTs could play an important role in improving the productivity of African agriculture by increasing the speed and efficiency of plant breeding programmes. It is however important to consider how these techniques complement or circumvent existing approaches, and to focus on the desired outcomes rather than on specific breeding methods and approaches.

The African Agricultural Technology Foundation (AATF) plays an important role as a technology broker in the continent, with a portfolio of 28 biotech related technologies developed both by the private and public sectors, which are licensed to farmers free of royalties. Traits targeted include: insect resistance; disease resistance; nitrogen use efficiency; water use efficiency; salt tolerance and drought tolerance. AATF coordinates the whole process of adoption: from the negotiation of intellectual property (IP) rights; to assessing market demands and opportunities; assuring regulatory compliance during testing; and managing the product development and commercialization stages of the projects.

Moving forward it is important to integrate plant genetic improvement with business initiatives and wealth creation. This approach will also facilitate public communication and outreach activities on the importance of new technologies and of plant genetics in general. To this goal it is important to:

- Re-prioritize investment needs to address food security and sustainability demands of Africa
- Enact enabling policies to promote private sector participation
- Promote commercial agriculture for farmers- critical for sustainable food security and promotes the availability and access of quality seeds through quality assurance and control.

Supporting research, understanding and uptake in Africa

Ethel Makila, BecA-ILRI

The Biosciences eastern and central Africa (BecA)- ILRI Hub was established as a centre for excellence *for Africa in Africa* to support and mobilise research for development, and to strengthen the capacity of African researchers to meet the continent's growing challenges. Increasing agricultural productivity and improving food and nutritional safety and security in the continent are key objectives. The Hub functions as a convening point for researchers for training and capacity building. It also aims to connect high-end bioscience research to capabilities already available in various national institutes and universities within the region, supporting NARS scientists of member countries (over 20 in number) in their work.

Since partnerships are central for the centre's activity, key are outreach and communication activities promoting the establishment of networks and collaborations in the African continent and abroad to increase the impact of research. These take several formats:

- Visits to the Hub
- Interaction with media professionals
- The use of a website and social media
- Connecting with end users
- Delivering talks/presentations at forums
- Disseminating printed materials and posters

Key objectives for the future are increasing the visibility of BecA at strategic regional and international forums; advocate for more policy influence to ensure sustainability of research; and increase connection with end users to ensure uptake of research.

Biosciences for Farming in Africa

Dr Claudia Canales, B4FA

Global food security is a pressing concern: 1 billion people do not have enough to eat in terms of calorie intake, and a further two billion suffer from deficiencies in essential nutrients. Africa remains the only continent where food insecurity continues to increase, and where agricultural productivity levels falls significantly below global averages, even in other developing areas of the world. Yet, by applying existing knowledge and available agricultural technologies, the productivity of African agriculture could double or triple. Biosciences for Farming in Africa (B4FA) was set to develop a model for promoting dialog and communication in the field of crop genetic improvement to increase the uptake and impact of research initiatives, focusing in four target countries: Ghana, Nigeria, Uganda and Tanzania.

B4FA consisted of three main activities:

1. Publications and B4FA website- Production and dissemination of two scholarly publications, Insights and Viewpoints, which synthesized information and views from global opinion leaders about the potential benefits, concerns, applications and consequences of new genetic technologies for farming in Africa. These were intended as personal accounts stemming from experience rather than advocating for specific positions in the debate. B4FA website: b4fa.org was developed to a) explain the science that underpins plant genetics and plant breeding to serve as a central resource with a clear focus on African crops; b) serve as a platform to broadcast the publications of B4FA media fellows (see below).
2. Effective Communication of Genetics- An initial analysis of the media establishment and scoping studies in the target countries showed that the technical knowledge and understanding of science by journalists and editors in Africa was then low, as a result of a lack of focus on science reporting as a skill in Africa. It also showed that there is a wealth of research taking

place in African research institutes, but due to the lack of funding for outreach activities much of it remains unknown. B4FA ran two long-term, overlapping professional development Media Fellowships on the new genetics of plant breeding, and a round of master classes for the best Fellows. A total of 160 journalists and editors from print, radio and television were enrolled by competitive application in a programme that offered technical training combined with field-visits, mentoring and support. The Fellowship also provided opportunities for long-term networking amongst the Fellows, and between them and the research community of their country. B4FA Fellows attended, by competitive application, field trips to 50 research institutions and commercial and experimental facilities in their own countries, and to nine international conferences in the UK, the USA (World Food Prize conference); Kenya; Ghana (the FARA African Agricultural Science Week); and Ethiopia. As a result, more than 1,000 journalistic pieces were published during the three years, and several fellows are still actively reporting on the topic.

3. Strengthening and Enabling Implementation- the third activity of B4FA consisted on three studies addressing how to strengthen extension services, or their alternatives, targeting smallholder farmers. These were carried out in collaboration with the National Institute of Agricultural Botany (NIAB), UK; Reading University, UK; Makerere University, Uganda and the NGO Farm Africa.

Session 4: Breakout sessions on outcomes

Breakout sessions on outreach for development outcomes – for both regulators and users/general public

Reaching out the general public

Rapporteur: Robin Fears

The group discussed first the particular relevance of NPBTs to achieving African development outcomes, and agreed that NPBTs may of particular importance to small and medium enterprises (as well as larger ones) for developing the commercial seed sector for major commodity crops. These techniques could also be applied to selected orphan and neglected crops as the first step in accelerated breeding, but at the same time it is necessary to address other gaps and rate-limiting factors in producing food from such crops.

NPBTs could be used to address constraints to production, for example to develop crops that are better suited to reduced water availability, required fewer inputs, and crops that are better suited to smallholder agricultural production systems. An advantage of using a number of NPBTs is that crops developed with a subset of these methods are likely to face reduced regulatory burden than GM crops. Documenting and sharing lessons of good practice and positive experiences is recommended.

While new technologies may provide specific advantages with respect to older methods, these need to be considered as additional “tools in the box” and not as a panacea. A focus on improving crop breeding must be accompanied by strategies to address other critical resources e.g. water and soil. Equally it is important that the use of NPBTs is not pushed by international donors and initiatives, and therefore the involvement, expertise and advocacy of African experts is critical. A challenge in this context is the large heterogeneity among African countries in terms of research capacity (for example, in the number and quality of research institutions), teaching standards and regulatory capabilities.

In terms of outreach and communication initiatives to promote the positive development outcomes of crops developed with NPBTs, the group agreed emphasis should not be placed on breeding techniques but on positive applications, that is focusing on trait/product, not technology. And communication initiatives need to be established as two-way dialogs. Further suggestions put forward were to phrase communication efforts in terms of “beliefs” to avoid the excessive emphasis of risk characteristic of the EU GM debate, and to learn from successful communication experiences in other sectors, such as healthcare. The rational for this approach is that once consumers want a specific product, policy impediments decrease.

Important target groups for outreach activities include journalists, extension workers, farmers and farmers’ associations, research funding bodies and schoolchildren. Finding champions within key groups, such as farmers’ associations, is a positive strategy since farmer-to-farmer communication is proven to be particularly effective. It is also important to use new technologies for communicating, such as mobile phones, and novel ways of phrasing messages. The group agreed learning lessons from other countries with more positive experiences on communicating GM (e.g. South America) to establish best practices is important.

Challenging topics to communicate include problems with food security (why could African countries feed themselves in the past and no longer can?); the impact of urbanisation; and the need to use of appropriate breeding technologies for specific outcomes.

Reaching out to regulators and policy makers in Sub-Saharan Africa

Rapporteur: Rod Scott

One of the main challenges in reaching policy makers in Sub-Saharan African countries recognised by the group is their high turn-over, which implies that communication efforts targeting this group need to be constantly renewed. The most effective method of interacting with policy makers is one-to-one meetings, especially since this allows building up personal relationships and trust.

In the case of regulators it is possible to structure information exchange, and workshops have been common formats of interaction and provision of training. Study tours (“seeing is believing”), for example taking people to Bt cotton fields in Burkina Faso, have been the most successful approach to inform regulators (and also farmers) on issues related to the cultivation of GM crops.

The influence of the EU on policy making, a negative when it pertains to the acceptance of GM technology, is significant and likely to remain an issue due both to trade considerations and strong historical ties between the two continents. This influence persists despite the difference in imperatives for policy makers and regulators in the EU and AU. While increased agricultural productivity is a key objective in Sub-Saharan countries, environmental considerations tend to dominate the political discourse in the EU. Many of the organised NGO-led anti-GMO protests are led and funded by EU groups, with a much smaller contribution of African institutions and individuals. Surprisingly, the negative influence of EU policy in Sub-Sahara Africa is not widely recognised in Europe, despite this being widely appreciated as an issue in the UK.

The current regulatory impasse with respect to the adoption of biosafety regulations in Sub Saharan African countries also represent a legacy of the Cartagena Protocol on Biosafety to the Convention on Biological Diversity and its emphasis on the precautionary principle. A United Nations Environment Programme initiative (UNEP-GEF) set to build biosafety capacity in Africa also resulted in placing biosafety regulations under the jurisdiction of ministries for the environment in several countries, often with no participation of the ministries for agriculture. The resulting balance in power and contrasting priorities (productivity increases versus environmental protection) are difficult to solve. In several countries farmers, although they represent the majority of voters, have failed to gain a strong and unified political voice and form powerful lobbies due to political restrictions to unions.

One strategy recommended by the group is to focus information and communication programmes on food crops consumed locally (and in particular orphan crops), rather than on cash crops for export. This could lead to a twin track approach where the export market remains conventional and the domestic market benefits from GM and NPBT.

It is also important for those who communicate science to be aware of the constraints that policy makers face and their need to secure votes.

The group agreed that a focus on stories is powerful, and that more documentaries on the benefits of GM African crops should be made and widely disseminated.

Session 5: International research, development benefits and outreach

NIAB – Leading the UK in Crop Innovation

Dr Tina Barsby, National Institute for Agricultural Botany

The National Institute for Agricultural Botany (UK) was established in 1919 and was supported by government funding until 2013 when it became an independent crop research and innovation centre with a not-for profit status. Currently 60% of the institute's funding is competitively won. NIAB mission is to provide an integrated research and knowledge transfer hub for the entire crop improvement pipeline, and to lead the UK in crop research innovation. It aims to:

- Provide an independent science-based research and information to support, develop and promote agriculture and horticulture.
- Help the industry to fulfil its potential in supplying food and renewable resources, while respecting the natural

environment, with a short to mid-term (1-10 year) service provision horizon.

NIAB's activities cover the entire crop improvement pipeline: from trait discovery, pre-breeding and commercial breeding through to the running of field trials and the development of new products. With several regional centres, NIAB has over 100 field sites in the UK with 90,000 small plots, of which 70,000 are taken to yield each year.

NIAB also provide two key services to the UK Government:

- NIAB is main technical contractor for UK DUS (distinctiveness, uniformity and stability) testing and related services, including provision of technical and policy advice. About a thousand varieties are tested each year, and recommendations provided are used to produce list of approved varieties and to grant plan breeders rights.
- NIAB provides Seed Certification services to ensure a supply of seed of appropriate quality, identity and purity.

Recent developments in NIAB include the establishment of genetic research and pre-breeding capabilities in 2005 (projects comprise the development of synthetic wheat; manipulation of flowering time; development of transgenic capability for wheat; and the establishment of a specialist potato unit in 2013).

NIAB International: better yields for farmers

Dr Tinashe Chiurugwi, National Institute for Agricultural Botany

Food security is an important concern in African countries, and unsurprisingly the topic features prominently in political debates and is frequently covered by the Africa media. However, messages and political measures are often contradictory. One example is that despite the very public negative stance of Zimbabwe towards GM crops, the country imports GM maize from South Africa during periods of famine.

People's attitude's to food and farming in the African continent is very different compared to European attitudes, and a good understanding of the context is important to design effective communication and outreach initiatives. Traditional farming in Africa relies on informal markets for obtaining seed and inputs and for selling (unlabelled) produce, generally with farmers and consumers having no specific knowledge of the origin, the names or specific attributes of the crop varieties cultivated and sold. Outreach programmes focusing on food production and food security developed outside of Africa by members of the international research community often lack awareness of the context in which agriculture is done in the continent, which limits their impact.

In the UK, NIAB works in the development and dissemination of new crop varieties; carries out education activities on new varieties and how to use them; and monitors the application of seed law (variety testing and certification). In order to determine which aspects of the NIAB Innovation Farm concept are applicable to Africa countries a scoping study was carried out in Ghana, Kenya, Uganda and Tanzania. This involved mapping the 'crop ecosystem' in each country: reviewing key players and existing systems; operating conditions; alternative models; and current and future roles. The informal system characterises 80 percent of agricultural production in most countries, and the seeds are unregulated (farmer-saved). The formal seed sector, accounting for the remaining 20 percent of planted food crops, is usually dependent on the government or on donor organisations.

As a follow-up, NIAB is currently working with partners to improve African seed systems to enhance delivery through formal and informal systems. Future plans include establishing a *NIAB Innovation Farm Ghana*, hosted by the country's Council for Scientific and Industrial Research (CSIR) Crops Research Institute, in Kumasi. Planned activities include showcasing, training and demonstration of agricultural and crop genetic innovation (focusing initially on maize, rice and cowpea) and the facilitation of multi-stakeholder problem solving in the seed system. Part of the funds required for this pilot project has already been secured.

The Consortium of International Agricultural Research Centers

Prof Wayne Powell, Consultative Group for International Agricultural Research (CGIAR)

The Consultative Group for International Agricultural Research (CGIAR) is the only worldwide partnership addressing agricultural research for development.

It is composed of 15 member centres that operate in close collaboration with a large number of partners, including national and regional research institutes; civil society organizations; academia; development organizations and the private sector. CGIAR technologies aim to deliver *Global Public Good* at scale, developed through long-term mission driven research, and delivering multiple benefits, products and knowledge. The CGIAR's past achievements include the development and release of 60% of the wheat varieties grown in the world, and the near totality of the varieties grown in Sub-Saharan Africa and South Asia.

What are the key strategic drivers that should guide the design of an effective agricultural research agenda? The increasing urbanisation of the world's population is foremost in the list. While at the beginning of the last century most people lived in rural areas, at the start this century the balanced switched towards city dwellers. This trend is expected to continue, with the biggest increase in urbanisation expected in Africa and Asia[5]. The supply of nutritious food, in particular fruits and vegetables, will therefore pose a key challenge, as urban inhabitants tend to rely more for their calorie intake on processed food, and typically consume higher levels of sugar and fat compared to rural inhabitants. Fresh produce becomes more expensive and less accessible in cities. At the same time, the rates of diet-related non-communicable diseases such as diabetes and hypertension are increasing rapidly in developing nations. A factor further aggravating the situation is the convergence of global diets: over the last 50 years diets are becoming increasingly similar, with a worldwide over-reliance on a small number of agricultural commodities and a decreased consumption of regional and local staple crops. The complexity of global trade flows of key seed and oil crops and its vulnerability to

[5] *India, China, and Nigeria together will account for more than a third of the projected growth of the world's urban population between now and 2050.*

disruptions potentially reduces the resilience of food systems.

Expanding the research agenda for nutrition-sensitive food systems is therefore a key objective. Micro-nutrient-rich crops developed for African countries (targeting 50 million people from 8 target countries) by the CGIAR represent examples of successful initiatives in this area. These include the following: cassava fortified with pro-vitamin A (released in DR Congo and Nigeria in 2011); beans enriched for iron and zinc (released in 2012 in DR Congo and Rwanda in 2012); pro-vitamin A enriched maize (distributed in Zambia in 2012); and pro-vitamin A sweet potato, recently released in Mozambique and Uganda. However, a critical challenge is that funding for pre-breeding is typically too low or inconsistent for many food crops and non-existent for under-utilised crops in developing countries.

The predicted effect of climate change on agricultural production is another important drive for establishing research priorities. CGIAR developed 100 new varieties of drought-tolerant maize -which yield up to 35% more than existing varieties- and released them across 13 countries, targeting 2 million smallholder farmers. Bean, the staple diet of 0.5 billion people, was also the target of a 15-years breeding programme to increased tolerance to high temperatures and the nutritional value of the seed (containing higher levels of iron and zinc). Improved varieties were released in 2014. And while most of the attention around climate change is directed towards heat and drought, beans are also very sensitive to excess water. Estimates of the likelihood of extended periods of rain with soil moisture in excess of field capacity suggest that as much as 20% of the current area under bean cultivation could be subject to waterlogging, especially in Central America, East and south-central Africa. This demands yet another dimension of breeding for a resilient bean crop. Funds are being sought for this purpose.

A further driver for research is the fact that our economy is increasingly being driven by technology and with a heavy reliance on large bodies of information. While research initiatives typically generate very large quantities of data, there is a growing chasm with the proportion of this data that is actually translated into information, knowledge and new products. Critically needed are fast data techniques and analytic tools to efficiently process information. Just as important though are new training of plant breeders who are specifically trained in data analysis and management.

In a nutshell, the key business of the CGIAR centres is plant breeding: the innovation captured in new seeds and planting materials is essential for improving yields; land and water use efficiency; the nutritional value of crops and resistance to pests and diseases. The integration of different technologies, from selection in open pollinated varieties to the newest plant breeding technologies is critical. Important technological advances of recent years include doubled haploid (DH) technology, which can reduce the number of generations to obtain genetic purity in maize inbred lines for the development of F1 hybrids from to 6-8 to just 2-3.

Maintaining crop diversity is paramount, and a key mission of the CGIAR, which holds 738,000 accessions (703,000 seed; over 31,000 tissue culture and just under 28,000 whole plants). Each year it responds to about

2000 requests and distributes about 130,000 samples to over countries. This is a very valuable resource, and all samples have to be considered as important since any one among them may hold the genes required to increase nutritive value, resist disease, adapt to new climates, or produce higher yields in a specific breeding programme.

Future opportunities for plant breeding include:

- Genomes as a source of genes for breeders, biotechnologists and biologists: broadening the genetic diversity in most key food crops is an imperative. Genomics, informatics and high throughput systems have changed the scientific landscape for gene identification, characterisation and introgression. This means that challenges that were previously too technically difficult, slow or just prohibitively expensive can be tackled now.
- Farmer participation in the processes of genomic selection and new population development is increasingly recognized as an essential component of plant breeding programmes, as is emphasis on gender-relevant traits.
- An ecosystems-based approach to plant breeding is required to increase overall farm productivity sustainably, leading to the integration of crop, agroforestry and livestock systems. A key question to answer is: What breeding approaches do we need to support mixed farming systems of the future?

EASAC and its academy collaborations

Dr Robin Fears, EASAC

The European Academies of Science Advisory Council (EASAC) comprises the national science academies of EU Member States (plus Norway and Switzerland), ALLEA (All European Academies), Academia Europaea (AE), with the Federation of European Academies of Medicine (FEAM) as observer. It provides a mechanism for academies to collaborate to provide independent, expert, timely advice to EU Institutions (in Brussels and Strasbourg). EASAC's secretariat is hosted by the Germany Science Academy Leopoldina, in Halle, Germany, and it also has a networking office in Brussels. EASAC has three main programmes: Energy, Environment, and Biosciences. Each programme has Steering Panel and constitutes Working Groups for specific projects.

EASAC has carried out a number of projects in the area of food and nutrition security and agriculture and relevant EASAC publications (all available at EASAC's website) in the field are the following:

- 2004 Genomics and crop plant science
- 2011 Plant genetic resources for food and agriculture
- 2013 Planting the future
- 2014 Risks to plant health: tackling emerging plant pests and diseases
- 2015 Ecosystem services, agriculture and neonicotinoids
- 2015 Marine sustainability

The *'Planting the future'* project aimed to review the policy implications for the EU in terms of food security, international food trade and agricultural research policies of the current EU stance on crop genetic improvement technologies. These comprised both genetic modification (GM) and the New Plant Breeding Technologies (NPBTs). The study also surveyed peer-reviewed scientific literature on the effect of GM crops on the economy, environment, and agricultural research landscape in five comparator countries that adopted a different stance to the EU towards GM crops: Argentina, Australia, Brazil, Canada and India. The differences in regulatory approaches towards GM crops were also reviewed. Planting the Future also included a collaboration with the Network of African Science Academies (NASAC), with continuing support to continue work on a number of areas, including agricultural biotechnology.

The recommendations of the Planting the Future working group to the EU included:

- Land use, innovation and productivity
- Reforming regulatory framework and promoting competition
- R&D priorities, collaboration, skills and infrastructure
- Global context – sharing good practice, addressing policy disconnects, developing partnerships
- Public engagement

Planting the Future also highlighted connections between EU and Africa, and the evidence that EU policy and practice may constrain the use of crop genetic improvement technologies in African countries, creating difficulties for scientists, farmers, policy makers. While the African continent is very diverse, there are important opportunities to use biotechnology to address local needs. Academies in Africa have important roles in identifying science and technology priorities; strengthening centres of excellence; and providing science-based advice.

There are also significant opportunities for information sharing and research partnership between Africa and EU, informed by local priorities and strengthening local systems.

Current EASAC activities that follow on from Planting the Future include:

- A statement on NPBTs published in March 2015, responding to the current EU controversy over the regulation of these technologies. There is a widespread concern amongst the scientific community that over-regulation in EU may inhibit public sector R&D using NPBTs. Academies also agree that the scientific case should be made for regulating the trait/product rather than the technology used for developing a new crop variety. EASAC also plans to publish a Statement later in 2015 to reinforce messages from PtF for EU policy-makers.

- A three-year food and nutrition security and agriculture project of the global InterAcademies Partnership (IAP, www.interacademies.net) started mid-2015. The project will consist of 4 parallel strands, each carried out by the science academy networks of Africa, Americas, Asia, and Europe, respectively, followed by a fifth synthesis report with global recommendations. The kick-off meeting took place in June 2015.

Session 6: Other considerations

The view from, and power of, the media

Tim Radford, the Guardian

Science needs society, and society needs science. Nonetheless, despite the mutual dependency, this relationship is often fraught. New scientific advances are often received by the public with a degree of distrust, at least initially. One of the main culprits is language: the vocabulary used in science is very technical and specialised. A telling example is that it is sometimes impossible even for the chief editor of the Nature journal to determine from the title of a publication the general discipline to which it belongs. And a very human reaction to scientific advances that may significantly change our world is a feeling that scientists may perhaps be meddling with something they shouldn't be, and could inadvertently unleash a set of negative consequences and events out of their control. These fears are well captured in some of the metaphors used by the media during the recent GM scandals: 'Frankenfoods'; 'the opening Pandora's box'; 'going down the slippery slope'. Ironically, although some of these expressions were used with negative connotations, occasionally they are quite fitting: the creature produced by Dr Frankenstein was initially of good nature, and he sought to win the heart of the family he spied from a distance by helping them, with the hope that when they realised his good character they would accept him despite his poor looks. But he was rejected, and for the second time since his creator had also shunned him. These rejections are the ones that turned him evil. And one of the most important details in the account of Pandora opening the forbidden box is also often let out: after all the plagues and diseases flew away, the last to leave the box was Hope.

But how much does the public really care about science? A few years ago a public survey carried out in the UK and the US asked people whether they would like more science coverage in the media. Overwhelmingly

GM media ironies #1 – "Frankenfoods"

The creature produced by Dr Frankenstein in Mary Shelley's novel was initially of a good nature, and sought to win hearts by helping people in the hope he would be accepted despite his looks. Only after he was rejected by his creator and by those he tried to help did he begin to turn against people.

GM media ironies #2 – "Pandora's Box"

One of the most important details of the Greek myth of Pandora's forbidden box is that after death and all the evils of the world were released from it, the single item that was left inside the box was Hope!

respondents said they would. But when asked whether the sun went around the earth or the other way round, and how long this takes, a significant proportion of the respondents answered incorrectly. So since not everybody has yet caught up with Copernicus, this is an important lesson to bear in mind when developing new science outreach and communication campaigns. But why did so many people answer incorrectly? Perhaps a reason is that for most people, *in practice*, when it comes to the sun and the earth it matters very little what goes around what, and as human beings we are very good at focusing on what we believe to have direct relevance to ourselves. This focus is in fact often a necessity in life.

Often the differences in work of scientists and journalists are highlighted: scientists have generally long-term projects, while journalists need to complete their assignments in a short time frame. But important similarities between the work of scientists and media professionals also exist: both have question (which can be a scientific topic, or arise from attending a conference or event or from an interview), which has to be researched and written up, and both accounts will be judged for accuracy and fairness. But a critical difference is that journalists are judged by a very large number of unknown examiners, and people who do not have to read anything. The worst that can happen to a media story is not to be read or heard, as it will have failed to meet its purpose of being.

Communication is crucial. Even technologies that initially were highly controversial (and with a high 'eek' factor- such as in vitro fertilisation or 'test tube babies') were rapidly accepted once the direct benefits they brought were clear to the public. The power of the media in forming public opinion about scientific advances cannot be ignored. Education is a long-term goal, especially since many of the concepts and the words used are new and unfamiliar to most people, and also to scientists of different disciplines. The media gets it sometimes wrong, and while the right to get occasionally things wrong is important, better communication between scientists and media professionals is essential to increase the quality of media reporting.

Need for evidence-based and globally-integrated regulation of New Biotechnologies

Prof Huw Jones, Rothamsted Research

Two decades' worth of experience regulating the products of plant biotechnology should encourage us to learn from our mistakes. In the current regulatory system a new crop variety resistant to a specific herbicide will be exempt from any form of regulation if developed by chemical or radiation mutagenesis, which causes unknown genetic changes, but heavily regulated if the exact same trait was derived using genetic engineering. Furthermore, the regulatory status in the EU of a crop with the same trait developed by the NPBTs is currently uncertain.

In cereals, current recent developments include a timely convergence of a suite of complementary genetic and cellular ('cellomics') technologies that allow for a faster and more efficient crop improvement. Genomic technologies include whole genome sequencing and RNA profiling and bioinformatics, while some of the technologies under 'cellomics' are genome editing and reverse breeding. Recent technological advances are however in conflict with current regulatory systems and trade agreements.

Genome editing techniques comprise a suite of technologies that allow making targeted changes to the genome. An example of the particular advantages of using gene editing techniques over other methods include the development of wheat varieties with resistance to mildew, which requires editing all six[6] MLO alleles of wheat. Are these wheat varieties GM or not? How will plant varieties developed by NPBTs be regulated in the EU?

In the US, USDA and APHIS have indicated that several new plant varieties made using genome editing techniques would not be regulated as GMOs. Similarly, Argentinian Regulatory authorities have just published guidance that, on a case-by-case basis, simple genome edited plants would not fall under the scope of GMO regulations. In EU however, it is still unknown whether crops modified using these genome editing technologies will be regulated as GMOs under EC 2001/18. The EC is currently considering this question and is expected to publish their views later this year.

The uncertainty over the regulation of genome editing techniques is hampering investment in applied research and commercial innovation in plant breeding. Should the EC define edited crops as GMOs, the high cost regulation and marketing issues over labelling will effectively block its commercial use by academics and small breeding companies. Since some crops developed by NPBTs are undistinguishable from crops developed by conventional breeding techniques additional consequences would include trade issues for intractable imports to the EU from countries where these are not considered GM.

The UK BBSRC has issued a position statement on crops developed by NPBTs that emphasizes that the particular benefits or

[6] *Wheat is a hexaploid, which means it contains six genomes of three different parental lines.*

risks of genetic crop improvement are associated with the specific changes introduced, and not with the method used to make the changes. NPBTs offer a way of making much more specific changes than older technologies, and in some cases it will not be possible to determine how a new plant variety has been produced, since the changes could also be the result of natural variation or conventional breeding techniques. As a result the boundary between GM and not GM becomes blurred, which raises issues on how the technologies should be regulated, and calls for a review of the current regulatory system. A more appropriate way to regulate improved crop varieties would be based on the characteristics of the crop rather than on the breeding method used to develop it.

A much more appropriate regulatory system would have the following characteristics:

- Logical, evidence-based, assessment focussing on food /feed safety
- Move towards a focus on trait or variety
- Capture more but assess at a level proportional to risks
- Move away from automatic pre-market regulation
- Include appropriate post-market monitoring as sole process of assessment for some traits already commercialised

Session 7. Regulatory considerations

NPBTs: state of the art, potential applications and regulatory challenges

Dr Emilio Rodriguez-Cerezo, European Commission, JRC-IPTS

The IPTS carried out a study on NPBTs to review the new techniques; determine the research landscape; commercial development and regulatory and policy issues related to their deployment. The NPBTs follow the introduction of GM, which necessitated a new regulatory framework and generated new intellectual property rights.

The NPBTs can be classified in three distinct groups:

1. *Targeted mutagenesis/genome editing techniques*. These can be subdivided into targeted mutations based on naturally occurring DNA repair mechanisms (SDN-1); and techniques that introduce site-specific changes with the use of a template (SDN2 and SDN3).
2. Negative (null) segregants: A GM event is used in the breeding process but the progeny plants released as commercial variety lack the transgene. Examples include the use of early flowering genes in tree breeding (to reduce the length of generation times) and the use of RNA-dependent DNA methylation to generate epigenetic modifications.
3. Variants of genetic transformation: examples include cisgenesis (where the transgene represents continuous and unchanged elements from same species or from sexually compatible species); and intragenesis, where inserted elements

from the same or a related species may be present in a new combination.

NPBTs have been the focus of an increasing large number of scientific publications (with the US in the lead, followed by the EU) and patents, in particular after 2005. The number of patents, mostly filed by the private sector, is also on the rise.

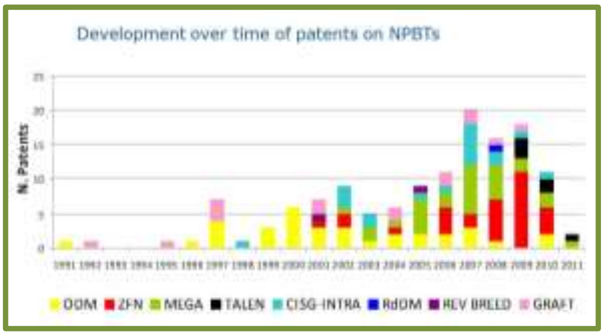

Fig 1: Patent application growth for NPBT's

An particular regulatory challenge of NPBTs is that while the products of a subset of NBPTs can be detected and identified (for example, cisgenesis and intragenesis; ZFN-3; a GM-rootstock); others can be detected but not identified (ZFN-1,2; ODM), while a third group leaves no molecular signature on the improved crops, so they can neither be detected nor identified (RdDM; reverse breeding; non-GM scions; Agro-infiltration).

A large number of cereal and oilseed crops, trees and flower are currently being improved with NPBTs. The economic drive for developing these techniques is the greater precision they allow, although the uncertainty over their regulatory status makes their deployment potentially very expensive. Therefore the extent of use of NPBTs as breeding tools will depend on the regulatory status.

Discussions on regulatory issues associated to NPBTs are taking place in many countries, and expert groups have been set up to advice on classification of the NPBTs and their products vis-à-vis biotech crop legislations. In many cases, legislation and definitions are some 20 years old. However, discrepancies in eventual regulatory status for certain NPBTs-products have already been identified as important trade barriers.

ASSAf Panel: Regulatory Implications of New Genetic Engineering Technologies

Dr Jasper Rees, Agricultural Research Council of South Africa and ASSAf working group

Why address new GM technologies in African countries now? While at the moment there are only three 3 GM crops in commercial production in the continent, 7 countries are carrying confined field trials; 14 countries are engaged in contained research and development; and 27 countries are building up their capacity for biotechnology R&D.

The ASSAf Panel on NPBTs was convened in 2015 to ensure an independent process to determine the regulatory status of NPBTs, inspired in part by the report on NPBTs published by the JRC in 2011. A Consensus Study Panel will be active 2015-2016 to determine the regulatory implications of the New Genetic Engineering Technologies, with the aim to provide credible, independent and unbiased evidence-based policy recommendations. Consensus is reached through study panel deliberations, in a process that is free from the influence of study sponsors or others with a vested interest in the outcome of the study findings, although sponsors may be invited to present to the panel in order to discuss their expectations and to provide relevant information to the study.

Deliberations of the panel group, chosen to comprise a comprehensive and balanced set of experts), are private, although they may be informed by public conferences, workshops, debates and hearings. The mandate of the Panel includes:

- Evaluate the risk/benefit implications and ethics of all relevant new technologies (generally, but also with specific reference to their ability to sustain the diversity of agricultural crops, their ability to improve the agronomy, production and/or value of the crops).
- Determine – with justification - which new technologies should fall under the GMO Act and which do not.
- Outline a framework that can be used to assess the applicability of future technologies to the existing GMO Act & regulations.
- Assess the appropriateness of South African biosafety regulatory framework for biosafety risk evaluation and management of all relevant new technologies.
- Where appropriate, recommend modifications/revisions and/or additions to the existing regulations, individually or collectively, for the new technologies.

Possible policy recommendations include: to leave the GM Act and Regulations as they are; recommend minor changes to the regulations; recommend changes to exclude some or all of these technologies from regulation; or recommend a major review of GMO Act to address review and regulation of novel traits.

NPBTs – Opportunities for Africa: Regulatory Considerations. Perspective from the Program for Biosafety Systems (PBS)

Dr John Komen, PBS

The Program for Biosafety Systems (PBS) supports partner countries in Africa and Asia in the responsible development and use of biotechnology to enhance agricultural innovation. Established in 2003, PBS is now in its third 5-year phase (2013 – 2018). It is primarily funded by USAID and managed by the International Food Policy Research Institute (IFPRI), with a team with expertise in legal matters; socio-economics; and communications and outreach issues.

PBS is works in six African countries (Ghana, Nigeria, Kenya, Uganda, Tanzania, Malawi) and it provides on-request services to Ethiopia, South Africa, Mali and Mozambique. It also collaborates with regional trade associations (COMESA, ECOWAS) for regional harmonisation, and is active globally with respect to the Cartagena Protocol.

Efforts of the past decade are bearing fruits:

- Ghana: National Biosafety Authority established; progress for cowpea, rice, cotton
- Nigeria: Biosafety Act signed & NBMA CEO appointed
- Kenya: WEMA/maize general release application submitted; progress on lifting ban
- Uganda: Progress on Biosafety Bill; expanding CFT portfolio
- Tanzania: Reforms to Biosafety Regulations; progress towards WEMA/maize CFT

- Malawi: Cowpea CFT approved; Bollgard cotton general release application
- COMESA: Common policy on biotech/biosafety adopted Feb.2014; implementation plan endorsed by member-state stakeholders March 2015

Regulators and politicians have in instances shown willingness to take bold steps, approving applications and bills. There is an expanding range of food crops and traits an increased expertise in the continent in the use of more advanced techniques. Also positive is that expertise and data is shared (for example, information on controlled field trials and food safety) among neighbouring countries. A further sign of success is the more balanced media coverage of agricultural biotechnology application and its benefits and risks.

Positive developments include the inclusion of exemptions in national biosafety laws. In Ghana, a GMO may be excluded from risk assessment in cases where it is satisfied that sufficient experience or information exists to conclude that the GMO does not pose a significant risk to the environment. Similarly, Uganda has proposed "expedited" review in cases where research on or commercial release of a GM crop has been approved in a comparable ecosystem, and in cases when a competent national authority or regional body has established that a GM crops poses no risk to human health or the environment. The expedited process will also be applied in case of emergencies, such as food aid.

Also positive is an improved sub-regional collaboration and data exchange. The COMESA common policy on GMO planting, trade and food aid (2014) aims to provide member states with a mechanism for an independent and scientific regional risk assessment of GM crops intended for commercial planting and as food aid. It will provide a technical, biosafety opinion that can be used by individual countries to make approval decisions within their own national regulatory frameworks and establish interactive regional information sharing mechanism on biosafety issues.

However, increased success also brings additional challenges. In Ghana increased activist pressure has resulted in a court case, and several issues around commercialization need to be addressed (for example, food safety, variety registration, liability, labelling). The relevant regulations need to be developed and implemented, and often this required the coordination of several agencies. Compliance in some cases can be problematic.

What are the lessons learned relevant to the 'Genetics for Africa' project?

- Share information on NPBTs early on, with regulators and through public forums such as OFAB
- Monitor discussions at CPB / COP-MOP and EU, and propose science-based options (PRRI)
- Conduct regulatory consultations in Africa regarding products in the pipeline, and possible exemptions
- Work with regional bodies such as COMESA on data exchange and acceptability

Session 8. Recommendations

1. Communicate the importance and value of new plant breeding technologies to the public by focusing on important breeding targets rather on the technologies per se.

- Outreach and communications programmes should highlight the applied nature of research with real-life examples of the benefits.
- The use of NPBTs should be promoted to solve intractable problems, such as the improvement of vegetatively propagated crops that cannot be easily improved by conventional breeding techniques or of crops with low levels of genetic diversity.
- Promote the use of NPBTs for 1) increasing our understanding of the biology of neglected and underutilised 'orphan' crops important in African countries; 2) in breeding programmes to increase the productivity and resilience of such crops. Important issues to address:
    - ❖ Is there interest for this area from funders?
    - ❖ Is there enough involvement of African partners in current breeding programmes focusing on orphan crops?
- Promote the use of NBPTs for improving multiple-use crops (e.g. for food and energy)

2. Craft appropriate messages with suitable, non-technical vocabulary for the target audiences

- The term NPBTs is not a good word to use in public outreach programmes, as it is too technical and detached for a general audience. The technology needs a better, sexier word!
- Promote discussions on the use of science, genetics and the NPBTs as critical for agriculture, the main economic activity and the biggest generator of employment of the continent. Agriculture is:
    - ❖ A way of life for the majority of Africans
    - ❖ Key for food security and a balanced human nutrition
    - ❖ Closely linked to the preservation of limited natural resources
    - ❖ A key priority for most governments
    - ❖ A major generator of employment
- Promote agricultural production as an entrepreneurial exercise for wealth creation: important source of opportunities for business; and promote the establishment of sustainable rural economies.
- Encourage thinking about genetics in an integrated way, for example, addressing farm productivity at different levels at once (crop, animal and microorganisms) and at the same time promoting human health and nutrition.
- Consider the nexus between agriculture, water and energy.
- Harness the open-mindedness among young people with respect to new technologies and biotechnology- promote the sector as pro-youth with good economic opportunities.
- Promote the use of technological advances in other areas (such as mobile telephony) to support agriculture and

rural businesses for a data driven bioeconomy.

3. Sensitize policy makers and politicians to the importance of new technologies, including genetics and NPBT

- Focus on personal relationships – this effort needs to be sustained as the turn-over of functionaries tends to be very high in many Sub Saharan African countries.
- Showcase and demonstrate the opportunities provided by new technologies using stories to back up claims and to provide a narrative they can use with their constituencies to gather support. Study tours for policy makers to other African countries that have already applied new technologies and to the EU and the USA are particularly effective. Identify lead countries in the region and continent as very important for sharing information and experiences.
- Focus on sustainability issues

4. Promote biotechnology in the school curriculum and post-graduate training courses

- Organise public lectures in high schools delivered by national researchers
- Redesign international postgraduate training schemes so that they include longer periods of time in home countries
- Improve the training support and physical infrastructure of national research organisations
- Establish three plant breeding regional centres for West Africa, East Africa and Southern Africa
- Facilitate leadership and articulation of critical issues and priorities in research and outreach by Africans
- Develop appropriate funding mechanisms and develop with research programmes that promote agriculture as a part of a bio-economy, e.g.
- Increase collaborations between African and Western researchers and maximise leverage and impact of initiatives carried out in the CGIAR centres.
- Extending the Media Program to other countries
  - ❖ Work with national journalism institutes/associations and training institutions
  - ❖ Explore how the media and science communications programmes may be developed to benefit African scientists, journalists and policy makers.
  - ❖ Establish a continuing education program for media professionals.

Appendix 1: Workshop Programme

Genetics for Africa – Strategies & Opportunities: Workshop

New Plant Breeding Technologies and other advances in plant genetic research for Africa

July 9th – 10th 2015; National Institute for Agricultural Botany, Cambridge
Sophi Taylor Building, NIAB Park Farm, Villa Road, Impington, Cambridge, CB24 9NZ

Day 1 – Thursday 9th July

Chair: *Prof Sir Brian Heap*

Session 1: Introduction

09.00 Genetics for Africa – Strategies & Opportunities: *Dr Bernie Jones, Co-leader G4ASO*

09.30 An introduction to NPBTs: *Prof Joachim Schiemann, Julius Kühn-Institut, Germany, and lead of EPSO Agricultural Technologies Working Group*

10.00 Epigenetics: *Prof Rod Scott, Bath University*

10.30 Coffee Break

Session 2: Research, development benefits and outreach

11.00 Presentations of research ongoing in or with Africa, with regard especially to development outcomes/potential

Prof Idah Sithole, University of Zimbabwe
Dr Lesley Boyd, National Institute for Agricultural Botany
Dr Jasper Rees, Agricultural Research Council of South Africa
Prof Diran Makinde, NEPAD
Prof Ian Graham, University of York

Discussion and questions

13:00 Lunch

Chair: *Prof Diran Makinde*

Session 3: Communication and outreach for genetics research in Africa

14.00 Presentations of activities to support research, research uptake and public understanding in Africa

"Harnessing Genetics for Africa at the Speed of Business": Dr Emmanuel Okogbenin, AATF
Ethel Makila, BecA-ILRI
Dr Claudia Canales, B4FA

Discussion and questions

15.30 Coffee break

<u>Session 4. Research outcomes</u>

16.00 Breakout sessions on outreach for development outcomes – for both regulators & users/general public**:** *Facilitator Prof Chris Leaver*

17.00 Report back and discussion

19.00 **Reception/Dinner – St Edmunds College**

Day 2 – Friday 10th July

Chair: *Prof Sir Brian Heap*

<u>Session 5. International research, development benefits and outreach</u>

09.00 Presentations of research ongoing in or with Africa, with regard especially to development outcomes/potential

Dr Tina Barsby, National Institute for Agricultural Botany
Prof Wayne Powell, CGIAR
Dr Robin Fears, EASAC

Discussion and questions

10.30 Coffee Break

<u>Session 6. Other considerations</u>

11.00 The view from**, and power of,** the media**:** *Tim Radford, the Guardian*

Discussion and questions

12:00 Lunch

<u>Session 7. Regulatory considerations</u>

13.30 European perspective: *Dr Emilio Rodriguez-Cerezo, DG JRC, European Commission*
Need for evidence-based and globally-integrated regulation of New Biotechnologies:
Prof Huw Jones, Rothamsted Research
African perspective: *Dr Jasper Rees, Ag Research Council of South Africa and ASSAf working group*
International perspective: *Dr John Komen, Programme for Biosafety Systems*

Discussion and questions

15.30 Coffee break

<u>Session 8. Recommendations of workshop</u>

16.00 Breakout sessions on key recommendations of workshop to funders, practitioners and other stakeholders**, and next steps**

17.00 Report back & close

19.00 Dinner (for those not departing on 10th)

STI4D