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Olivier O. Le Gall

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Food and Agriculture Organization
of the United Nations

Proceedings of the FAO International Symposium on the Role of Agricultural Biotechnologies in Sustainable Food Systems and Nutrition



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Proceedings of the FAO International Symposium on the Role of Agricultural Biotechnologies in Sustainable Food Systems and Nutrition

Edited by John Ruane, James D. Dargie and Catriona Daly

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Foreword

We face enormous challenges as we work to eradicate hunger, improve nutrition and make food systems more sustainable. Climate change in particular is undermining the livelihoods and food security of the world's poor, 80 percent of whom live in rural areas and depend on agriculture, including forestry and fisheries.

In addressing these challenges, we need to consider all possible approaches. I believe that the application of science and technology can play a substantial role. We must work to ensure that relevant knowledge and a broad portfolio of tools and practices are available to family farmers.

It was in this context that FAO convened the international symposium on *The Role of Agricultural Biotechnologies in Sustainable Food Systems and Nutrition* on 15-17 February 2016 at FAO headquarters, Rome. The symposium brought together over 400 people, including 230 delegates from 75 member countries and the European Union, as well as representatives of intergovernmental organizations, private sector entities, civil society organizations, academia/research organizations and producer organizations/cooperatives.

The symposium highlighted the important contribution that agricultural biotechnologies can make to achieving the Sustainable Development Goals. It also provided numerous examples where both low- and high-tech biotechnologies are being applied to meet the needs of family farmers.

The symposium successfully broadened the discussions beyond the narrow and polarized debate on genetically modified organisms. It reinforced FAO's role as a neutral forum that can bring together stakeholders from different backgrounds for a frank, open and constructive dialogue and exchange of knowledge on a controversial topic.

To meet the unprecedented challenges of the twenty-first century, a combination of responses from agroecology, agricultural biotechnologies and other approaches will be needed. The symposium indicated that agricultural biotechnologies and agroecology can be used as complementary options.

These proceedings bring together the keynote addresses, perspectives from high-level government representatives, summaries of the symposium's presentations and discussions, and more.

I hope they will contribute to more informed discussions at national, regional and global levels on the role of agricultural biotechnologies in meeting the myriad challenges faced in achieving sustainable agriculture and food security.



José Graziano da Silva
Director-General, FAO

Preface

Estimates indicate that almost 800 million people, about one out of every nine, do not have enough food to eat, while an even greater number are malnourished. At the same time, we are in a phase of exceptional population growth with the global population expected to pass 9 billion by the year 2050. One result is that the demand for food will increase, driven also by changes in dietary patterns towards more livestock products. The agriculture sectors, including forestry and fisheries, are also expected to produce more non-food products, for energy and feed.

This increased demand for food must be achieved while the natural resources upon which agriculture depends, such as land, water and soil, are increasingly threatened by environmental degradation and climate change. Because of climate change, key variables – such as temperature, rain patterns, water availability, frequency and intensity of ‘extreme events’, sea levels and salinization – will all change and have profound impacts on the crop, livestock, forestry and fishery sectors.

It is imperative to move towards food systems that are more sustainable yet produce more food that is of adequate nutritional value and that preserve and enhance ecosystem services and biodiversity.

Science and technology can play a substantial role in providing solutions to these challenges. The suite of practices and technologies available to producers should be as broad as possible, including all of the conventional technologies, such as those used to improve water management in irrigated and rainfed production systems, as well as the wide range of agricultural biotechnologies.

This symposium focused on the role of agricultural biotechnologies and took a multisectoral approach, encompassing the crop, livestock, forestry and fishery sectors, as well as the use of microorganisms within these sectors. In organizing the symposium, FAO used a broad definition for biotechnology which covered low-tech approaches, such as those involving artificial insemination, microbial fermentation and biofertilizers, as well as high-tech approaches, such as those involving advanced DNA-based methodologies and genetically modified organisms (GMOs).

The symposium ran for two and a half days, beginning with an opening plenary session where keynote addresses were delivered by José Graziano da Silva, the FAO Director-General, and a distinguished group of speakers. The main technical discussions were organized around three main themes (climate change; sustainable food systems and nutrition; and people, policies, institutions and communities) and delivered through nine parallel sessions. A high-level ministerial session involved representatives from eight countries. There were five side events organized by external stakeholders as well as an innovative interactive session involving students from different universities around the world. The final plenary session included closing remarks by Louise Fresco (co-chair of the Advisory Panel) and José Graziano da Silva.

These proceedings, organized around eight chapters, provide a record of the main highlights of the symposium¹.

Chapter 1: Opening plenary session, contains the welcome address by the FAO Director-General and three keynote addresses.

Chapter 2: High-level ministerial session, contains the statements by the high-level representatives of eight member countries plus a summary of the subsequent question and answer session.

Chapter 3: Climate change, contains the summary report for the three parallel sessions presented at the final plenary session by a theme leader; the session reports prepared by the FAO rapporteurs; and summaries of the 17 presentations² given by the invited speakers.

Chapter 4: Sustainable food systems and nutrition, contains the summary report for the three parallel sessions presented at the final plenary session by a theme leader; the session reports prepared by the FAO rapporteurs; and summaries of the 15 presentations given by the invited speakers.

Chapter 5: People, policies, institutions and communities, contains the summary report for the three parallel sessions given at the final plenary session by a theme leader; the session reports prepared by the FAO rapporteurs; and summaries of the 14 presentations given by the invited speakers.

Chapter 6: Student session, contains the report presented at the final plenary session by the moderator plus ‘inputs for policy-makers’ from students of eight universities worldwide (Brazil, Colombia, Ghana, Indonesia, Italy, Lebanon, the Netherlands and the United States of America).

Chapter 7: Side events, contains the reports of the five side events arranged by external stakeholders. These side events were chosen based on pre-defined selection criteria following an international call for proposals. Reports were written by the side event organizers.

Chapter 8: Final plenary session, contains the statements by Louise Fresco (co-chair of the Advisory Panel) and the FAO Director-General.

¹ Video recordings of all plenary and parallel sessions, including the high-level ministerial session, student session and five side events, are also available at www.fao.org/about/meetings/agribiotechs-symposium/webcasting/en/

² PowerPoint presentations of these and all other talks given in the nine parallel sessions are available at www.fao.org/3/a-bc787e.pdf

Acknowledgements

Organization of this symposium³ would not have been possible without the dedicated support and commitment of many people.

First and foremost among these were the members of the external **Advisory Panel**, established in April 2015 to provide FAO with guidance and advice on the thematic areas and overall structure of the symposium. We would like to give special thanks to the Panel's co-chairs: Louise Fresco (Wageningen University and Research Centre, the Netherlands) and Shadrack Moephuli (Agricultural Research Council, South Africa).

We would also like to gratefully acknowledge the extensive contributions of the other members of the Advisory Panel: Sachin Chaturvedi (Research and Information System for Developing Countries, India); Appolinaire Djikeng (Biosciences eastern and central Africa Hub, Kenya); Gebisa Ejeta (Purdue University, the United States of America); Sergio Feingold (National Institute of Agricultural Technology, Argentina); Olivier Le Gall (Institut National de la Recherche Agronomique, France); Margaret Gill (CGIAR Independent Science and Partnership Council, Italy); Dominic Glover (Institute of Development Studies, United Kingdom); Paulo Kageyama (University of São Paulo, Brazil); Adrienne Massey (Biotechnology Industry Organization, the United States of America); Eric Meunier (Inf'OGM, France); Thuy Nguyen (Department of Economic Development, Jobs, Transport & Resources, Australia); David Spielman (International Food Policy Research Institute, the United States of America); and Kongming Wu (Chinese Academy of Agricultural Sciences, China).

Theme leaders, working in cooperation with the Advisory Panel, played a key role in the development of proposals for the three parallel sessions held under each of the symposium's main themes:

- Climate change: Olivier Le Gall and Chittaranjan Kole (Jacob School of Biotechnology and Bioengineering, India)
- Sustainable food systems and nutrition: Sergio Feingold and Margaret Gill
- People, policies, institutions and communities: Sachin Chaturvedi and David Spielman

An **FAO interdepartmental Task Force** was responsible for the development and delivery of the symposium. The Task Force was chaired by Ren Wang (Assistant Director General, Agriculture and Consumer Protection Department) under the direct guidance of Maria Helena Semedo (Deputy Director-General, Coordinator for Natural Resources). Their clear leadership and strong support throughout the whole process was fundamental for the success of the symposium.

³ The detailed symposium programme is available at www.fao.org/3/a-bc547e.pdf

The commitment and dedication shown by the Task Force members is gratefully acknowledged, particularly Devin Bartley, Julie Belanger, Paul Boettcher, Clayton Campanhola, Rodrigo Castaneda, Frederic Castell, Saulo Ceolin, Catriona Daly, Larissa Domínguez Fuentes, Kakoli Ghosh, Robert Guei, Jorge Hendrichs, Ljupcho Jankuloski, Aikaterini Kavallari, Jarkko Koskela, Harinder Makkar, Chikelu Mba, Alexandre Meybeck, Kae Mihara, William Murray, Karin Nichterlein, Arshiya Noorani, Erwin Northoff, Halka Otto, Melba Reantaso, John Ruane, Masami Takeuchi, Alberto Trillo Barca, Gerrit Viljoen and Daniele Volpe.

Most of the parallel and plenary sessions were chaired and/or moderated by Advisory Panel members. Apart from FAO staff, the remainder were kindly facilitated by Delia Grace (International Livestock Research Institute, Kenya); Courtney Paisley (Young Professionals for Agricultural Development [YPARD], Italy); Vimlendra Sharan (Embassy of India, Italy); and Eduardo Trigo (Ministry of Science, Technology and Productive Innovation, Argentina). YPARD (Marina Cherbonnier and Courtney Paisley) is also thanked for organizing the student session together with FAO.

FAO provided the majority of funding required to host the symposium. The remainder came from voluntary contributions provided by Agriculture and Agri-Food Canada (AAFC), Canada; the Ministry of Economic Affairs of the Kingdom of the Netherlands; and the United States Department of Agriculture, Foreign Agricultural Service, which are all gratefully acknowledged.

Finally, the FAO Plant Production and Protection Division (AGP) provided the core technical and organizational secretariat for the symposium, and special thanks are given here to Chikelu Mba, William Murray and John Ruane. AGP was also responsible for the administrative and operational aspects of the symposium, and the contributions of Sandra Castrucci, Catriona Daly, Diana Gutierrez Mendez, Desiree Kedjour, Alessia Laurenza, Elena Rotondo, Petra Staberg, Juliet Upton, Deborah Welcomme and Tania White are all gratefully acknowledged.

Abbreviations and Acronyms

ABCF	Africa Biosciences Challenge Fund
AI	Artificial insemination
AOCC	African Orphan Crops Consortium
ASF	African swine fever
AU	African Union
BecA–ILRI Hub	Biosciences eastern and central Africa – International Livestock Research Institute Hub
BNI	Biological nitrification inhibition
Bt	<i>Bacillus thuringiensis</i>
bTB	Bovine tuberculosis
CFT	Confined field trial
CGIAR	Consultative Group on International Agricultural Research
CH ₄	Methane
CIMMYT	International Maize and Wheat Improvement Center
CITT	Comparative intradermal tuberculin test
CO ₂	Carbon dioxide
COP21	21st Conference of the Parties of the United Nations Framework Convention on Climate Change
CRISPR	Clustered, regularly interspaced, short palindromic repeats
CRISPR-Cas9	Clustered, regularly interspaced, short palindromic repeats- CRISPR associated protein 9
ELISA	Enzyme-linked immunosorbent assay
Embrapa	Brazilian Agricultural Research Corporation
FAO	Food and Agriculture Organization of the United Nations
GEA	Genotype-environment association
GHG	Greenhouse gas
GM	Genetically modified
GMO	Genetically modified organism
GSR	Green Super Rice
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
INTA	National Institute of Agricultural Technology (Argentina)

IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual property rights
IRRI	International Rice Research Institute
JIRCAS	Japan International Research Center for Agricultural Sciences
MAS	Marker-assisted selection
N ₂ O	Nitrous oxide
NARS	National agricultural research systems
NEPAD	New Partnership for Africa's Development
NGO	Non-governmental organization
NUE	Nitrogen use efficiency
PCR	Polymerase chain reaction
PPD	Purified protein derivative
PPP	Public–private partnership
QTL	Quantitative trait locus
QTLs	Quantitative trait loci
R&D	Research and development
RNAi	RNA interference
SNP	Single nucleotide polymorphism
SSA	sub-Saharan Africa
SSC	South–South cooperation
TALEN	Transcription activator-like effector nucleases
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USDA-ARS	USDA Agricultural Research Service
WEMA	Water efficient maize for Africa
YPARD	Young Professionals for Agricultural Development
ZFNs	Zinc finger nucleases



Chapter 1

Opening plenary session



1.1 Welcome address

José Graziano da Silva

Director-General,
Food and Agriculture Organization of the United Nations (FAO),
Viale delle Terme di Caracalla,
00153 Rome,
Italy

Dear Ministers; Excellencies; Honourable keynote speakers; Distinguished delegates; Representatives from Civil Society, Private Sector, Research Institutions, Academia; Ladies and gentlemen;

Welcome to this International Symposium on “The Role of Agricultural Biotechnologies in Sustainable Food Systems and Nutrition”.

I am delighted to see representatives of governments, civil society and private sector, as well as eminent experts, opinion leaders, research organizations, cooperatives and development partners, gathered here at FAO for this three-day event.

Thank you for coming in order to share your views, experiences and lessons learned on such an important issue.

As you all know, we have many challenges ahead by 2030 to eradicate hunger, improve nutrition and make food systems more sustainable.

And these challenges are surrounded by uncertainties and complexities, especially in the context of a changing climate.

We are constantly facing new and unexpected situations that emerge as a national, regional or global threat. The Zika Virus, in the health sector, is just an example of such unexpected scenarios.

It reminds me of the words of Lord Keynes, which I quote: *“There is no scientific basis on which to form any calculable probability. We simply do not know what may happen”*.

I am afraid that the challenges posed by climate change to the world food security should be considered under this Keynesian perspective. Because we simply do not know much about what has been called the “new normality”, in order to make calculations on the most probable scenario in the coming years.

The huge amount of information and sometimes mere speculation circulating today increase the uncertainties even more.

Professor Bertrand Hervieu has recently addressed this issue in Paris. Let me quote:

“The events we are experiencing refer to the obvious uncertainty of the course of history and the complexity of the world. This uncertainty and complexity are enhanced by the immediacy of information, which leads to fragmentation, preventing any development of perspectives, explanations and understandings of the world and of the time we live in.

You can be sure”, said Professor Hervieu, “that the year 2016 will be at least as uncertain and complex as 2015 was. So, let us wish for each other the intellectual strength and courage to penetrate this complexity, and, if possible, to control it. Let us not give up to the hardships of our times. Let’s try to master them”.

Ladies and gentlemen,

I am using these words to highlight the importance of considering every possible solution to achieve world food security for all in the years to come.

We must count on a broad portfolio of tools and approaches to eradicate hunger, fight every form of malnutrition and achieve sustainable agriculture in the context of climate change.

As a neutral forum, FAO has been promoting debates, dialogues and exchange of information in order to enhance our knowledge of these tools and approaches.

We held an international symposium on agroecology in 2014.

We helped launch the Global Alliance on Climate Smart Agriculture in the same year.

And we have just released a new edition of “Save and Grow in Practice”, FAO’s model of ecosystem-based agriculture.

Now it is time to discuss and analyse what agricultural biotechnologies have to offer.

This symposium aims at showing the many possibilities and benefits of applying biotechnology in the agricultural sectors, including crops, livestock, forest and fisheries.

Showing, for instance, how it can help to transition to an agricultural production that relies on fewer inputs with less negative environmental impacts.

And, ladies and gentlemen, let me state this loud and clear: this symposium is not only about genetically modified organisms. Agricultural biotechnologies are much broader than GMOs.

Biotechnology gives us options and improves our capacity to act and respond in many different areas.

We will address fermentation processes, biofertilizers, artificial insemination, the production of vaccines, disease diagnostics, just to name a few.



I look forward to hearing stories on how biotechnologies can accelerate the development of improved and locally-adapted crop varieties. And can permit the rapid diagnosis of diseases and pests.

We want also to investigate and give examples of how modern biotechnology can be compatible with principles of agroecological approaches.

Knowledge and innovation are also key to address complex challenges:

- knowledge and innovation that are grounded on sound evidence and science;
- that leads to better integrating different concerns and perspectives of women and men of all ages;
- that can facilitate transfer of technologies and practices, and promote collaboration, including through South–South cooperation.

Ladies and gentlemen,

We cannot lose sight of the fact that biotechnology, knowledge and innovation must be available, accessible and applicable to family farmers. Otherwise, they will have a limited impact.

We must find means to remove the barriers that prevent their availability to family farmers.

They are responsible for the largest proportion of the food we eat.

I hope we will be able to identify new, better and innovative ways to make agricultural biotechnologies accessible to those who could benefit most.

Ladies and gentlemen,

The symposium is planned around three main themes:

- climate change;
- sustainable food systems and nutrition;
- people, policies, institutions and communities.

We will have a high-level segment where government representatives shall express and exchange their views.

There will be also a special student interactive session to provide an opportunity for the young generation to interact.

The symposium will be webcast live on the FAO homepage. That enables everybody, especially those not present in Rome, to follow the proceedings.

This event is another critical step in our efforts in order to reach zero hunger, improve nutrition and promote sustainable food systems.

I thank the members of the Advisory Panel who worked very hard with FAO in developing the programme.

Once more, thank you all for coming and participating in this symposium. I wish you fruitful debates and a successful event.

Thank you for your attention.



1.2 The state of knowledge in biotechnology

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Mr Director-General, distinguished delegates, dear colleagues and friends, it is a great pleasure to stand here again in the Green Room. And for a subject that is so dear to my heart and that we have been discussing at FAO for at least 20 years, if not more. A subject, I think, which more than any other current issue is fraught with difficulties, with misunderstandings, with great hope, with missed opportunities and with wonderful challenges. So let us see where we are today and where we can go from here.

Since the dawn of agriculture, men and women have been selecting species or individuals from species in terms of the most favourable characteristics for human use: bigger apples, stronger animals, fuller ears of corn and wheat. It was actually only one and half centuries ago that visual, phenotypical, selection led to something else, to a better understanding of the laws of inheritance, starting of course with Gregor Mendel. It took a long time for statistics to slowly come into the equation in regards to the probability of inheritance. It was only about 60 years ago when we started to unravel the mechanism of inheritance with the discovery of DNA. The molecule that actually is, in a way, the blueprint of life and the blueprint of inheritance. And then, things changed rapidly. The 1980s saw molecular biology and synthetic biology, and in the 1990s the first work in genetic modifications began. It was, and still is, a revolution as well as a continuity of men's working with nature.

To understand what we have done so far means understanding how genetics actually work, and that unfortunately is complicated, so bear with me. Now this conference is about biotechnology, and biotechnology, as the Director-General said very clearly, is not the same as genetic modification. To put it very simply, biotechnology is an enormous toolbox with lots of different tools that somehow, in some way or another, enable us to understand and unravel the genetics pertaining to the characteristics that make up the actual plant or animal and determine its performance. Genetic modification is a subset of that. It actually allows the introduction of, if you will, alien or foreign DNA into the DNA of the desired individual. You cannot do that without understanding the genetics. And the real breakthrough actually only came in this century and that is when we started to sequence entire genomes of plants and animals. Starting with humans in 2003, the last decade or a little over a decade has seen tremendous progress in getting this full genome sequence. So that means actually understanding the whole of the DNA. Not understanding it in the sense of knowing every characteristic, but we know now the DNA, the genome, of all the major cereals, apples, plums, tomatoes, cocoa and banana. About 80 crops are now fully known in terms of their genome. And

for animals it is even more, about 140 types of animals that we have now sequenced. From horses to cats and dogs, but, of particular relevance here, also goats, pigs, chickens, you name it. Starting with chicken in 2004, we achieved all of this in only ten years. It is a marvellous achievement because it is like knowing a dictionary; it is like knowing the letters of a language. It is only through genomes that we can be far more precise and target the different characteristics that we want to know.

Genetic improvement exists only if there is variability; if there are different individuals with different characteristics. Otherwise, if everybody was identical, there would be no genetic improvement. So biotechnology is a combination of techniques that allows us to better target the kinds of characteristics we want. Let me make that clear through a number of examples that are immediately relevant to small farmers and poor consumers. I think that the thing that is foremost in our minds is, of course, nutritional quality; enhancing nutritional characteristics. The most famous example of that, which you probably know, is golden rice. A genetically modified (GM) crop which contains a fragment of DNA that actually codes for a precursor of vitamin A. Simply put, it has a yellow colour and vitamin A which was not there before. Currently, work is also being done on these characteristics for cassava, and getting a GM cassava is probably around the corner, if it has not happened already. Why is this necessary? Why can we not do this differently? We cannot, because rice does not contain any coding for vitamin A and it has to be found somewhere else. And it can only be found in crops or in plants that are quite different, so you have to introduce a different piece of DNA. In the case of cassava there is an additional complication which makes genetic tools necessary. Cassava does not flower very well at all, so it is very difficult to get new generations with new characteristics. In the case of poor flowering or null characteristic in the original crop, GM techniques (genetic modification) are the tools you need to use. In terms of terminology let me just say that there is a great deal of confusion. Genetic modification yields transgenic plants, transgenic being different from the original genome. Sometimes it is called manipulation but that is, I think, not the term scientists like me would like to use.

Now, another interesting aspect in nutritional improvement is the recent case of the purple tomato. Tomato, as you know, contains lycopene, which is an essential set of ingredients and antioxidants. But interestingly enough, tomato also contains genes for two other antioxidants. However, these are silent and this is something that happens in the genome that we did not know about before. Sometimes the genes are present but they need to be opened in a way. It is like opening the pages of a book. So by using genetic techniques to wake up these genes, we get a purple tomato with much better quality. The result is not a genetically modified tomato. It is a tomato that has undergone a kind of genetic transformation, if you will, only to wake up genes that it already had. So it is still the same genome. We will come back to that difference later.

The most important application, however, is not in regards to nutrition. It is regarding pests, insects and disease resistance. Viruses, bacteria and fungi greatly hamper yields, especially for small farmers. We have seen a surge in applications the names of which all started with Bt. Bt is derived from a soil bacterium, *Bacillus thuringiensis*, which actually confers quite a few properties that protect a plant against certain insects. A good example is papaya in Hawaii where half of the plantations at one stage were wiped out by ringspot virus. GM papaya, this is genetic modification because a piece of the bacterium was actually introduced into the papaya genome, has helped tremendously to revive the plantations. I should hasten to add that, sadly, this was not acceptable everywhere and to everybody,



so the case of papaya is in many ways on hold. We have more examples and the best example for African farmers is, of course, Bt maize which has now been introduced in countries such as Sudan, Burkina Faso, and South Africa and has been a big success.

Another case, an example of what these genetic tools can do, is the potato. You remember the story of potato crops being wiped out by *Phytophthora* in the nineteenth century causing the death of one third of the Irish population. That disease is still around. It is very difficult to find a resistance. The resistance does not exist in the potato that is grown normally, but the resistance exists in a wild progenitor of potato, say a wild relative, an uncle, if you will. And through a process that is called cisgenesis, a piece of the DNA of that wild potato is actually put into the potato and that has had tremendous results. It means that after 50 years of trying to breed for a resistance, we now suddenly have three types of resistance, three genes, if you will, that help to protect the potato and help the potato to win the race against *Phytophthora* which is an extremely difficult disease.

Another example of the types of applications that we can think of is regarding the flowering of fruit trees. Now, you know if you want to improve a tree it often takes generations. Not just generations of trees but generations of humans to actually get the right tree. By using a gene from a plant, actually a model plant, *Arabidopsis*, we can actually shorten the number of generations by inducing early flowering. So instead of thirty years of fruit tree breeding, we can bring it down to about five years. After that period, the gene can be taken out of the fruit tree again so that the fruit tree itself and its fruit are not genetically modified. It is then the last generation that you allow to grow.

In animals we have similar types of results. One important area is, of course, disease resistance, for example in porcine pests. But there are two other areas that you might not realize. One is the defining of the sex of the chicken already in the egg by introducing a gene from the jellyfish, luminescence gene, which allows you to see the sex of the chicken embryo through the egg shell. What does this mean? You can eliminate all male embryos and therefore you do not need to kill all the male chickens after they are born, because male chickens, as you know, do not produce eggs. This is a very simple, more humane, and more animal-friendly technique. Another vast area of application is in the area of vaccine production. The introduction of genetic modification in the virus itself, such as for bluetongue or Rift Valley fever, allows a vaccine to be produced that is not dangerous, but confers resistance to the animals. So there are indeed many applications, including new areas in which we are not just looking at animals and plants but also at bacteria in the gut of animals, such as helping to reduce the greenhouse methane emissions from the stomachs of cows. Another area is the use of waste. Waste, as you know, contains lots of fibres, particularly cellulose and lignin, which can be broken down by bacteria. Genetically modified bacteria help to make your waste more palatable as animal feed.

So how have small farmers benefited? Well, first of all, let me say that of the 18 million farmers that are using genetically modified crops, which is a subset of what we are talking about, 90 percent, nine-zero, are small farmers, according to FAO definitions. And what have they mostly benefited from? From pest and disease resistance, Bt crops which also lead to a reduction in pesticide use, improvements in nutritional quality, and improvements in shelf-life and storability of products so that they can be brought to the market. What has not been very successful yet, but is in progress, is work on improved taste, complex nutritional qualities, and the issue of climate change in particular.



Yes, we have drought resistant maize that has been successful in recent years, but the entire issue of climate change has not been addressed very well.

Now before I go on, I need to explain something about the breeding techniques themselves. So far we have talked about a toolbox and genetic modification, but there are some extremely exciting, very new developments that are extremely relevant today to small farmers but also to regulatory agencies and countries that are here today. We have three ways of doing our breeding. One is just classical crop or animal breeding – you cross the lines and you hope for the best in the next generation. The other one that we just discussed is genetic modification – you introduce a piece of DNA from somewhere else and you get a transgenic crop or animal. But the third way actually supersedes that and changes the story completely and that is what we call “new breeding techniques” or, as I like to call it, precision genetics. It is actually using a pair of scissors which allows you to extremely precisely and efficiently cut the DNA at the place you want and to introduce changes. Introducing changes in such a way that the end result is not a genetically modified crop. Remember my example of the purple tomato? There is no strange DNA. It is only waking up silenced genes or it is using genes for a while and taking them out later in the process. So sometimes, technically speaking, we have a mutation but it comes from the DNA itself and sometimes there is not even a mutation but only, as I call it, the waking up of genes.

Now, I know some of you might be bored by this time but this is an extremely important difference because it means that we have a process to actually conduct changes in the DNA without producing genetically modified organisms. And that is very important for everything that has to do with regulation. That technique is called CRISPR and sometimes is called CRISPR-CAS. CAS is the related protein, but that does not matter so much. To give you an idea, genetic modification is like



MS-DOS on an old computer. CRISPR is like supercomputing or Windows 10 and beyond; it is a completely different ball game. It is precise, it is exact, and it is efficient. And more importantly it can be used in any organism's DNA. Interestingly enough, the CRISPR itself, that is the protein sequence, is part of the natural immune system of bacteria. It was actually a way for bacteria to protect themselves from viruses and that is why it is so precise. But now we find a dilemma, and the dilemma is how can we regulate this? We suddenly have a third category of biotechnology that does not fit the regulations we have so far.

Now I need to add one other complication to that, and that is the issue of food safety which is so dear to our hearts. Risk assessment can use some of these precise techniques to see whether a product going to the consumer is actually genetically modified or not. It can also look at whether something is contaminated with other types of viruses or toxic products. So the assessment techniques actually also evolve and that is very important for poor consumers, who often have poor quality food. We have a number of unresolved problems here. And they are not technical or scientific as much as they are political, and that is why I need to bring them to your attention. One is the whole issue of intellectual property. Who actually owns the results of this work? And this is a tricky issue because apart from farmers and scientists who have done their work, it is obviously companies, particularly large companies, that have a stake or that have done a lot of the research. We have here two opposing political and legal regimes that some of you may be familiar with: breeders' rights and intellectual property rights. In a way, they are opposed because breeders' rights allow scientists to continue with the results of research while intellectual property and patenting does not allow this unless a fee is paid. Now breeders, obviously, want some protection and governments that do not allow that protection will see that breeders will be more hesitant to bring their products to market. On the other hand, obviously, they also need access to what is considered, in a way, the inheritance of mankind. So this is an unresolved issue.

This issue is related to something else: the speed of the whole process. At the moment, it takes about 14 years in pre-regulation processes and maybe another ten to get the regulation organized elsewhere. That is far too long. That is a whole generation of farmers. Now, one of the problems in regulation is that we have, again, two opposing regimes here. We have regulatory agencies that look at the process. Has DNA been introduced or not? If so, is it GM or transgenic? Or they look at the end product. Is the end product GM or not? That is the difference between the United States of America and European regimes and many countries are somewhere in between. This is something that we need to resolve quite urgently because if we do not resolve this, the risk is that national regulation will actually re-do some of this process.

The bottom line is that we have a very complex process here, which is political as well as technical. And it comes as no surprise that it is so difficult for society to follow these huge steps that science is taking and for politicians to have the political courage to move forward in an area which seems very risky in many ways. What are the societal concerns that we should address? First of all, there is a sense that big companies dominate the market. If you want to use a loaded phrase, this is a plot, a neo-liberalist plot, to keep small farmers and poor countries out of the market. I am not talking about my ideas but rather the general perception as this is a big issue. It is true that small companies are only just emerging in this field, particularly in Asia and to some extent in the U.S. Secondly, the perception is that this technology is not very useful to small farmers. I have indicated that there are

many areas where small farmers benefit, but there are some areas where the focus is not on small farmers and the results are only indirect. In particular, the concern is that small farmers will depend on seeds which will create an even greater dependency on the market. That is not exactly true because farmers are used to using hybrid seeds so that problem can be laid to rest to some extent, but it is still the prevailing perception. Then there is the concern about transparency and labelling. Now this a difficult issue. We can do this even better with the new techniques, but big companies are loath to do this very often. Additionally, there is ample evidence that providing more information on labels does not necessarily lead to greater understanding.

There are also a series of other risks that we addressed even in the past here in FAO: human health, animal health, and environmental health. So far, there is no evidence from a scientific perspective that there are any risks, and I choose my words carefully here, that there are any risks with this type of biotechnology that are greater than the normal risks that we accept in classical plant breeding. But no evidence of risk is not proof that there is no risk. I hope you see the difference. But we are a long way from 20 years ago when the first GM herbicide-resistant soy and maize came to the market, for large-scale zero tillage production. As I said, 90 percent of the farmers that are benefiting are small farmers. But still, four crops dominate and they are all feed crops. Food crops are following slowly, particularly rice, potato and tomato. There is a great deal in the pipeline. But it is fraught with difficulty when it comes to regulation which can take 20 years or more.

So the issue is urgent. What can we do to make sure that poor consumers and poor farmers actually benefit? What needs to be resolved? Let me give you a few ideas here which I hope you will discuss.

First of all, I think we have to understand that with the delays, the current delays, and even future delays, we are targeting not today's small farmers but the next generation of small farmers. And that generation needs to be more entrepreneurial and more professional because young people will not want to remain small farmers if they can help it. So this technology needs to be part of a far larger package of agricultural development.

Secondly, we need to resolve some of the biosafety issues, particularly with CRISPR. This new genetics allows far better targeting for small applications, local applications but it needs to be able to come to the market.

Thirdly, we need to do something about the controversy between breeders' rights and patenting. This is an unresolved issue for many reasons, I know, but still, we cannot go on this way.

Next, we need far more public–private partnerships. This cannot be only a government issue or only a private sector issue. This needs collaboration, especially to help smaller companies with local clients and targets get to the market. And we need more research, long-term focused research, on the needs of small farmers and poor consumers, on the issues of climate change, and on nutritional quality. We need to acknowledge that some of these techniques are still neutral. They are applicable, like Bt, to small and big farmers but we need a far longer commitment and more funding to really do the trials and do the work in the fields. We need a systems approach.



And then we need a social dialogue. This is an issue with a great deal of misunderstanding because it is complicated and we need to resolve this. This is not a matter of us scientists coming out of our ivory tower, it is a matter of working together to identify the issues and to try and resolve them. The social dialogue is as important as the science today.

And then, we need to resolve things in an international forum, and that is my last comment. I think, that it is extremely appropriate that we are here at FAO. This is the heart of FAO's mandate. It also requires us to think about the international agreements that we have that touch upon this. Think of the Convention on Biological Diversity, think of course of FAO's own bodies, but also other bodies that are relevant here in some way or another. And maybe what we need to think about these days is a kind of platform to bring different parties together and to talk about what kind of regulation is needed in the future. Both unqualified optimism and severe pessimism are wrong in this case. The devil is in the details. It is probably the most important issue for the future of food and nutrition. We have to resolve it politically and technically. The future is already here but it is not evenly distributed. We must make sure that everybody has access to technology that betters his or her life. Thank you very much.

1.3 Biotechnologies in action in Brazil

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Brazil is one of the largest countries in the world, with an extensive surface of continuous land, a large supply of freshwater, abundant solar energy and a rich biodiversity. The wide range of climatic conditions, from temperate to tropical, together with advanced capacity in technology development, allowed considerable diversification of agricultural systems in the country, which has become one of the world's largest producers of food, feed, fibres and renewable fuels. In this presentation, we will evaluate the impact of research and innovation in the process of agricultural modernization in Brazil, with emphasis on advances in biotechnology and related fields.

The presentation is divided into three parts as follows:

- a) A summary of the constraints to agricultural development in Brazil, the key drivers for agricultural innovation, that led food security and enhanced export capacity in the short span of 40 years;
- b) A synthesis of the development of modern biotechnology in Brazil and its role in the recent development of Brazilian agriculture, and
- c) The new wave of biotechnologies and their potential impact in the nascent bioeconomy and sustainable agriculture and food production in the country.

Brazilian agriculture, after the 1970s, is a story of success. In the past 40 years the country was able to transform its traditional agriculture into a dynamic and competitive agriculture strongly sustained on science and its wealth of natural resources. Besides its 8.5 million km², Brazil has also a significant supply of fresh water (15.2 percent of the world's renewable water resource), large availability of arable land (13.5 percent of the world's equivalent potential arable land), abundant solar energy and a rich biodiversity. Among the 250 000 species of higher plants, nearly 60 000 are native to Brazil. In addition to the world's largest tropical forest, the country has over 200 million hectares of savannas (known as Cerrado in Brazil), which had its immense agriculture and livestock production potential unleashed through a science-based approach starting in the early 1970s.

During the past 40 years, Brazil has been able to successfully use its natural resources endowments to effectively become a world leader in the agricultural sector and more effectively boost backward and forward linkages in the economy. The traditional agriculture that prevailed in Brazil until the 1970s was progressively transformed in the following decades into a modern and highly competitive agriculture based on science and technology. Overall, such outcomes have made Brazil the world's largest producer of citrus fruits, frozen concentrated orange juice, sugar cane and coffee. The country is also a serious global competitor for many other products — soybeans, tobacco, poultry, corn, beef, biofuels — and self-sufficient in the production of most agricultural goods.



One common feature throughout this period was the huge agricultural research effort that generated important spillovers of knowledge and technology to farmers with an ample array of positive outcomes to Brazil and other countries in the tropical belt of the world. The Brazilian approach to develop autochthonous science and innovation for agriculture allowed for increased agricultural productivity, production and exports and decreasing food prices to consumers. The development path of Brazilian agriculture, especially from the 1990s onwards, was strongly based on productivity gains. Overall productivity gains in Brazilian agriculture have reflected a range of policies that varied markedly in the past 40 years. This virtuous growth path in Brazilian agriculture explains the country as a world's top agricultural producer at the same time it maintains over 60 percent of its territory preserved. In spite of this progress, it is necessary to recognize some localized drawbacks among agricultural production, environment and social claims, and the need to move even further in this sustainability path.

The key drivers for the tremendous advances achieved by the country can be summarized as: a) improvement in fertilizer recommendations and acidity control; b) availability of quality and certified seeds; c) governmental commitment and public policies for agricultural development; d) a landscape available for mechanisation; and e) availability of mineral resources. Ironically, with the acidic soils that dominate the landscape of the Brazilian Savannah, there is a plethora of limestone mines. The last and most important driver is by far the will and the entrepreneurship of our farmers that migrated from the south and embraced the huge challenge of developing advanced agriculture in tropical Brazil.

Institutional building and strengthening is also at the root of these developments. Brazil has developed a large and complex agricultural research basis, which is composed of public institutes, universities, private companies and non-governmental organizations. This capacity stands as one of the most comprehensive and most efficient in the tropical belt of the world. Beginning in the 1970s, Brazil improved its structure and capacity substantially, developing a two-tier system of federal- and state-based agencies. This so-called National System for Agricultural Research and Innovation (SNPA) has developed and promoted a wide array of technological innovations that triggered the expansion of agribusiness over the past four decades.

The SNPA is responsible for organizing, coordinating and implementing research that objectively contribute to the development of agriculture, sustainable use and the preservation of natural resources. Implementation of the SNPA concept led to the strengthening of agricultural research and development (R&D) capacity in Brazil, with improved infrastructure, human capacity, management mechanisms and support policies on a national scale. Embrapa is by far the largest component of the Brazilian SNPA system. A semi-autonomous federal agency administered by the Ministry of Agriculture and Food Supply, Embrapa is the largest agricultural R&D agency in Latin America in terms of both staff numbers and expenditure. The agency is headquartered in the capital Brasilia and operates 46 research centres throughout the country.

Given this background, we want to explore the importance of research and innovation in biotechnology for Brazilian agriculture. Despite the advances achieved in the past four decades, the challenges arising from global warming, the consequent climatic extremes, and an increasing world population make sustainable food production a key issue for the tropics. To maintain productivity and sustainability of agricultural systems, it is crucial to be alert, informed and acquainted with new

technologies that could change production and consumption concepts, standards and paradigms. Scientific revolutions are happening in various fields of knowledge, in biology with genomics, in physics and chemistry with nanotechnology, in information and communication technology, with innovations that increase our ability to respond to risks and challenges.

In recent years, biology has produced tremendous advances which allow us to broaden our understanding of complex mechanisms in plants, animals and micro-organisms. New biotechnologies are already impacting agricultural diversification, specialization and value aggregation, besides increased productivity, safety and quality of food. Using advanced biotechnologies in agriculture to confront the challenges ahead is strategic not only for Brazil, but for the world. Among the wide range of biotechnologies available and in development, genetic modification of crops stands as one of the most successful to date.

In the past decade, Brazil has become the second largest user of genetically modified (GM) crops, with an area greater than 42 million hectares during the last crop season (2014/15). As of July 2015, there are 45 GM events approved for commercial cultivation in Brazil, of which 25 events for corn, 12 for cotton, six for soybeans, one for dry edible beans, and, most recently, one for eucalyptus. GM events with herbicide tolerance traits lead the adoption rate with 65 percent of the total area planted followed by insect resistance with 19 percent and stacked genes with 16 percent.

The adoption of biotechnology products in agriculture definitively helped the country to reach its current production level, even with the late adoption of GM crops, due to a “non-official moratorium” caused by legal disputes from 1998 to 2005. Only after the implementation of the new Biosafety Law was the use of GM plants officially endorsed in a trustable legal framework, essential for the stability of any economic sector. Several public and private, national and foreign institutions conduct research and development in Brazil to produce GM plants with several agronomic traits and/or characteristics that add value to the agriculture product.

The majority of GM crops being grown in Brazil are soybeans, corn and cotton, all belonging to the first generation of transgenic plants, which are insect and/or herbicide tolerant. As is the case in the rest of the world, the biggest share of GM crops being produced commercially in Brazil were developed by private companies such as Monsanto, DuPont Pioneer, Syngenta, Bayer and Dow, among others. However, the local research community has the capabilities to prospect genes of interest, “proof concept” of novel genetic engineering strategies, test it in controlled and real field conditions and take the developed product to the market.

Research institutes, universities and Embrapa have been developing various GM plants with different traits of interest. Embrapa developed and deregulated the first GM bean (*Phaseolus vulgaris*) with resistance to the golden mosaic virus to be produced commercially in Brazil, and, in a joint venture with the German company BASF, developed and deregulated a herbicide-resistant soybean. The new variety, which has resistance to imidazolinone herbicides, was released commercially in the 2015/16 growing season under the trade name “Cultivance.”

In addition to soybean, corn and cotton, various other GM crops are being tested in advanced development stages in field conditions in Brazil. Rice, passion fruit, eucalyptus, cowpea and sugar



cane are examples of species being tested in actual field conditions for different traits such as yield improvement, drought tolerance, fungus resistance, oil quality and wood density. It is undeniable that there was a rapid increase in the utilization of genetic engineering technologies in Brazilian agriculture after the new Biosafety Law, in 2005. The unification of laws, rules and guidelines by all agencies involved in the biosafety legislation framework allowed, undoubtedly, the rescue of the confidence by investors, researchers, private/public institutions, and by all other stakeholders involved in Brazilian agribusiness.

In the area of animal breeding, several Brazilian companies have expanded the use of biotechnology tools to develop new cattle breeds well adapted to the tropical climate using genomics, artificial insemination and animal cloning and are exporting improved genetic material (semen, embryos) and live high-performance animals to developing and developed countries, such as Mozambique, Costa Rica, India and the United States of America. As a pre-condition for further export, sanitary protocols are being discussed by the Brazilian Ministry of Agriculture with Angola, Bolivia (Plurinational State of), Colombia, Ecuador, Mexico, Panama, Paraguay and Venezuela. As much as in breeding, biotechnology tools are helping to improve the sanitary conditions of the herds by making possible the production of a number of vaccines.

From the microbial world, one of the most interesting biotechnologies developed in Brazil has been the use of nitrogen fixing bacteria, which began with *Rhizobia* in soybean some 40 years ago and has now been adapted to help the growth and production of sugar cane, corn and other legumes. In the tropical world this is a very important tool to help in the mitigation of climate change. The development of biological nitrogen fixation for soybean, which allowed this crop to be grown without mineral nitrogen fertilizer, had a major impact in the country. Today, Brazil cultivates over 30 million hectares of soybean without the need for chemical nitrogen, saving farmers about US\$ 5 billion every growing season.

Also, cloning and micropropagation are widely used for several ornamental plants, fruits such as banana, pineapple and strawberry and forest species such as *Eucalyptus* and *Pinus*. And biotechnology tools are also helping to develop new biological control formulations to be used in integrated pest management – a most welcome concept used more and more in sustainable agriculture.

Brazil is also investing in biotechnologies that can connect its agricultural system to the nascent bioeconomy. Among the major routes considered in the pipeline are the metabolic processes of organisms (plants, animals and micro-organisms) with focus on the production of materials and substances of high value, targeted to multiple uses (chemical and biochemical, medical, pharmaceutical, nutritional, energy, etc.). Multiple efforts for development of plant biofactories, genetically modified and cloned animals are underway. And biomass and biorefinery technologies are being developed to meet the demands for sustainable energy, chemicals and new bio-based materials. The growth of the bio-based economy can generate multiple opportunities for economic growth and creation of new jobs, including in rural areas.

New cutting-edge biotechnologies will become more and more important for Brazil for obvious reasons. More efficient technologies will be necessary to supply the needs of food to Brazilian society, besides the production of exportable surpluses to the world, thus fulfilling expectations of the

country's contribution to food and nutritional security, globally. Technological advances will have to facilitate preservation of natural resources such as soil, water, forests and biodiversity. Add to that attention to global warming and its potential effects on agricultural production. More research is needed to mitigate effects of extreme weather events and to allow adaptation to new presumptive scenarios of biotic and abiotic stress intensification, as well as energy insecurity.

Despite the scale of the challenges, one must also recognize that the technological progress in several fronts is impressive, increasing chances of successful response. It is also important to think beyond the wonders of biology and modern biotechnology. Innovations in the fields of information technology and communications, remote sensing, advanced instrumentation, automation and robotics indicate that precision agriculture will emerge as common practice in agriculture in the near future. These tools and processes will allow smarter use of our natural resource base, ensuring more productivity, efficiency and sustainability in production systems. Nanotechnology, with innovations in the scale of the billionth of the meter, also promises to revolutionize the development of multiple products, processes and instruments. Advanced sensors will enable the monitoring of production systems with great precision, and new materials and processes will allow development of machines and equipment that are more efficient, accurate and durable.

All these innovations will have enormous implications for the future of agriculture. In order to benefit from them, and to remain competitive, countries will need to invest in training of human resources and sophistication of processes, methods and instrumentation. Information and communication technologies also promise to further revolutionize methods of managing agricultural production, access to markets, logistics and the relationship between producers and consumers. New information and communication technologies have also the potential to change behaviour, requiring increasing attention to consumer demands and to perceptions of society in relation to agriculture.

Conclusions

The agriculture of the future will be impacted by concepts, methods and multi-functionality far beyond conventional. Technological standards of the global agriculture are now being changed by the introduction of new technologies resulting from very recent advances in scientific knowledge.

The challenges ahead indicate the need to adjust and change agriculture and food production in ways that ensure improved sustainability and a healthier and more nutritious food supply. It involves, necessarily, the increased use of advanced technologies, with special emphasis in creative uses of genetic diversity – modern biotechnologies, following the development of the bioeconomy. Despite the scale of the challenges, one must also recognize that the technological progress in several fronts is impressive, increasing the chances of successful response.

In recent years, biology has produced tremendous advances, which allow us to broaden our understanding of complex mechanisms in plants, animals and micro-organisms. From such advances will innovations arise to agricultural diversification, specialization and value aggregation, besides increased productivity, safety and quality of food essential to assure a more sustainable future for humanity?



1.4 Breakthroughs in resource productivity

Gunter Pauli

Founder,
Zero Emissions Research and Initiatives Network,
Japan

Let me, first of all, thank FAO for inviting a rebel like me to come to this podium. The Huffington Post calls me the Steve Jobs of sustainability but my friends in Latin America call me the Che Guevara of sustainability. I think it's very important that in this debate we enlarge discussions of the very narrowly defined biotechnologies which only seem to look at a few plants and a few animals. Ladies and gentlemen, "bio" depends on "eco" – ecosystems. We need to understand the ecosystems as such and find the greatness of the ecosystem which gives us solutions we can never imagine in a laboratory. And let me just give you a first example when it comes to golden rice.

Income, malnutrition and control over seeds

In the Rio Grande do Sul State in Brazil, we have studied how to enrich vitamin A in food, especially for the malnourished children. We quickly concluded that there is no need to genetically manipulate the rice. You only have to harvest the microalgae that grow in the water that you use for irrigating rice paddies. Lo and behold, we found out that there is 12 times more vitamin A and beta-carotene in the microalgae in the rice water than you could ever get genetically into the kernel. So my question is: do you want something that is poorly designed, controlled by one company, and in the end not so efficient, or do you want to double the farmers' income and use local biodiversity? To me, the key priority is to ensure that there is income for the farmer, and that we fight malnutrition with what is locally available and ensure wide access of the benefits to everyone in the community, not just the one company that owns the intellectual property.

Ethics at the core

We have to put ethics at the core of this. I ask each country to never permit any company to operate in the nation if farmers are forbidden by contract, and even taken to court, to keep seeds from that specific plant variety. Excuse me, ladies and gentlemen, that is ethically incorrect. We have to permit the farmer to do what the farmer has always been doing: keep seeds for the next season. Therefore I am very firm and I disagree with the arguments sometimes forwarded by multinational companies, mentioned by a previous speaker, whereby governments of developing nations are corrupt, have inefficient bureaucracies and lack scientific knowledge when the seed companies cannot sell their engineered seeds to farmers.

“Think tank” and “Do tank”

In 1994, I was invited by the United Nations in Tokyo and the Japanese government to assist in the design of business models that would have zero emissions, hence still the name of my organization. We created over the years a network of 3 000 scientists that I call the “think tank”. We have, on the other hand, 850 implementers – we call them the “do tank”. We combine the thinking and the doing. It is a tremendous honour to know that while 20 years ago we were considered to be dreamers imagining a world of no waste or emissions, we now have 200 projects implemented, US\$4 billion invested and 3 million jobs generated. At the end of the day, if we don't keep the generation of jobs as a top priority – especially in shanty towns and rural areas – in whatever we do we are not serving society.

Biodegradable is not necessarily sustainable

The biotechnologies must be at the service for all. I set up 12 corporations myself. Two failed. One of these corporations took on Procter and Gamble, Henkel and Unilever for the production of biodegradable soaps. The company was very successful. We took market share without advertising. When these fast-moving consumer goods producers don't see advertising they don't understand how it works. But, as shareholder and CEO, I had decided to invest the near total of a three-year budget for advertising in the first zero emissions factory, a factory that had no waste. In 1992, the company's car fleet was running on biofuels. We were early. But, I had become the biggest buyer of palm oil and the Indonesian government hosted me as a VIP in Kalimantan, I realized that, while I was this green entrepreneur and had this ecological factory, unfortunately I was destroying the rainforest. I was destroying the habitat of the orangutan and the dwarf elephant.

It is very important to accept that when we want to do business, we can never foresee all consequences. Innovations will always result in unintended consequences. Now, as long as you didn't know it had this consequence then it is unintended, and you have a clear conscience. But, the moment you know there is the negative impact and you knowingly continue, then it becomes collateral damage. That's ethically not permitted. Unfortunately, industries today, backed by major investors, particularly hedge funds, are not prepared to take responsibility for their unintended consequences. Worse, these companies want fast-track approvals for any innovation be it chemical or biological. Therefore, in my view, the world has to redefine their license to operate and accept that quick fixes are not necessarily long term solutions.

Bamboo vs eucalyptus

Unfortunately, I had to realise that biodegradable palm oil is not sustainable. It is very unfortunate since it is more than the palm oil. There are these plantations – which I call empty forests. Nothing grows in there except a genetically modified (GM) tree. You know, how could we ever sustain a growing need for food and jobs in this world if we create empty forests? I must say that I do not understand this obsession for GM. For example, the recently approved genetically modified eucalyptus trees in Brazil. Why? Because Brazil has the world's largest biodiversity in bamboo and we have demonstrated to Embrapa that on one hectare you can generate 60 times more fibres over a 100 year period than you can ever do with a GM eucalyptus that grows to maturity in eight years.



Bamboo grows to maturity in three years, does not need replanting for at least 70 years, and has a much higher incidence of fibre per acre. Bamboo simply is much more efficient. The only reason why GM eucalyptus reigns is the prevailing institutional, technological lock-in of the paper processors with forestry companies, due to locked-in investments in millions of acres of planted empty forests. Even when the efficiency for the earth, the nation and the people on all counts from jobs to water are in favour of bamboo, the industry will insist on “business as usual” refusing to rely on “nature’s best”.

Ladies and gentlemen, sometimes we have to look reality in the eye. We have to say what is not popular and some will even tell that it is not politically correct. Doing less bad is bad. If I’m telling you that I’ve been stealing, I’m called before the judge and I’m promising him that I’m going to steal less, do you think the judge will consider me a good citizen, qualifying me for an early release from prison? Of course not. But, when we have companies that pollute and contaminate and don’t want to take risks beyond the very narrowly-defined logic of risk by their core business, and they are committing to reduce risk and pollute less, then I must say you are still polluting. Polluting is polluting. Polluting less is polluting. Stealing less is stealing. How can we sustain a double moral along those lines and even offer these less-polluting companies environmental awards?

Blind search for productivity

Therefore, I must sometimes say that I am ashamed at how we have developed our food industry. I do not understand how we have come to the stupidity and, to me, even the insanity to have one-day old chickens flown around the world on jumbo jets. We don’t want to have a male when it should be a female and don’t want to have a female when it should be a male. I mean, ladies and gentlemen, why don’t we let the males and the females live? One for the meat and one for the eggs. But we don’t do it because we have genetically transformed those chickens to the point that the males that come from the egg-laying chickens cannot even walk. So what do we do?

Should I herald it as a breakthrough when scientists are injecting molecules derived from an octopus in order to see early on if it’s a male or a female chicken because that is considered an improvement from the shredding of chickens, which is still the standard today. Ladies and gentlemen, we are shredding millions of chickens every day. We don’t realize it, we don’t want to know it. After a major outcry in the social media in 2015, the German Government suggested that instead of shredding, producers should gas them to death. I don’t get it. Now we just have to ask ourselves a question: how come we don’t succeed in leaving both of them alive? How come we can lose sight of this 50 percent all for the sake of productivity?

A new model for fishing

If you give a man a fish for a day he will not be hungry. If you teach him how to fish he will overfish! So the hard reality is not only that we overfish, we enjoy eating the eggs of these fish. Can you imagine that a farmer goes with a cow to the butcher to slaughter it while the cow is going to calve in a few weeks’ time? I think that in many countries the butcher and the farmer would be put in jail. We would not tolerate it with animals, but we enjoy it with fish all the time. Is it because the animal is hairy and has four legs? I mean how can we have a fishing system where fish eggs are a delicacy? Now if you kill the females with eggs, plus overfish, how sustainable is your fishing technique? Now

do you think GM tilapia is going to solve that problem? I wish you good luck. Because then you get into the hands of a feed business that has only one interest, to sell feed. We have this persistent drive to cut costs and go for the cheapest option. We have to start looking at generating more revenues with what we have, and we need to have a persistent drive to respond to the people's needs. May we put it as a priority? This is the United Nations right? May we have the interest and the benefit for society as a priority in policy-making and technology decisions? That requires new business models combined with different priorities for technology and innovations. We've heard from three speakers one type of technology, genomics and genetic modification. Permit me to share what we do.

You know how the whales fish their krill? With air bubbles. The whales are capable of designing an envelope of air bubbles around krill that permits them to catch all the krill. Smart! How come we can't do that? Well we can. I have not only been involved with a team of about 20 researchers to design this but the first tests have just been done in Peniche (Portugal) where the fishermen tested fishing with air bubbles. When the fish float, thanks to the air bubbles, we scoop them into the boat and then check if the females have eggs. The females with eggs are returned to the sea. Doesn't it make sense? Tests for two years in El Hierro (Canary Islands, Spain) allowed fish stocks to jump to the level of 1974. Why? Because we don't kill females with eggs. Are we ready to do that kind of research? Is there money available for that? This research and development is privately funded because the governments think that this is not the way to go.

We have now gone into the next phase which is the design of the boats. Because if you fish with air bubbles then you have to have a catamaran. Catching pelagic fish with air bubbles is easy. Now if you don't need to pull the nets and you don't have to freeze the fish, you save 80 percent of the required energy. That means this boat will be a cheap version of the Tesla for the fishing industry. Why? Because we can now process every fish on the boat, and we ensured that all females with eggs will continue their life cycles. We redesigned the fishing logic, not just the technique. Everything is done with seawater, eliminating freshwater. These fishing vessels save 250 000 litres of fuel per year per boat. When I met with the Minister of Marine Resources and Fisheries of Indonesia in Jakarta, she indicated that the nation needs at least one boat for every island. That's 17 000 boats. When you share a vision and make it clear that there are opportunities to change our food base, our protein search, and generate new industries, including shipbuilding, that work with the ecosystem and display a regenerative capacity, then we are contributing with technologies that empower fishermen.

Recover the mangroves and the shrimp farming

In Indonesia, as well, I would like to share that partnership of the government with the private sector is regenerating mangroves these days, where there used to be shrimp farms. You remember there were massive investments in shrimp farms and then the white spot virus attacked bankrupting the areas where the mangroves once stood. Seventy-five percent of the business evaporated and the European Union, rightfully so, objected to the use of antibiotics. The Indonesian Government, under the leadership of its Ministry of Marine Resources invested years to regenerate mangroves along the coast of East Java, outside of Surabaya. Here, channels in the newly planted mangroves are rich in shrimp which no one has to feed. Shrimp which you don't have to feed? Do you think this business model is competitive?



Salt resistant rice

Since we know there are rising sea levels, because of climate change, the encroachment of the seawater into the land is very plausible. Therefore, we need to look at the opportunity to propagate a natural hybrid salt resistant sea rice, which grows in China. Ladies and gentlemen, there is the first harvest of 158 hectares of sea rice in Zhanjiang City, Guangdong Province where land had been encroached by the sea. Biologist Chen Risheng and the Chinese government have been leading this research and seed propagation. The world should be happy to learn from this fundamental progress.

From 2D farming on land to 3D farming at high sea

Across the Atlantic Ocean, we are witnessing another breakthrough in food production. We need to rethink farming the sea. Whereas on land we can only exploit the surface and a thin layer of fertile soil (two dimensions), we have to embrace the revolution of exploiting the full water body, which is recently called 3D sea farming. We suggest to apply the same logic as with the mangroves. The goal is to regenerate the ecosystem of the sea. This strategic approach allows us to harvest without having to feed. Humans have the responsibility to create the conditions conducive to the generation of food, feed and raw materials for industries as diverse as pharmaceuticals, cosmetics, energy crops, chemicals and textiles. The aim is nothing less than to restore Nature and put Nature back on its evolutionary path so that we can respond to the basic needs of all with whom we share this planet with what is locally available.

Brent Smith operates a 3D sea farm in New Haven, Connecticut. The farming system is simple. To restore a bay or a coastline that has been overfished with nets being pulled time after time over the bottom to the point that nothing grows anymore the starting point is to reintroduce the bottom of the food chain including kelp, seaweeds, sponges, sea urchins, scallops, mussels, and oysters. Once this ecosystem has been reconstructed then fish will return, and traps are added on the bottom. Everything works. The advantage is a low investment cost: the biggest expense is the ropes and the buoys. No need to put any money in feed. This means that we relieve the pressure on the world stocks of sardines and herring which are overfished to feed salmon. The operational costs are so low that most of the people think it's not possible. I know most of you are going around and saying that what Professor Pauli is saying cannot be true. Let me invite you to come and see. I'm not prepared to debate the science of what we are doing. I'm prepared to show the results of what has been done on the ground and in the sea.

Research to mainstream the bottom of the food chain

Regeneration of the sea focuses on a few basic species at the bottom of the food chain. This reduces the cost of operations. 3D farming is a third of the price. It is important to state at this moment that I am not against anything in this world. I am in favour of what is better in spite of the established interests and the fierce lobby for a *status quo* with marginal improvements at the fringes. The research required to mainstream these new food, feed and industrial feedstocks must be mainstreamed. We have emptied the top of the food chain like tuna and spent a disproportionate amount of money to artificially produce the fish at the top of the food chain. We need to start rebuilding the oceans from the bottom and this will ensure food security and a healthy diet for generations to come.

Dr Ronald Oringa, Professor at Wageningen University, has gone on record stating that with 180 000 km² of 3D farming we could feed the world with all the protein we need. That is the area of the territorial waters off Washington State in the United States of America. We have a capacity to generate nutrition beyond what we know. Now, how much research is going into this? Very little. What we have been able to share, is that 3D farming is not just into scallops, mussels and seaweeds. It is securing the supply of the feedstock for cosmetics, animal feed, fine chemicals and textiles. It is timely to remind everyone that this type of farming requires no inputs, no pesticides, no herbicides, no fertilizers. Ultimately, this frees farmers of the dependency from feed or seed companies. It is quite a different business model than the one that dominates farming on land.

Coastal defence against rising sea levels

The seas and oceans bring us food, but also challenges. We need coastal defences against rising sea levels. What I shared is not only a new model for agriculture and fisheries, these models also mitigate climate change. The ecosystem we can regenerate creates the real biotechnologies. The insights and how this works offer opportunities not just to get food and jobs but to improve resilience. How do we regenerate coastal systems where the rising sea levels are going to dramatically affect us?

First we need to tackle plastic waste in the sea – or also called plastic soup. This is what I call an unintended consequence. No one knew this was going to happen. But when it happened, and even as the science emerged, none of the companies who made this mess of plastics take any responsibility. Amazing isn't it? Where have the ethics gone? What we see is that by 2030 and at the present rate of discharge of plastics in water bodies, there will be 250 million tonnes dispersed as tiny pieces smaller than one millimetre. Nature Magazine ran an article in 2015 confirming that already 100 million tonnes float in the sea and that we are adding every year another 8–12 million tonnes. There is no strategy to remove it.

Now if we collect plastic soup composed of seven different types of plastic, it can be converted at low temperature pyrolysis into fuel (80 percent), carbon black (15 percent) and syngas (5 percent). New research at the University of Washington in Seattle has indicated that when you have these plastic beads there is a surface tension with a positive and negative charge that generates a tiny layer of freshwater. In nature, whenever there is freshwater and saltwater there are dynamics because everything gets stressed leading to more nutrition, different types of nutrition. So algae grow around the plastics because of the freshwater film generated by these plastics. This research is not yet described in numerous scientific papers. Unfortunately, for many, this makes this innovation invalid for most readers.

The freshwater–saltwater interface

Freshwater in the ocean attracts a whole range of micro-organisms which are unique and therefore the fish eat them, not because they like the plastics or they are only confused by the plastics but because there are so many micro-organisms living on the plastics thanks to this freshwater–saltwater combination. We propose to turn this around because these are the micro-organisms that extract phosphorus from the sea. This is interesting because in agriculture we know that we can process nitrogen and potassium in nearly unlimited quantities, but phosphorus is running out, with the exception of Africa.



Therefore, we are focusing on how we could clean up the plastic soup while harvesting phosphorus without destroying the bottom of the sea. That's the kind of work that my organization's members get excited about. The plastics get harvested while harvesting phosphorus. A pioneering company "The EVP Group" based in Taiwan, which developed the technology known as "R-One", has been running a two tonnes per day installation for two years. We support innovators who take their insights out of the laboratories and into the real world. Now, when 100 tonnes plastic soup can generate 85 tonnes of fuel combined with the generation of 50 m³ of upwellings per second through this saltwater–freshwater combination that gives us 100 tonnes of phosphorus per year at very low energy cost, while we are recovering the minute plastic beads that are risking our food chain.

Now these projections are not large-scale yet. Do you know of any research programme funded on this? One day in a distant future we can imagine generating fuel on the high sea that could supply fuel to the ships en route. You need to have that multiple cash flow and that is the big change from the core business model logic based on a core competence that students are taught at business schools all around the world.

Tea and park management

Let us look at the logic of tea in the northeast of India. Assam is home to the Kaziranga National Park, the largest natural park which is recognized as a world heritage where you have 1 200 wild elephants, 2 500 rhinos, the largest group of rhinos in the world, an incredible collection of 120 wild tigers and, next to it, you have tea plantations. You can only imagine the chemical run-off from these plantations into the park. The owner of the plantation decided to have the whole plantation converted to organic. This is the largest organic tea plantation in India.

The bad news is that since this plantation has been farmed for over 100 years, there is less than 1 percent carbon in the soil. So, as a result, if you extract the chemicals from the equation of production, then the plantation's output drops overnight. I was asked by the owner whether we could double employment within three years because the financial people want to cut costs and put 1 500 people on temporary contracts. Since the harvesting of tea is limited to seven months per year it makes sense with the decrease in tea output to cut employment costs. You know what temporary contracts, working for 7 months instead of 12 months, means? It means increasing the risk of poaching.

So, building on the great work initiated by the Indian teams, we started to imagine where we can increase income and value, instead of cutting even further, and the first results are quickly visible provided one goes beyond the core business of tea. This is tea plantation under a canopy. Every tree is now growing pepper vines. The plantation now produces pepper which potentially brings a 20 percent increase in jobs. Then, tea bushes are pruned to foster a fresh flush. All the tea pruning are used to farm mushrooms. It is possible to generate more tonnage of mushrooms than tonnage of tea, using what the tea plantation has. China has been farming mushrooms on agricultural waste for more than 12 centuries. There is no reason this cannot be successfully introduced in Assam.

In order to alleviate the irregular supply of water due to the erratic monsoon rains, 18 retention ponds were created. These are water reserves that are also used to farm fish. The Kaziranga Park is based on the Brahmaputra River, the largest brooding region of the world after the Amazon, providing fish

protein for an estimated 400 million people. Building on the existing biodiversity of the region, the tea plantation can increase protein output through fish farming with local species, increasing jobs. This tea plantation could soon make a profit and be on track to double employment around the tea plantation. This is the best protection for wildlife.

These are ecosystem-based innovations. Use what you have. Generate more with what is available. Use the five kingdoms of nature not just the plants and animals. The fungi are very efficient protein producers as well we all know. And let's not forget the microalgae. This Hathikuli tea will be launched internationally as a special brand generating higher returns. What is important is the increase in employment, the protection of biodiversity and the capacity to compete on the international market. At the end of the day we need to be competitive. How can the tea in Assam be competitive in a world market when the drive is a ferocious cost-cutting drive only without any generation of additional value? Now a new form of tourism can emerge and thrive.

The panda vs the cockroach

The problem we are facing is the concept of the core business characterised by an obsessive focus by scientists and business on one subject only. I tell them they behave like pandas. You know the panda! We love the panda. They're plushy, they're nice, they're lovely and you know the pandas are endangered. Why? Because we encroached on their land and now they don't have the bamboo to eat. But is it not true that the panda is part of the problem because it only wants to eat bamboo. I mean if the panda was ready to change its diet it would survive anywhere in the world. But the panda eats bamboo or nothing else.

That is exactly how business behaves these days. They consider it a risk if they have to go outside their core business. They consider that adaptation to new realities in the world is not permitted. They want to take companies and governments to private courts under a very special regime whenever the framework conditions change. I don't understand it. Why don't we simply behave like cockroaches? Cockroaches eat everything, anything, anytime. They have been around for 100 million years. They will be around for another 100 million years and if you try to kill them, you succeed with one or the other but you never kill them all. This is a need for a new mind-set of how we operate and let me exemplify that with coffee chemistry.

Coffee chemistry

The next example will surprise with all you can do with coffee. Do you realize the inefficiency of coffee drinking? When you drink a cup of coffee in the morning you basically only ingest 0.2 percent of the biomass that the farmer harvested. Can you imagine? A whole supply chain is organised for 0.2 percent of the biomass. Everything else is thrown away. That implies that coffee as a hard wood is a great substrate for mushrooms then we start mushroom farming. There are over 3 000 entrepreneurs in cities and rural zones that have started mushroom farms on coffee waste. We think there is space for at least 1 million. Mushrooms are cholesterol-free. It's the kind of food that we should be having. It is rich in essential amino acids, it can compete on protein dry-based basis with meat. Better, the spent substrate of mushrooms is enriched with amino acids and provides a great chicken feed.



This is the first value chain from coffee residues. Now coffee particles are mixed in clothing. Ladies and gentlemen, outdoor clothing like Patagonia, Adidas and Hugo Boss use special yarns produced with a 6 percent coffee content, micron-sized coffee mixed in polymers for textiles. Why would one put post-industrial coffee waste into the textiles? Because it absorbs odour. Timberland now puts it in its shoe soles. Twenty percent of the Timberland's sole is coffee. What does it mean for the farmer? What is the price for a functional chemical like coffee in the sole or coffee into clothing? It is US\$2 500 per tonne. How much do you think you get for coffee these days? You don't even get US\$500. We are increasing the revenue for the farmer by a factor of five. Coffee particles are mixed in carpets. Now we can add it to methyl diphenyl di-isocyanate (MDI) to make polyurethane with coffee. Coffee can be added to paint because coffee is also a natural UV protector. The latest research shows that coffee is an efficient storage medium for methane and hydrogen. The value of the total chain of coffee can be increased by a factor of 500. That is the real bio-economy. That is high tech because it brings food and nutrition as well as functionality. Do I have to add that genomes and genetic modification are irrelevant in this proposal? After all, these technologies may reduce cost and increase output of the core crop, but it is dwarfed by these ecosystem-based business models that provide income for the farmer and build on local biodiversity.

Thistle chemistry

In my last case, permit me to talk about Italy. The thistle is not very well liked because it is considered a weed. In Europe, we have an estimated 20 million hectares of these weeds growing because the European Union pays farmers not to farm. If you pay farmers not to farm what do you get? Thistles! On the island of Sardinia under the leadership of Dr Catia Bastioli, who is the CEO of Novamont, thistles are converted to the building blocks of bioplastics, including pelargonic acid and azelaic acid that can be formulated into herbicides. Novamont extracts lubricants. The coffee capsules of Lavazza in the future will be biocapsules. The waste from this process could be formulated as an animal feed. By the way, Novamont can extract enzymes from the thistle flowers which have been traditionally used to produce goat cheese. FAO is based in Rome. I suggest you visit Novara or travel to Porto Torres in Sardinia and see how this is being implemented. That is a new form of competition. On top of that, this is being processed in the former petrochemical facility of ENI which was transformed into a biorefinery.

Conclusion: Education

To conclude: if we only teach our children what we know our children will never be able to do better than we do. Therefore, I translate everything that has been successfully developed into children's stories, fables. I am very grateful to the Chinese Government because the Ministry of Education and the Ministry of Environmental Protection of China have approved these fables for distribution to all children in China. This is a gift I could never have imagined. We are in need of inspiring a new generation about the technologies and the business models where ethics is at the core, where serving society is the priority. If we are not inspiring the next generation what are you doing here on this earth? Ladies and gentlemen, with the wise words of Nelson Mandela I would like to close: "It always seems impossible until it's done".

And let me send you an open invitation to please come and see any of the projects that we have implemented. From there on, let's enjoy this great future that we all have. Thank you.



Chapter 2

High-level ministerial session



2.1 Statement by Néstor Roulet

Secretary for Added Value,
Ministry of Agro-Industry,
Argentina

I would like to start by thanking FAO for organizing this international symposium on biotechnology, which is an important development for the whole world.

Argentina is a clear example of what can be achieved with a full and accountable application of biotechnology. Our country is one of the pioneers in the extensive use of this technology, and in the 20 years that have passed since the first event (it will be 20 years this March), we have not only secured social and economic benefits for Argentina, but for the whole world. Argentina has doubled food production in these last 20 years. For example, we have increased grain production from 50 million to 100 million tonnes. This was not achieved by increasing the surface area – which increased only by 18 percent – but by a substantive increase in land productivity.

It is also important to highlight that the use of this technology in Argentina is closely linked to the introduction of other improvements, such as direct seeding and precision agriculture, which have enabled us to intensify our production whilst improving the efficient use of water and nutrients, increasing the production and quality of our products, reducing soil erosion and saving on fuel consumption, resulting in a reduction of greenhouse gas emissions.

Today, Argentina is the country that uses the least amount of fuel per tonne of food produced. This is all thanks to a technological package that includes biotechnologies and direct seeding. Even though these benefits at present are mainly in field crops such as soybean, maize and cotton, they are also becoming available in other crops, including wheat, potatoes, and those with improved nutritional values, such as high oleic acid soybeans. It is likely that in the future, these technologies will be present in other crops, such as safflower and sugar cane.

We are also working on the development of technologies to enable better adaptation to climate change, helping to guarantee food security. This is the case of drought-resistant soybeans and wheat, which we expect will shortly be available to producers.

Argentina also has a research institute, the National Institute of Agricultural Technology (INTA), which is a public institution working, *inter alia*, on the development of genetically modified crops, on vaccines based on viruses and on genome projects, aimed in particular at small producers and regional economies.

In parallel we are developing an active policy on the use of bio-inputs. These include biofertilizers and biopesticides, aiming at replacing chemical inputs and at promoting a more sustainable approach, given that replacing chemical fertilizers and pesticides leads to a major reduction in gas emissions caused by the machinery used for their application.

To conclude, I would like to add two comments. One, on the importance of the legal and regulatory framework, and the other on how we see the future. In relation to the regulatory framework, it is worth highlighting that many of the benefits and improvements that I have mentioned have been possible because the necessary regulatory frameworks were in place. We believe that biotechnology, along with other technological tools, offers us huge benefits; however, for these to become a reality, both regulations and biosafety are essential.

In this sense, I would like to share with you something that makes us all proud. In 2014, FAO recognized our National Advisory Commission on Agricultural Biotechnology (CONABIA), which is made up of more than 20 public and private sector scientists, as a reference centre for the biosafety of genetically modified organisms. FAO reference centres are institutions designed to give technical and scientific advice on specific questions related to global FAO programmes on agriculture and food. Argentina is an example of how proper regulation contributes, to a large extent, to the development of specific technologies or disciplines. Through this decision, we are now in the position to offer the expertise of our regulatory organizations, which include CONABIA, the Regulatory Commission and other associated mechanisms, to anybody who wishes to cooperate in implementing their regulatory systems. This has already been done during a seminar in Santa Lucia and we are hoping to hold seminars in Africa and Southeast Asia later this year or next year.

In terms of the future, we are fully aware of the challenges being faced by the world in addressing the demands of an ever-increasing population, urbanization, greater scarcity of farming lands and water resources for irrigation, together with an also increasing strain on energy resources. All of this leads us to rethink the issue of sustainable agricultural productivity, without affecting diversity but, at the same time, guaranteeing the necessary increase for food production. We have no doubt that an increase in production is required, but not at any cost. This is why we are putting biotechnology within a broader framework, to encompass the bioeconomy, where the goal is to use all biological resources in a more efficient and effective manner, which includes processes, biomass, food production, industrial inputs and the energy that will be required for the next decade.

We would like to confirm our firm commitment to the 17 United Nations Sustainable Development Goals, which were adopted last September, and particularly with those related to the sustainable use of natural resources, ending poverty and eradicating hunger. Today in Argentina, we produce food for 400 million people, and we are only 40 million people. Our goal is to be producing food for 500 million people by 2020, increasing to 700 million people by 2024. We believe that in order to end poverty, adding value at source is essential. This is why we want to end certain levels of primary marketing, whereby we offer the world the products and the world accepts the end products. The challenge is to produce more, with fewer resources in a sustainable manner, and we see biotechnology as a central component in the necessary technological leap, helping not only crop production but also the whole economy, where innovation and technological exchange and cooperation between countries plays a very important role.

Argentina is ready and willing to be part of this process. Many thanks.



2.2 Statement by Frédéric Seppey

Chief Agriculture Negotiator,
Agriculture and Agri-Food Canada,
Canada

Mr Director-General, Excellencies, Ladies and Gentlemen, on behalf of Canada's Minister of Agriculture and Agri-Food, the Honourable Lawrence MacAulay, it is a great pleasure for me to share with you Canada's perspective on agriculture biotechnologies.

I am delighted to share the floor this afternoon with my fellow panelists to share the Canadian perspective on biotechnology and its importance in agriculture. I am also very grateful of the FAO for organizing this week's symposium on such an important topic.

From a food security perspective, we collectively face a number of complex challenges. We are all aware of the forecasts:

- The world must produce 60 percent more food by 2050 to meet demand created by an increased population.
- And this with nearly the same amount of arable land in 2050 as we have today.
- Climate change is expected to have a growing negative impact on agriculture, creating even greater food insecurity than today.

These are some of the key challenges we are facing as a global community.

The world has committed to Agenda 2030 and the Sustainable Development Goals of eliminating hunger, improving nutrition and eliminating extreme poverty around the world.

In order to meet this ambitious target, we need all the tools that we have in our toolbox.

And among these tools are agriculture biotechnologies.

Innovation has a key role to play in the fight against hunger.

We need more productive crop varieties that could increase nutrition and lead to more sustainable practices.

Canada's approach

Let me take a few minutes this afternoon to give you an overview of Canada's regulatory and policy approach to innovation.

In Canada, innovation is a key pillar of our current federal-provincial agriculture policy framework.

Programs and policies are in place to encourage partnership among public and private sectors with respect to research in the agricultural field. Through the years, Canadian producers called for products allowing them to be more competitive, adopt more sustainable and environmentally-friendly practices and be better equipped to meet consumer demand for safe, high-quality and nutritious food.

Providing Canadian producers with choice with respect to the type of products they want to use in their agricultural practices is a central component of our policy toward innovation. The Government of Canada does not advocate for or against any technology – its role consists of providing producers with a selection of options that all meet the highest standards of safety from a food, feed and environmental perspective.

The Canadian government has a robust regulatory system to regulate innovative products. Canada has over 20 years of experience in regulating products of biotechnology through its integrated framework. Canada's approach relies on rigorous science-based safety assessments that protect human and animal health and the environment, and is in line with our international trade obligations.

In 1993, when we considered how to best regulate products of modern biotechnology, we made the choice to regulate the final product rather than the process by which the product was developed. It is the final product characteristics that trigger the pre-market assessments, not the means by which it was developed.

Plants with novel traits and the novel foods and novel feeds derived from them, are subject to safety assessments for environmental, human and livestock health respectively. The three assessments are performed at the same time, with strong collaboration between the agencies responsible for each of the different aspects of the assessments – food, feed and environment.

Such a flexible approach based on products allows Canada to adjust to the emergence of new technologies, such as gene editing and other precision breeding techniques, without having to modify its regulatory framework.

This flexible approach has served us well as demonstrated by the high level of confidence in the regulatory system and the high rate of adoption for plant biotechnology by Canadian farmers.

Another key principle underpinning our approach is transparency. Canada recognizes the importance of transparency in decision-making, including in the development and application of its regulations and is committed to this principle.

Our regulations are posted online and are available to all. In addition, a summary of each of our food safety assessments is shared on the FAO genetically modified food platform. Sound practices with respect to transparency help create a regulatory environment that offers predictability to importers, exporters, seed developers and the feed and food value chains, which in turn gives agricultural producers access to new products resulting from innovation, including biotechnology products.

Allow me to share with you an example that we consider to be a Canadian success story: the development of canola.



Canola was developed jointly by researchers from the Canadian Department of Agriculture and the University of Manitoba in the 1970s. Through this partnership, researchers were able to develop a new crop that, today, generates over \$7 billion in farm receipts – or 13 percent of total farm receipts – putting it just behind the cattle industry.

Canola is at the forefront of Canadian crop innovation, and was one of the first genetically modified plants to be marketed when, in 1995, a herbicide tolerant variety was offered to producers.

As a result, the crop area increased from 143 000 hectares of rapeseed in 1956 to over 8 million hectares of canola planted in 2015. And today, Canada has over 43 000 canola producers who are proud to make this crop a driver of Canadian agricultural prosperity.

This example illustrates what can be achieved through a science-based regulatory environment, coupled with public, private and producer partnerships supporting innovation.

More examples of practical approaches to science-based regulation and oversight of agricultural biotechnology from both developed and developing countries will be presented at a side event to be held today at 17:45 in the Iran Room, just after this high level segment.

International cooperation:

Now, what can we do TOGETHER?

We are at a crossroad in terms of agriculture development. We are collectively facing enormous challenges that will need to be addressed. Biotechnology is an important tool available to farmers and countries to assist in responding to these challenges.

As Dr Fresco noted yesterday, one of the components to help developing countries' farmers benefit from biotechnology is to find solutions to regulatory challenges. In this regard, it is paramount that we encourage innovation in agriculture and provide the possibility for farmers to have access to the best possible products that meet their needs. In Canada's view, this could be best achieved through:

- Development and adoption of science-based regulatory frameworks ensuring the food, feed and environmental safety of these products;
- Increased regulatory transparency;
- International cooperation to build understanding and confidence in one another's regulatory systems.
- Better regulatory alignment, especially at the regional level. Resources are limited, and collaboration can help countries pool resources and target priority areas.

Canada believes that FAO has a pivotal role to play in assisting countries to working toward these objectives.

This symposium convinces us that the FAO should undertake more work on biotechnology. The symposium should not be an end in itself; it must be part of a continuing FAO leadership in facilitating the global dialogue on issues associated with agriculture biotechnology.

In our view and in light of the significant challenges that lie ahead of us, it is not only FAO's role, but its duty to disseminate scientific and evidence-based information on biotechnology.

The FAO can also be instrumental in assisting countries in developing regional regulatory and policy approaches to biotechnology. Through regional conferences, the FAO could lead a dialogue with the different regions on this issue and explore how and what might be done in follow-up to this symposium.

Let me conclude by saying that the principles I have been talking about apply to any innovative practices, not only to agriculture biotechnology. As we were reminded by the Director-General in his keynote address yesterday, the challenges of food security are so great that ALL possible tools should be considered.

Mr Director-General, Excellencies, Ladies and Gentlemen, I thank you for your attention.



2.3 Statement by Katalin Tóth

Deputy State Secretary,
Ministry of Agriculture,
Hungary

Distinguished Chairperson, Director-General of FAO, Ministers and Deputy Ministers, Delegates, Ladies and Gentlemen!

It is a great pleasure and honour for me to participate in this highly important discussion on agricultural biotechnology. First of all, I would like to thank FAO for organizing this symposium, and providing us a neutral forum to discuss this issue in its complexity.

Indeed, agricultural biotechnology is a broad term, which refers to a wide range of techniques and methods and provides plenty of opportunities. The use of biotechnology applications and products can be highly beneficial for the society including farmers. In combination with the traditional knowledge, these techniques and applications, although have significant impacts on plant and animal genetic resources and biodiversity in general, but in return they contribute to meeting the needs of the population and to sustaining life under rapidly-changing conditions.

Please allow me to highlight some of the recent advancements we achieved in Hungary in the biotechnology sector. Over the past 15 years, more than 70 biotechnology companies were founded in Hungary, mainly in the field of so-called red (medical) biotechnology. Most of them were registered in the last five years. Besides these, there are three major agricultural biotechnology research institutes in Hungary (the Centre for Agricultural Research, the Agricultural Biotechnology Centre and the Biological Research Centre) whose aim is to facilitate the competitiveness of the Hungarian agriculture with the latest achievements of their biotechnological experiments.

Nowadays, special attention has been paid to biotechnology, as this is a rapidly emerging field. It may provide solutions for many of the world's major challenges, such as climate change or global food security. Agricultural biotechnology could greatly contribute to the fight against hunger in developing countries, for example by decreasing food loss.

So it is a great opportunity on one hand, but a huge responsibility on the other. It is important to bear in mind that the long-term effects of these novel technologies are still uncertain, so in the future we may come across new unknown types of risks in human and animal health or in the environment.

While Hungary is supportive of biotechnology research and the use of its applications in general, it is a strong opponent of a particular segment of biotechnology, the agricultural gene technology. Our position is based on scientific results and on the precautionary approach addressing the existing gaps and uncertainties in the risk assessment of GMOs. Our scientific studies have proved that several current GM crop varieties have negative effects on the environment and the risks of the cultivation

of these plants have not been adequately assessed. We think that the hypothetical advantages of some “improved” GMO seeds are overshadowed by risks to human health and the environment, which are not yet known to their full extent. Unfavourable social consequences may also arise due to a greater seed supply dependency of farmers. We propose, therefore, to concentrate on the use of numerous other achievements of biotechnology, which have proven to be safe and having undoubtedly benefits and which are not contentious.

We are convinced that agricultural biotechnologies must be based on the precautionary approach in accordance with domestic legislation and relevant international obligations. We believe that there should be more research on social, environmental and health issues, and capacity building for better assessment of biotechnology. Countries also need to be able to monitor and evaluate the possible effects and share the data gathered with all stakeholders. Recognizing the limitations and applying a precautionary approach will help us to address the gaps in our scientific knowledge, respect the importance of traditional knowledge, as well as broaden our options and perspectives.

Finally, discussing modern biotechnology (including GMOs) within the wider context of sustainable innovation and sustainable use of biodiversity is absolutely necessary. We believe that this should go hand-in-hand with employing a participatory and bottom-up approach towards modern biotechnology and its applications.

Excellencies, distinguished Delegates!

Sustainable agriculture using cutting-edge technologies in a safe way is a complex and far-reaching topic. It requires the spirit of cooperation and firm stance at the same time. We have to be wise and responsible in our decisions on how to use its advancement in agriculture.

Hungary is strongly devoted to exchange knowledge on responsible use of biotechnology. A good example of our commitment is the participation in the South–South and Triangular Cooperation Program of the United Nations. In the frame of this initiative, Hungarian scientists and experts can share information about best practices with colleagues of Morocco, Algeria, Uzbekistan and Turkey.

In addition, the Hungarian Government together with FAO has been offering a scholarship program for students arriving from developing countries. Due to this programme, since 2008 over 200 university students have deepened their knowledge in agricultural studies, including biotechnology.

Thank you for your kind attention.



2.4 Statement by Papa Abdoulaye Seck

Minister of Agriculture and Rural Equipment,
Senegal

Senegal is in the process of building a competitive, diversified and sustainable agriculture. It is therefore seeking to incorporate the use of technological innovations to produce more and better quality products. While biotechnology is thus an opportunity to be seized, we have six strong beliefs that must be upheld:

First, biotechnology must be underpinned by robust African agricultural research. Africans must be the users and producers of knowledge and technology, rather than simply being consumers who wait for scientific suggestions that do not necessarily meet their needs. This requires large-scale investment in agricultural research, since evidence shows that competences should be created, not dictated.

Second, biotechnology must not result in dependency that impedes the availability and accessibility of production factors, particularly for small farmers. We wish to promote sustainability of production systems, security of rural revenue, reclaiming of domestic markets and a better position on the world stage.

Third, biotechnology is not incompatible with agro-ecology. Tolerant plant varieties created through biotechnology can be of better sanitary and phytosanitary quality, resulting in a reduction in the number and volume of chemical treatments required. Biotechnology also enables marginal lands to be cultivated and to face climate change, a constant concern for humanity.

Fourth, biotechnology must not just be an issue for specialists, but for the whole of society. This is why awareness raising among all rural workers and consumers is urgently needed to manage fear of change and promote intelligent application. To this end, in Senegal, we have established a legal and regulatory framework to regulate the production and use of biotechnologies.

Fifth, biotechnology is a tool for bridging the global agricultural divide and promoting equity. By “agricultural divide”, I mean the difference in agricultural productivity between developed and developing countries, owing to the number of technical operations in use that can lead to positive change. By way of example, in Senegal, thanks to biotechnology:

- The yield of rainfed rice could be increased four-fold; in banana, five-fold; and in tomato, two-fold.
- With artificial insemination, 30 to 50 litres of milk can be obtained from improved cattle breeds, as opposed to 1–3 litres from local breeds.
- There is better management of animal health problems owing to more reliable disease identification (African horse sickness, avian influenza, Newcastle disease) and vaccine production.

Sixth, biotechnology can contribute to maintaining and strengthening biodiversity through better molecular characterization of crops.

In conclusion, to be translated into economic and social progress, all scientific progress should be used carefully and realistically. To this end, farmers' aspirations and the constraints they face should be central to scientific considerations. This is a prerequisite for achieving useful and usable results that will change the face of world agriculture.



2.5 Statement by Begum Matia Chowdhury

Minister for Agriculture,
Bangladesh

Honourable Chairperson, Distinguished delegates from different (member) countries, Diplomats, Representatives of Development Partners, Distinguished Guests, Ladies and Gentlemen,

As-salamu Alaikum and Good Afternoon to you all.

I have the honour to be here in this symposium on the “The Role of Agricultural Biotechnologies in Sustainable Food Systems and Nutrition”. Thank you very much for the invitation to this important event in the beautiful city of Rome.

Distinguished Participants,

Agriculture is the primary base of livelihood and the heart of Bangladesh’s economy and has made significant progress since our independence in 1971.

Rice is the staple food of Bangladesh and the production of rice has increased from 23.53 million metric tonnes (MT) in 2006 to 34.60 million MT in 2014. The increased production has been possible with intervention of modern crop varieties and technologies. The productivity of wheat has also substantively increased by the development of heat tolerant and high yielding wheat varieties. Similarly, maize production has significantly increased with highest productivity in South Asia. The country is now self-sufficient in cereal production to ensure the food security of the country.

The success was achieved by developing climate resilient and high yielding varieties of rice and wheat. Bangladesh has also made significant progress in potato production with a production of 9.50 million MT in 2014 against 4.16 million MT in 2006.

The country is now working hard for nutritional security. Recently the zinc rich and wheat varieties were developed. Vegetable production has increased manifold in recent years, rising from 2.03 million MT in 2006 to 13.8 million MT in 2014. The production of fruits, pulses, oilseeds and spices are not adequate to meet the requirements, which needs to be increased manifold.

By now, the country is transformed from subsistence to semi-commercial agriculture and working for commercial agriculture through technological intervention.

Dear Participants,

In spite of achieving this success, agricultural production in the country is facing number of challenges due to population pressure and conversion of agricultural land for urbanization.



Salinity, drought, flood, hot and cool climate, soil degradation, groundwater depletion, infestation of pests and diseases are the common problems for crop production and the problems are worsening due to climate change.

The country faces natural disasters every year affecting land productivity and food production. The population of the country is estimated at about 160 million. To meet the huge demand for food and nutrition in future; conventional agriculture is not sufficient to meet the upcoming challenges of increased demand.

Ladies and Gentlemen,

Application of modern biotechnology provides an opportunity to improve productivity as well as production through development of biotic and abiotic stress tolerant varieties of major crops.

Biotechnology provides an opportunity to transfer genes from a wide range of living sources, not just within the crop species, but from other species.

The combination of conventional crop improvement approaches and modern biotechnological techniques can contribute to human well-being by increased production and nutrition. Genetically engineered (GE)/GM crops have positive impact on farm incomes worldwide through enhanced productivity and efficiency. About 28 countries are cultivating GM crops (e.g. Bt brinjal/Bt cotton).



Dear Participants,

Honourable Prime Minister of Bangladesh Sheikh Hasina is committed to ensuring food and nutrition security for the people, especially the most vulnerable group of mothers and young children through a comprehensive approach for food availability, access and utilization for their nutrition.

It has been mentioned earlier that Bangladesh attained self-sufficiency in food production when the country's gross production in cereals (rice, wheat and maize) reached at 38.17 million MT. In addition, the dietary diversity is increasing by diversification and intensifications of crops through improving cropping patterns.

The availability of fruits, vegetables, pulses and oilseeds is increasing in their daily diet indicating nutritional security of the common mass. We are trying to introduce new food in our dietary system like seaweeds, which is rich in nutrition. The country has enormous potentials to produce seaweeds in the coastal belt of the Bay of Bengal.

Honourable Chairperson,

Realizing the importance and benefit of biotechnological intervention in our perspective, Bangladesh has started biotechnological research at some leading national research institutes and public universities on a number of important crops.

Four varieties of Bt brinjal have been developed against fruit and shoot borer by the Bangladesh Agricultural Research Institute (BARI), one of the leading research organizations of the country. These varieties are now being cultivated in farmers' fields on a limited scale.

It is to be mentioned here that the brinjal is an important vegetable of Bangladesh and that the fruit and shoot borer is the most harmful pest hampering its production. The cry1Ac gene was introgressed in our local brinjal varieties to develop these Bt brinjal. The cultivation of Bt brinjal significantly reduced the use of harmful pesticides.

In addition, confined field trial (CFT) of late blight resistant (LBR) potato is being conducted to protect potato from late blight diseases – a very devastating disease of potato. The institute is working on polymerase chain reaction (PCR)-based detection and characterization of tomato leaf curl virus and on the development of a tomato transformation protocol.

The protocols for seedling production using tissue culture of fruits (banana, jackfruit, pineapple, papaya, grape etc.); vegetables (potato, brinjal, sweet gourd, tease gourd, watermelon etc.); and flowers (orchids, rose chrysanthemum, gladiolus etc.) have been developed for quick multiplication. Somatic embryogenesis, *in vitro* regeneration of some horticulture crops are also going on in different laboratories.

Distinguished Participants,

I have mentioned earlier that rice is our staple food and we have given due importance for the

improvement of rice through biotechnological tools. Contained and Confined Trial of golden rice were conducted by the Bangladesh Rice Research Institute (BRRI) in collaboration with the International Rice Research Institute (IRRI).

Submergence tolerant rice varieties have been developed through marker-assisted breeding, namely BRRI dhan 51 and BRRI dhan 52. Also, quantitative trait loci (QTLs) for zinc have been identified from local rice variety (KaloBokri).

Besides some important ongoing research on rice are gene pyramiding for resistance to bacterial blight, salinity, submergence, and heat tolerant rice through marker-assisted selection and identification of QTLs for salinity tolerance and cold tolerance both at the seedling and reproductive stages.

Genetic fingerprinting of rice and sugarcane has also done for characterization of the crops. The milestone was set by genome sequencing of jute and its fungal diseases by the Bangladesh Jute Research Institute (BJRI) in collaboration with the University of Hawaii in the USA. Different public universities are also working on genetic transformation, micropropagation and stress breeding on a number of important crops.

Dear Participants,

With every new emerging technology, there might be some potential risks. There is a widespread concern regarding the safety of biotech crops. Though GM crops have potential risks, it still provides great benefit for the improvement of crops. Its potential risk can be avoided through rigorous testing and safety assessment before any such crops are approved for commercial cultivation. Development and use of GM products requires appropriate policy, controls and cross-border movements to protect human health, biodiversity and the environment.

Considering the facts, the application of modern biotechnology requires adequate legislation and capacity building in relation to institution and human capacity. Bangladesh as a signatory of the Cartagena Protocol on Biosafety is committed to developing and implementing the biosafety regulatory system.

Bangladesh adopted biosafety guidelines in 2005 and a framework in 2007 to conduct biotechnology research and testing of GM products.

In order to enforce the biotechnological research, the government approved “Biosafety Rules of Bangladesh” in 2012. Recently, the Ministry of Environment and Forest has adopted “Guidelines for the Safety Assessment of Foods Derived from Genetically Engineered Plants”.

The country is conducting biotechnological research following all international rules and regulations. Some of the national agricultural research systems (NARS) institutes and public universities have good laboratory facilities and others are in the developing stage. But we need more skilled technical personnel in our national research system, especially on biotechnology.



Ladies and Gentlemen,

In conclusion, I would like to mention that Bangladesh is a country of boundless potential which was born in 1971 under the great leadership of the Father of the Nation Bangabandhu Sheikh Mujibur Rahman through historic liberation movement.

The Honourable Prime Minister Sheikh Hasina has successfully established the vibrant economy for the country. We are trying to make the country free from hunger and poverty under the dynamic leadership of the Honourable Prime Minister.

Democracy of the country is the key point of these growth and development along with gender balance, good governance and favourable agricultural policies. We are pursuing an inclusive growth strategy to become a middle income country by 2021 and a developed one by 2041 under the dynamic leadership of Sheikh Hasina, Honourable Prime Minister of Bangladesh. We established a climate change trust fund from our own resources.

The 6th Five Year Plan has been successfully executed and it makes the country self-reliant in food production. We have formulated the 7th Five Year Plan to make the food security sustainable in our country. Due importance is given on biotechnological research and development in our present Five Year Plan along with a number of priority areas. Some development partners are working with us for the advancement of the country aiming at food and nutrition security by using modern biotechnology and other tools.

We are producing food to feed the people and therefore, we are not supporting the conversion of food to bio-fuel. We would be happy if we get more support in the field of agriculture from the development partners in our development pursuits.

Our joint efforts will certainly make this beautiful world free from poverty and hunger.

Finally, I would like to conclude my speech by saying that we will conserve the nature but we will not be conservative denying the facts and achievements of biotechnology as well as Science. Our choice is very simple– whether we will have pesticide or pesticide-free GM food.

Thank you very much to all of you once again.

Joy Bangla, Joy Bangabondhu.

Long Live Bangladesh.

2.6 Statement by Henri Eyebe Ayissi

Minister for Agriculture and Rural Development,
Cameroon

Distinguished Ministers, Director-General, Your Excellencies, Ambassadors and Permanent Representatives, Distinguished delegates, Ladies and gentlemen,

As Minister for Agriculture and Rural Development of Cameroon, I have the honour and the pleasure to take the floor here today to share with you Cameroon's experience with regard to agricultural biotechnologies.

Before I start, I would like to express our deep appreciation to the Italian authorities for the warm hospitality they have shown the Cameroonian delegation, and for all the facilities they have put at our disposal since our arrival here in Rome.

I would also like to take this opportunity to express our sincere congratulations to FAO Director-General, Mr José Graziano da Silva, for taking the initiative to hold this international symposium on the role of biotechnologies in sustainable food systems and nutrition, and for inviting us to take part in this important event.

Ladies and Gentlemen,

The agricultural way of life in Cameroon is both an established fact, and a deliberate political choice on the part of the President of the Republic, his Excellency Paul Biya, who has made agriculture the cornerstone and driving force of Cameroon's economy and development. The agriculture sector involves more than 70 percent of the population, and accounts for almost 52 percent of gross national income.

Another objective reality has become apparent over time: low levels of agricultural productivity. With a view to ensuring availability of food for an ever-increasing population, and in order to substantially reduce imports of food products, Cameroon has been committed, since 2011, to what is known as "second generation agriculture", which is in line with all major FAO guidelines on food and nutrition. In this regard, the Government of Cameroon has shown committed political will, and has engaged with all stakeholders, including the private sector and civil society organizations.

In this context, it should be pointed out that agricultural research in Cameroon is already well under way in respect of conventional and modern biotechnologies, with a view to markedly improving both the quality and quantity of foods available to the population.

Several research institutions are involved, including:



- The Institute for Agricultural Research for Development (IRAD) in Yaoundé, the activities of which involve a wide range of agricultural products: grains, roots and tubers, pulses and fruit trees, as well as research into cattle and aquaculture. The Johnson Biotechnology Laboratory within IRAD, which was established in 1986, deals with *in vitro* root and tuber culture (cassava, sweet potato, banana and plantain, taro and yam);
- The Centre for Research and Biotechnology (CRB) of the University of Yaoundé, which comprises two sections: a section for plant biotechnologies, and a section for animal biotechnologies. This centre also conducts research into biofertilizers (mycorrhiza);
- The Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang;
- The African Centre for Banana and Plantain Research (CARBAP), which is a public, subregional research institution established in 1989, conducting plant selection on banana and plantain plants, focusing mainly on the production of hybrids resistant to specific diseases and parasites;
- The International Institute of Tropical Agriculture (IITA), which is conducting research into the development of new varieties of cassava, banana and plantain plants and has a biotechnology and molecular biology laboratory which is producing plants *in vitro* and supporting diagnostic study of parasites and diseases;
- The biotechnology laboratory of the University of Buea;
- The Cotton Development Society (SODECOTON) laboratory in Garoua, which is working jointly with IRAD to introduce varieties of cotton into Cameroon, especially Bt cotton, work which is still at the experimental stage; and
- The national veterinary laboratory (LANAVET) in Bokle (Garoua), which specializes in the production and trade of vaccines for cattle, sheep, goats and poultry.

The use of classic biotechnology has enabled various high-yielding, disease resistant and drought tolerant plant varieties to be introduced in Cameroon. For example, varieties of “new rice for Africa” (NERICA) rice, maize, sorghum, root vegetables and tubers (cassava, yam, sweet potato, potato) palm trees, cocoa, coffee, cotton and banana plants.

Similarly for biofertilizers, the use of mycorrhizal fungi, *Azolla* and *Rhizobium* for improving phosphorus and nitrogen needs in plants such as cocoa, coffee and tea plants, pulses and grains, is at the experimental stage.

In order to ensure that modern biotechnology is used properly, without causing any threat to local populations and the environment, particular attention should be paid to: (i) the risks associated with using transgenic crops, and whether they could be harmful to people’s health; (ii) allergens and toxins; (iii) the impact on non-target species; (iv) insecticide resistance; (v) loss of biodiversity; and (vi) complex technologies that are hard for farmers to access and not easy to adopt.

Other potential uses are being investigated, such as the introduction of varieties of certain tree species of economic importance that are high-yielding, have high nutritional content, are disease- and pest-resistant, climate-smart and have a short growth cycle.

Steps remain to be taken, however, to strengthen the legislative framework with regard to biotechnology, through the law regulating the use of modern biotechnology, which was adopted in 2003, and other legislative instruments, which include: the framework law on the environment, the

biosafety act, the act on classifying hazards, the seed act, the phytosanitary act, the decree on the application of the biosafety act, the decree on the establishment of the national biosafety committee, the decree on seed quality control, the decree on the establishment of a seed quality control council, as well as the application of international conventions to which Cameroon is party, including the Rio Convention on Biological Diversity and the Cartagena Protocol on Biosafety.

Fully aware of the potential of agricultural biotechnologies in sustainable food systems and nutrition, the Government of Cameroon organized a series of meetings at the national level:

- In 2012, the Embassy of the United States of America organized a meeting with a specialist from the New Partnership for Africa's Development (NEPAD) as the keynote speaker. The aim of the meeting was to highlight the advantages of using biotechnologies in Cameroon.
- On 4 September 2013, also at the initiative of the Embassy of the United States of America to Cameroon, a conference on biotechnology was held, entitled "The contribution of biotechnology to the Cameroonian agriculture sector".
- In September 2015, a national forum was organized on formalizing the use of certain technologies, including the use of genetically modified organisms, in Cameroon.

In conclusion, distinguished Ladies and Gentlemen, Cameroon has chosen to exercise care with regard to the use of biotechnologies; seeking to improve the productivity of land currently in use, while at the same time seeking to guarantee biosafety for its people.

Thank you for your attention.



2.7 Statement by Gerda Verburg

Permanent Representative of the Netherlands to the UN Organizations in Rome,
on behalf of the Kingdom of the Netherlands

The Netherlands commends the Director-General and FAO for organizing this BIOTECH Symposium, two years after the Symposium on Agro-Ecology.

It's an excellent moment to make clear that we need all kind of sustainable and innovative agricultural systems and techniques to create food security and nutrition for all people (leaving no one behind) and at the same time deal with climate adaptation and mitigation.

We need agro-ecology *and* biotech as a toolbox; they are interlinked, we need them to walk hand-in-hand, to work together, to inspire each other, to learn from each other.

Traditional knowledge combined with innovative technologies and opportunities can contribute to productive, sustainable agriculture and food systems.

At the same time we have to recognize that it will be quite a challenge to make them work together. Sometimes one has the feeling that it is either-or-. And each way of production has strong advocates pro and con and they don't touch only on agriculture and food but also on food safety, health, environment, social impact, economy and even justice.

Looking at the challenges for today and tomorrow, it's time for a paradigm shift.

A paradigm shift to fulfil Agenda 2030: Zero Hunger, improved nutrition, zero stunting, 100 percent sustainable agriculture, 100 percent increase of smallholder incomes, about healthy oceans, sustainable forestry, a better position for women and women farmers, etc. etc.

A paradigm shift, because at the same time we know that farmers and people in the rural area are most impacted by the effects of climate change. Droughts, heavy rains, floods etc.

A paradigm shift, because we have acknowledged that we need to work together as partners to get sustainable and durable results. Governments cannot do it alone, neither can business nor farmers, science and research or civil society. We need partnerships in which every partner has a specific role.

Only by working together, by listening, learning to understand each other's language, starting to discuss and agree upon challenges, causes and possible solutions, different stakeholders will be able to build trust. And in the Committee on (world) Food Security (CFS) we have learned that *trust* is crucial to work together and be successful at all levels, including at grassroots, taking into account local realities.

Building trust won't be easy because some gaps are big. For example about Breeders rights and intellectual properties, about ethics, about possible environmental or health impact, even about the size of a farm; do we only need family farmers and smallholders to feed the world or do we also need bigger farms?

So where do we go from here: FAO has taken the initiative to put Agro- ecology and Biotech on the agenda to create future for both.

This Symposium should be the starting point to bring the different stakeholders together and offer them room and support to start to work together in order to stimulate co-existence, collaboration, share lessons learned, to tackle long-lasting problems like on breeders rights and intellectual property.

How to make agriculture and food systems more sustainable by developing the right links to markets and the food value chain.

How to connect farmers and research to make research more farmers-oriented, how to build supportive and inclusive institutions, for example to support participatory precision breeding programs and promote open access to precision breeding methods.

How to get legislative systems and regulatory processes ready and well equipped to support transparent policies and developments.

The future of agriculture and food systems must be built on sustainability, inclusiveness, transparency, (multistakeholder) partnerships and trust.

Only then we can implement Agenda 2030, end hunger, make agriculture, forestry and fisheries sustainable and durable, create equal opportunities for men and women, attract young farmers to take over, support a better life in the rural area and hand over our planet in a better condition to our children and grandchildren.

Thank you for your attention.



2.8 Statement by Michael Scuse

Under Secretary for Farm and Foreign Agricultural Services,
United States Department of Agriculture,
the United States of America

Thank you. My name is Michael Scuse and I am the Under Secretary for Farm and Foreign Agricultural Services at the United States Department of Agriculture. I would like to thank the FAO and Director-General José Graziano da Silva and his staff for organizing this important Symposium. Thanks also to my distinguished colleagues in this session, and to all the participants providing insights in these important discussions.

Like the FAO, the United States believes we are witnessing an unprecedented confluence of pressures on global food and agriculture. These pressures have the potential to cause significant environmental degradation, and to exacerbate hunger, poverty and malnutrition. Our agri-food systems, our environment, and even our societies are being threatened, especially in developing countries. These challenges are very real and so should be our responses.

This symposium has renewed dialogue and highlighted a simple message that goes at least as far back as Agenda 21 and the 1992 Earth Summit in Rio – ***that the safe and appropriate use of biotechnology is one of the most important tools to foster sustainable agricultural development.***

There is no single technology or approach for making the transition to sustainability. But science, knowledge and evidence should be the basis for our decision-making. All of the technologies discussed at this Symposium have a critical role to play. Increasing populations and stagnant yield gains for major staple crops are driving the need for increased productivity on existing cultivated lands. The use of agricultural biotechnology is helping improve livelihoods for smallholder farmers and helping adapt agriculture to the expected impacts of climate change. The Stress Tolerant Rice for Africa and South Asia (STRASA) project and the New Rice for Africa (NERICA) project are just two of many notable successes that demonstrate this.

The question for all of us now is: What should we do with this message? How should we move forward? Empowered with new evidence, having built new relationships, and being reminded of the urgency of the situation and the pressure upon people, our food and agriculture systems, and the environment, what is it that we do now?

We are all well aware of the issues surrounding public acceptance of agricultural biotechnology, most notably genetically modified (GM) crops. I believe these particular challenges compel us to ask ourselves: What are our duties and responsibilities? Are we willing to accept the notion that these challenges are somehow just immutable facts of life, or do we feel there is a stronger obligation for us to try to make progress and overcome the obstacles to the deployment of safe and beneficial new technologies?

As some of you may know, almost twenty years ago the U.S. papaya industry in Hawai'i was saved when our growers adopted a GM papaya that provided resistance to a devastating viral disease. This happened at a time when no other options were available. It is a great story, but this experience needs to be better understood so that the lessons we learned can be replicated when necessary. For example, next week I will be in Florida, where the citrus industry is being decimated by citrus greening disease. Growers face the possibility of their groves being wiped out completely. Not because there is no viable solution, but because of possible challenges regarding public acceptance of the best/only viable solution – a greening-resistant, GM variety.

So, I have to ask, are we in a position to take any safe and useful technology off the table? Is this the direction we want to be moving? I don't think it is. I don't think we should be eliminating viable and vital tools in the face of climate change, in the face of increasing global demand for food, and in the face of increasing pressures on the environment and biodiversity.

Not when genetic modification can help re-introduce the American chestnut tree – a once dominant, keystone species of our Eastern deciduous forests before it was decimated by blight in the early twentieth century. Not when genetic modification can help produce healthier, more nutritious foods – things like:

- high-oleic soybeans, with increased levels of healthy mono-unsaturated fats; or
- White Russet potatoes, with reduced levels of acrylamide, a potential carcinogen; or
- a yeast that has been engineered to produce omega-3 fatty acids, which is helping reduce pressure on wild fish populations by providing an alternative source of these important nutrients; or
- crops that provide needed vitamins and minerals like vitamin A, zinc and iron, and that can help address severe micronutrient deficiencies that billions of people around the world suffer from.

Not when “Bt” crop varieties, including eggplants and cowpea, can greatly reduce pesticide use and exposure in some of the most important vegetables and pulses in the developing world. Not when GM, virus-resistant cassava and banana can help improve livelihoods. Not when GM reduced-methane rice can mitigate greenhouse gas emissions from rice production, and when there are GM salt-tolerant crops that are able to grow in areas where soil salinity is increasing due to climate change. And not when GM crops are helping reduce the environmental footprint of agriculture.

According to a 2010 report by the U.S. National Research Council, GM crop adoption in the United States has significantly reduced insecticide use, driven down carbon dioxide emissions, reduced agriculture's water use, and has improved soil and water quality.

And the list goes on.

If we believe that acceptance challenges are just limited to one type of agricultural biotechnology – genetic modification – it is worth considering how these acceptance challenges will impact the agricultural biotechnologies to come. In many ways, GM crops are emblematic of the power and the possibility emerging from the decades of scientific research. Will acceptance challenges associated with GM crops in fact be carried over for any and all new and emerging agricultural biotechnologies?



We anticipate that rapid advances in knowledge and development of new technologies will continue, but has the future of these technologies already been pre-empted?

We believe the FAO is an important partner in finding answers to these questions, both because of its expertise, and because it is a neutral forum for sharing reliable, science-based information. The role of the FAO is especially important for addressing the most controversial topics, like genetically modified crops, where decision-makers in developing countries could benefit from unbiased, reputable information. To put it another way, if the FAO does not engage meaningfully and clearly in these debates, who does? Who better than the FAO to put the range of technologies in a broad context, and align them with the challenges they are poised to address?

Perhaps part of the acceptance challenge is political, and surely part of the resistance to GM crops comes not from questions about their potential contributions to sustainability, but from unease with their place in the market alongside conventional, organic and identity-preserved products. We must recognize that there is more market differentiation in the agricultural sector than ever before. This new complexity, just within the last decade, along with consumer expectations that do not match what the market can practically provide, has contributed to questions and fears about how GM presence may impact different market segments.

To address these issues, we would like to propose, for FAO Members' consideration, that we develop a multi-year program of work that focuses on the strengthening of science-based decision-making processes for GM crops developed by the public-sector to address sustainability challenges faced by smallholder producers in developing countries. Components of such a work program could include:

- (1) strengthening governance systems for the oversight of these products, including best practices for science- and evidence-based decision-making;
- (2) exploring potential opportunities for global and regional coordination; and
- (3) sharing information about mechanisms and strategies that have been deployed by FAO Members domestically for supporting co-existence of GM crops with organic, conventional, and identity-preserved agricultural production.

In closing, on behalf of the United States, I would like to thank the FAO once again for organizing this symposium. I look forward to continued dialogue and consideration of these matters with the FAO and its Members.

2.9 Questions & Answers with the moderator

The high-level ministerial session was organized in two parts, where high-level representatives of four FAO member countries made statements from the podium. After each part, there was time for at least one question from the FAO Moderator (Marcela Villarreal, Director of the FAO Partnerships, Advocacy and Capacity Development Division) and answers from the high-level representatives.

QUESTION 1. Marcela Villarreal, FAO Moderator

Earlier you heard from the FAO Director-General. He said he would like to hear from our distinguished panelists what they see as the future for FAO in terms of biotechnology – what is FAO's role?

Frédéric Seppey, Canada

Yes, I covered the role of FAO to a certain extent in my presentation. I think that the multilateral nature of the FAO, its expertise on food and agriculture elements, makes it a forum where we can have an excellent dialogue in that regard. I must say that we very much appreciate the opportunity in the symposium to have civil society, private sector and colleagues from all the membership gathered and having the opportunity to exchange, not only in sessions, and we find that the symposium right now is extremely rich, but also in side events or in corridor discussion. This is a unique venue for all of us to exchange on issues that are very complex. I think that in the various presentations we see that, although we may have different perspectives and different regulatory legal realities, there are a lot of very interesting ideas and agricultural biotechnology is much more than GMOs. We heard yesterday about very interesting innovative practices that I think can benefit all of us.

The main element that I think the FAO adds is the regional footprint because in an event such as this there is just a logistical limitation in numbers, despite the fact that we can webcast etc. But we do hope that we can have this dialogue continued in various regions of the world to deepen it and to have more of the scientists, regulators and policy-makers exchange and share their experiences and perspectives in that regard.

Katalin Tóth, Hungary

The main element concerning Hungary's point of view was heard in my statement and as you could witness we have a very specific position on this symposium. However, we are very grateful to be here and to be able to share our views on the issue with you. What I wanted to emphasize is that sharing knowledge and having a full, complex and comprehensive picture on the issue is a question of primary importance for us. That is why we would like to keep the so-called precautionary principle in mind, as I have stated before that we don't have a very clear picture about GMOs and it is the main threat we address usually when speaking about biotechnology. However, as I also stated, we have founded a lot of institutions lately to deal with this issue. So, it is very important. However, to have all the necessary information, to share it with the farmers and to have our voice heard is very important in this case.



As far as FAO's role is concerned, I think sharing knowledge, techniques and solutions in agriculture is a key element, so it should be the focus for the future as well. That is why training the future generations and sharing the basic knowledge and innovations with developing countries is a crucial point as well. That is why, as I mentioned before, we organized several programmes which address students as well as farmers. Last year we were invited to take part in the United Nations South-South Cooperation. We got familiar with the needs of the farmers and people concerned with agriculture and the issue of biotechnology and they're asking us to address this issue, so it is on our agenda. However, we have a very strong and oppositional position concerning the GMOs as we don't know what the future brings and that is why we say that we have to be very cautious and we have to be very careful when involving everything under one umbrella.

Papa Abdoulaye Seck, Senegal

We have more or less addressed this issue in our statement. Last year we organized a major international conference on agro-ecology in Dakar. We would certainly be willing to pursue this initiative with FAO and all partners as a means of moving from the theory to practice. In other words, how is it possible to find interrelationships between agro-ecology and biotechnology to be sure of placing our agriculture in a sustainable and productive dynamic? This could form an axis for cooperation between us.

Another axis for cooperation: If an assessment of existing laboratories in African countries is not carried out and careful thought is not given to see how it may be possible to upgrade these laboratories, we will end up in conferences listening to what the laboratories have instead of what our laboratories produce. In the interest of fairness, it is important that international institutions contribute to enable us to assess existing laboratories so that we can see to what extent it is possible to upgrade them, even if it means creating reference laboratories on very specific subjects within a framework of effective capacity development so that we can play our role and everyone can benefit.

For example, we have the vaccine production laboratory in Senegal which is a reference laboratory. The laboratory in Farcha is also a reference laboratory. Perhaps other laboratories ought to be upgraded as well as boosting research in this field because we are, what I sometimes like to call, users and producers of knowledge. Without this, every day we will hear you say: biotechnologies, dependence, etc. No! We need to say that the world makes progress if its different parts progress and it is not possible to make progress without strong agricultural research. At present, developing countries are not in an ideal position to undertake quality biotechnology research. Today, we are much more likely to be waiting for a science-based offer; something that we no longer want. We want to offer our solutions and this is something that can be done through research. Therefore, I would urge FAO to help the countries to carry out an assessment and upgrade their national laboratories and also to foster the emergence of cost-sharing regional laboratories, effectively enabling them to take responsibility of the comprehensive challenges related to biotechnology.

The other axis that I think is important: people speak of dialogue, but a dialogue needs to be structured. Perhaps we should strive to create observatories in different countries, perhaps federate and have regional and even international observatories on biotechnology, which would be multi-stakeholder observatories that should enable one and all to express their concerns on biotechnology and enable others to reassure them, so that we can have collaborative analyses resulting from collaborative activities on biotechnology.

It is possible to list more axes, but for the moment I will stop there. In summary, strengthening axes on agro-ecology, assessments and upgrading of our laboratories and creating biotechnology observatories based on a multi-stakeholder framework of dialogue.

Néstor Roulet, Argentina

In our case we have already explained how biotechnology along with other technological packages have helped to restructure agricultural production in general terms, not only for farming but also for livestock, dairy and regional economies. These are the reasons why biotechnology is so important to us.

We believe without a shadow of doubt that FAO must be proactive, which for us is something extremely important. FAO must somehow continue to organize these conferences and these meetings, which if they were to be regional would be of great significance. Nevertheless, in Argentina we always say that symbiosis has been achieved, a very good relationship between all stakeholders in the production chain and among the general population.

I always say that as well as Argentina's great soil and great climate, we have been able to add two things in the last 20 years, which is the possibility of agro-input companies offering this type of innovation and technology together with public bodies. Nevertheless, the bonus, which I think is something important and which needs further work in the country, is the technology absorption of the Argentinian farmer. It seems to me that we need to work seriously, as I said in my initial speech, on the issues of control and biosafety, something that Argentina is doing extremely well.

It is clear that FAO's recognition of the National Advisory Commission on Agricultural Biotechnology (CONABIA) is something that fills us with pride. However, I would also like to say that universities, NGOs and public bodies are also involved. There are protocols in place, a clearly defined system based on morphology and physiology, work carried out in conjunction with the environment and comprehensive work on markets and food safety. After much work, all of these practices, all of this science, comes through to this Commission, and may or may not be approved. Indeed, many experiments have not been approved. In short, as it forms part of the State it unquestionably puts me at ease, because it is something that we are not only telling the people of Argentina but also the world. Ladies and gentlemen, these procedures that we are using are totally safe in terms of morphology, physiology, the environment and food, which is why I believe that the world needs this technology.

Another thing that I would like to clarify is that our vision encompasses not only food but also energy, which is a very important issue. For example, in our case, we are using this technology to produce bioenergy. An illustration of this is that last week Argentina increased the percentage of ethanol in its gasoline by 20 percent.

In essence this is all thanks to biotechnology. It enables us to do these things because we have overcome a production barrier. For example, in 1996 we produced an average of 5 tonnes of maize per hectare and today we are close to 9 tonnes per hectare. This is why we think it is extremely important. This is the message we have for all countries that are open, that as Argentinians, as inhabitants of the planet who wish to eradicate hunger and poverty, who wish to tackle global warming, I believe that these are very important tools. This is why I think that FAO has to play an active role. I am grateful for this symposium, but undoubtedly I would ask for much more and hopefully people will listen to us.

**QUESTION 2. Marcela Villarreal, FAO Moderator**

At this time, we are in direct link with seven universities around the world as well as with a number of students here locally in Rome. What we have discussed this afternoon has been transmitted throughout the world and the students who are listening to us will be able to react later in the student session after this high-level segment. So, I would like to ask our panelists if they would send one message to the young people who are listening to us throughout the world. What would your message be to the young generation on the topic of biotechnologies?

Frédéric Seppey, Canada

I presume that the message can be very different depending on the context. I think it is a very exciting moment to be in agriculture because the challenges that we globally face call for stark, very clear solutions. In Canada right now, we have a new government that has introduced a slight change in orientation. We have, for example, issues like climate change that take more prominence. It is a priority of the new government, to the point that our Ministry of Environment is now the Ministry of Environment and Climate Change and one reaction that we see early on is that the agricultural sector is quite keen to participate in trying to work globally and trying to find solutions to that global challenge. So this is just one illustration where by adopting novel, innovative practices, by working together, there will always be a very important role for agriculture in feeding the world, especially with the challenges that we have. I think it is the role of governments and the political elite to provide this global orientation.

Now, in terms of a Ministry of Agriculture we definitely want to favour a change in terms of our research, to encourage as many students as possible to go in these fields because the possibilities of work, and work of significant importance that could make a huge difference, are enormous. So, this is contrary to what some commentators in Canada recently said – that agriculture is really a sector that is dealing with nineteenth century commodities. I know that in many parts of Canada these kinds of allusions generated a very passionate reaction because agriculture is anything but a sector of the past. There is a lot of innovation to take place in that area.

Katalin Tóth, Hungary

If I have to sum up in one sentence I would say: let there be more and more farmers all over the world, and responsible farmers. As far as this question is concerned, to address the young generation is a complex issue in the sector of agriculture. Each country faces the same problems, how can we address the young people, how can we divert them to agriculture? It is very, very difficult. We have a family farm at home with 100 hectares of land and I have a 20 year old son and it was very difficult to motivate him and to direct him toward agriculture. However, this family farm has quite a long tradition. My father and my husband's father were also involved in the same activities. So, it is a very important question. It should be the focus of our attention for the future. It is not simple. It is a very complex issue to address the young people, to make them motivated and, at the same time, to make them familiar with the challenges that modern agriculture faces.

There are different factors involved – we can see this now in this conference; productivity, sustainability, environmental concerns, health concerns and so on. So, somehow we have to find answers to these elements one by one and integrate the future generation, to direct them to this very important sector. Agriculture is our future. What I wanted to say during the panel is that production

is a very important factor but it is not everything. If we think in a short-term view, we can say that productivity must be an important element and everybody says that productivity is very important – we should feed the world, we somehow have to tackle hunger and so on. Yes, that is true. But I think that when we want to address this question we should see what else there is behind it. So, productivity is just one concern. But, at the same time, what effects will this productivity have on our future? It is another important concern.

Papa Abdoulaye Seck, Senegal

First of all, you have spoken of seven universities but we do not know if there are any African universities on the list. So I do not know who I should ultimately address, but I can say that in terms of young people, we are increasingly in favour of young Africans committing themselves to high-level scientific and technical research. Why? Because we need these young people to become part of the knowledge generation, which will effectively enable African agriculture to change positively and sustainably. Yes! Science is universal but still we must always remember that it is the field that should control the process and that those who are effectively at the field level are better placed to provide results that are both practical and workable. So what we need is a critical mass of researchers and we are counting on young Africans so that, over time, we can call on biotechnology, and in this union of “giving and receiving” of knowledge, we can come to give and to receive, instead of just simply receiving.

The second message that I would like to deliver is that of encouraging young people to take up farming, especially well-trained young people because they will be able to use their knowledge and expertise to contribute to this continent, to Africa, so that there is adequate agricultural supply in terms of quantity, quality and income for producers, and so that we can resolutely progress towards sustainable food and nutrition security. Consequently, the accumulation of knowledge as well as investment in agriculture will help convert farming into a business, a trade that can be undertaken, to earn a good living and have a respectable social standing at the heart of our society.

These are the two messages that I wanted to transmit.

Néstor Roulet, Argentina

I will begin with a life story. I live in the inland province of Cordoba in Argentina, in a small village of 8 000 inhabitants located in the middle of the country, where we had first-hand experience of immigration to the cities. At one stage we thought that agricultural production in Argentina had no future, production was not possible, because of problems related to climate. However, the reality is that now many young people are returning to the countryside, and these young people are returning because we offered them a framework of innovation and technology.

I have seven sons, and today I can say with pride that two of my sons are working with me, something that fills me with emotion, and all of this is thanks to innovation and technology, because we realized that the agriculture sector was not making a profit. We can live at ease in the countryside, whereas before we could not. This is why I would like to tell young people that biotechnology is just one more tool. It is one more tool among the many other possibilities available to us. In our case it was direct seeding, and now we use precision seeding, using a satellite-based green index and, in areas where more fertilizer is required, we put more fertilizer and in those areas where less is required we use less.



And this is done with young people. That is why I say to young people: embrace this innovation and technology package because we have a great future, come back to the countryside, and live well. The fact is that we are ignored even when sometimes we pay premium rate taxes and yet when things need to happen we are considered second, third or fourth rate citizens. This is why I tell young people: embrace this technology that is beneficial for our future and that also gives us huge opportunities.

I always say that each country has a moral, social and humanitarian obligation to offer the world what it does best. In Argentina, one of the things that we do best is food. This is why we have the moral, social and humanitarian obligation to produce food. And that young person who wants to work, will also want to produce food. This is why I say to young people: let us work in this together, because the world has one of the necessary tools to prevent hunger and it also has a tool to tackle climate change.

QUESTION 3. Marcela Villarreal, FAO Moderator

Earlier in the first session of this high-level segment, we had two different questions. One was about thoughts and recommendations regarding the future of FAO in the area of biotechnologies. The other was about the message that you would like to give to the young students listening today – from seven universities around the world, from all the regions, and also students here today in Rome. Please respond to one of the questions, choosing which one you want.

Begum Matia Chowdhury, Bangladesh

Dear sweet people of the world. People and civilization, it goes with science. I was thinking of one of the dramas some time back. The drama was of Galileo. The debate was whether the sun moves or the earth moves. Galileo was executed but the reality is that the earth moves. So, you cannot deny science and you are to go with science. That is the answer.

Henri Eyebe Ayissi, Cameroon

I think that we have clearly understood FAO's role and we have addressed it in our presentation. We must propose that FAO really does support this project through its research and above all, as part of Africa, Cameroon, following on from what my colleague from Senegal said, recommends that FAO helps to facilitate regional dialogue in Africa, working to make research results available so that validated results can be used by farmers. This is because we need to use the results from research that is conducted in well-prepared and equipped laboratories. However, I would also like to highlight, along with my Senegalese colleague, that we continue strengthening research in this area.

Regarding the young people, we have already said that agriculture is the most important area for employment. We must encourage well-trained young people to commit to work in farming, especially emphasizing their level of qualification so that family farms can be transformed by the level of knowledge of these young people using what they have learned, and in particular to help exploit new techniques, including both technological and biotechnological inputs for greater yields. In essence, in order to encourage young people into farming, Cameroon's Head of State, the President of the Republic, Paul Biya, recently said in a speech to young people that those who were committed to farming would be able to build their lives and succeed in life. In reality, there are no other alternatives but it is a question of beginning a journey where agriculture that has been modernized by new

technologies producing greater yields will permit these young people to build and fulfil their lives. This is the most appropriate message to give on this issue at this moment in time.

Gerda Verburg, the Netherlands

First, let me underscore the importance of a good connection between farmers and research because I agree with all those people that science is crucial. But the link between farmers who have the experience, the wisdom, the generations in their DNA, they know what they want, they know how to work together and they are able to ask the right questions. So, I would like to promote the idea of participatory breeding programmes and I am also very much in favour of promoting access to precision breeding methods.

To young farmers I would say: speak up. Because what we need to do is to encourage young farmers and to create a future for them, both for male and female farmers, which means access to education, which means indeed the affordability and the accessibility to new technologies, linkage to markets, opportunities to make a proper income so they deserve fair prices in order to build their family, send their children to school and have a future in making progress. We should not tell young people to stay on the farm poor, hard-working, dependent and, from time to time, hungry. That is not the message to our youth. So, let us give them the opportunity and support them in making progress and a good income so that we, as consumers, have to pay fair prices as well and there have to be fair prices in the value chain.

Michael Scuse, the United States of America

I want to address all those students that are out there that are watching. I think now is probably the most exciting time that our young people can get involved in agriculture. There are so many areas where we need the enthusiasm and the intelligence of our young students that are out there today. And it is not just about biotechnology. We're looking at making advances in organic agriculture, in technical agriculture that need to be done. If you look at the science, the technology, the mechanical technology is changing, the equipment is changing. We're using satellites now, so we're talking about space to use satellites to track our equipment in the field. There are the environmental sciences to look at ways that we can do agriculture in a more environmentally-efficient way. There is a need for engineering students.

Education is not just about producers out on the farm and it is not just about the scientists. But so many of our population now no longer lives in our rural communities. They have moved to the cities and are generations removed from agriculture. There is a need for teachers to have the ability to go into the classrooms and teach our young people, that next generation, about the importance of agriculture. So I think now is probably the most exciting time that our students can get involved in agriculture, because there is so much to do, so many opportunities, so many different fields and I would encourage all of our young people to take a real hard look at agriculture and what it has to offer.



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Chapter 3

Parallel sessions: Climate change



3.1 Report of outcomes from the three parallel sessions dedicated to the theme of climate change

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Among the challenges faced by food systems is that we have only one planet and we see the limits of it. There is a nutritional shock now: there are more obese than undernourished people in the world. Climate deregulation and the loss of references for climate is another challenge. The agricultural and food systems are a victim of this problem and they have to adapt. Among other factors, they have to adapt to heat tolerance, drought tolerance, flooding and to the emergence of new pests and diseases out of their original range.

We had very interesting reports about adaptation, and the role that agricultural biotechnologies can play there during the first two parallel sessions of this theme. These included use of genomic technologies to characterize wild relatives of chickpea to develop climate-resilient varieties in Ethiopia and India. Other speakers described how biotechnologies have been used, *inter alia*, to improve drought tolerance and flooding tolerance in rice as well as drought tolerance and pest resistance in maize. Presentations also covered forest trees, including how biotechnologies can be used to help them to adapt to the changing climatic conditions that the trees are likely to experience in their long lifetimes.

Aquatic animal and livestock systems also need to adapt to face the challenges of climate change. For aquatic animals, presentations showed how climate change will affect farmed fish populations and that selective breeding can be an important tool enabling them to adapt. Biotechnologies currently play an important role in diagnosis and prevention of aquatic animal diseases. Similarly in livestock, vaccines were shown to be essential tools for disease prevention. Presentations also described the role of biotechnologies in breeding animal populations that are better adapted to climate change; in understanding the genetic basis of adaptation in goats; and in producing better livestock feeds.

However, food systems also contribute to climate change. They have to mitigate those impacts, a topic that was covered in some presentations in the third parallel session held this morning. The three main greenhouse gases produced by food systems are nitrous oxide, methane and carbon dioxide. Regarding the first one, we had a talk about biological nitrification inhibition in plants to increase nitrogen use efficiency and reduce nitrous oxide emissions.

We had a very interesting talk about the types of technologies that can be used to reduce the production of enteric methane by ruminants when they digest what humans cannot digest themselves. Regarding

carbon dioxide, mostly related to deforestation and afforestation, we had a talk highlighting the importance of biodiversity in forest systems.

Beyond mitigation, agricultural and forest soils can also sequester carbon dioxide. This is an ecosystem service that agriculture can provide to mankind and we had a very stimulating talk this morning about the “4 per mil” initiative regarding how carbon sequestration by soils can at the same time increase their quality and thus food security, and mitigate greenhouse gas accumulation and thus climate change.

So, altogether, climate change is a global issue – that is what came out of these different talks. It is a global issue that must be addressed in a cross-cutting manner using all different approaches, including technological, and all different actors and must be addressed locally. A global challenge addressed locally – that is difficult! The difficulty is that we do not know the final plateau so the target is unknown – what is the climate going to be like in 50 years or so? That is one of the big issues, although we did not address it in these parallel sessions. But, we had a presentation with an economic view this morning about the equilibrium between poorer and richer areas of the globe and the importance of innovation in agriculture. End users innovate a lot and that is also the case in agriculture.

Local knowledge is very useful, and this was shown in a presentation on breeding durum wheat in Ethiopia in the third parallel session. But, when dealing with climate change, it is not always completely suited because the climate *changes* and so it is difficult to address the change with local solutions because these have been optimized for the previous situation. For instance, that is the case of chickpea. We had a talk about going back to the areas of domestication and diversification of this crop to look for more diversity etc., to address problems that the modern varieties cannot address completely now.

Another problem, especially for mitigation, is that there is no direct gain for the farmer. The fact that agriculture might make a smaller contribution to climate change is an indirect gain. It is very strong but it is long-term and indirect. There may be even a cost for the farmer. There may be a gain in some practices, such as biological nitrification inhibition, for instance, described this morning. But it is an issue that those who act are not those who benefit immediately at least. However, we heard this morning about an interesting experience in Mali where about 20 technologies related to climate change had been identified through a participatory approach and where the support of international partners could be important in applying them for the benefit of smallholders.

Agricultural biotechnology is much broader than just genetically modified organisms (GMOs). There is a lot of innovation going on. There is a lot of innovation that is on the shelf. We have to take it and put it together to address the issues. These innovations regard artificial insemination and reproductive technologies, marker-assisted breeding, fermentation and probably genome editing. We did not talk about genome editing in these parallel sessions, but it is probably very, very useful.

So, to conclude, I think the most striking point is, and there is quite a consensus, that we should not approach the problem one-by-one but in a cross-cutting manner. Probably FAO could organize this because of the breadth of its partnerships – from many different countries, fields and specialities.



FAO probably has to tackle this challenge of climate change in a silo-breaking manner somehow. Maybe having a climate change champion or something similar. Because it is very obvious that big challenges are more and more inter-connected with each other. For instance, the inter-connection between agricultural biotechnologies and agroecology is an obvious one.

3.2.1 **Report of the parallel session**

Facing the challenges of climate change: Adaptation in the crop and forestry sectors⁴

Chittaranjan Kole, one of the two ‘theme leaders’ for climate change, chaired the session. He welcomed the participants and provided background information on the theme and its three parallel sessions. He also explained the objective of the session and introduced the scope of the five presentations.

Abdelbagi Ismail (International Rice Research Institute, IRRI) presented four case studies on developing rice varieties with enhanced adaptation to lowland farming systems of South Asia. The case studies addressed the following problems: 1) increasing use of direct seeding in rice production systems; 2) complete flooding (submergence); 3) drought; and 4) salinity in tropical coastal deltas. He explained that few rice accessions tolerate anaerobic conditions during germination. These accessions were identified, and molecular and physiological mechanisms associated with the tolerance were studied. Breeding lines for direct seeding tolerating anaerobic conditions have now been developed and are being evaluated at various locations in Asia. Regarding the submergence problem, the discovery of the *SUB1* quantitative trait locus (QTL) in the mid-1990s was an important turning point for breeding. *SUB1* confers tolerance of complete submergence for 10 to 18 days. Subsequently, numerous *Sub1* varieties have been developed and commercialized in several countries. He continued by noting that several drought tolerant rice accessions have been identified and crossed with high-yielding but drought-sensitive varieties. In the case of salinity, numerous tolerant accessions have also been identified over the past decades and used extensively in breeding salinity-tolerant varieties.

Yoseph Beyene (International Maize and Wheat Improvement Center, CIMMYT) presented some results of the water efficient maize for Africa (WEMA) project. He pointed out that average maize yield is low, 1.8 tonnes per hectare in sub-Saharan Africa as compared with the global average yield (4.5 tonnes/ha). Advanced conventional breeding techniques have been used to generate new high-yielding hybrids with 25 percent higher yield as compared with earlier hybrids developed in 2008. A total of 59 drought tolerant maize hybrids have been developed and recommended for commercialization in four WEMA countries (Kenya, Uganda, United Republic of Tanzania and South Africa). The project has also carried out molecular breeding which has provided two to three times higher grain yield than conventional breeding. Furthermore, the project has used transgenic approaches and tested *Bacillus thuringiensis* (Bt) maize hybrids in controlling the spotted stem borer (*Chilo partellus*) in the field and the African stem borer (*Busseola fusca*) in the laboratory with significant results.

Douglas Cook (University of California Davis) presented the work done on mapping the wild relatives of chickpea and how their germplasm could be used for breeding of climate-resilient crop varieties.

⁴ This report was prepared by the FAO rapporteurs for the climate change theme - Jarkko Koskela, Paul Boettcher and Melba Reantoso.



A large collection of wild *Cicer* species from a representative range of natural environments has been built for characterization. Genomic technologies have been used to characterize genetic diversity among ~1 100 accessions and to nominate particular plant accessions as targets of pre-breeding, phenotyping and breeding. Three *de novo* whole genome assemblies have been produced to provide reference genomes for cultivated *Cicer arietinum*, wild *C. reticulatum* and wild *C. echinospermum*. A large programme of genetic crossing is being used to introduce wild genetic diversity into phenology-normalized backgrounds. The base populations involve 20 diverse wild donor accessions crossed into five cultivated elite varieties.

Ciro De Pace (University of Tuscia) provided a review of genomic approaches used for dissecting fitness traits in forest tree landscapes. He pointed out that forest ecosystems, harbouring up to 90 percent of the world's terrestrial biodiversity, continue to disappear due to deforestation and forest degradation. Climate change is altering temperature regimes, rainfall patterns, and the life cycles of pathogens that have co-evolved with forest tree hosts. To conserve forest biodiversity services and resilience in the rapidly changing world, it is necessary to understand how ecological assemblages in forest landscapes have been formed and how they respond to novel environmental conditions. He then explained how forest landscapes can be described based on fitness (fitness landscape), genome architecture (landscape genomics), the spatial distribution of environmental variables and population genetics parameters (landscape genetics), and the relationships between spatial patterns, geo-climatic variation, and ecological processes (landscape ecology).

Sally Aitken (University of British Columbia) made a presentation on using genomics to understand and manage adaptation to climate change in forest trees. The AdapTree project in western Canada has used phenotype-environment associations, genotype-environment association and genome-wide association studies to assess climate adaptation in two economically and ecologically important conifers, lodgepole pine (*Pinus contorta*) and interior spruce (*Picea glauca*, *P. engelmannii* and their natural hybrids). Approximately one million single nucleotide polymorphisms (SNPs) were genotyped for around 23 000 genes, as well as non-coding regions, for trees from hundreds of populations in each species. Genotype-environment association analysis identified hundreds of SNPs in each species that were associated with climatic variables. The primary climatic drivers of local adaptation were low temperatures. These findings were supported by results from seedling common gardens. The results suggest that assisted migration and assisted gene flow could be used to translocate more productive warm-adapted genotypes from milder climates to colder locations as climates warm, and that this should not increase the risk of drought injury relative to using local seed sources.

After the presentations, there was a discussion moderated by the Chair. The first questions were related to the use of seawater and interaction between soil and environment in the rice production systems. It was clarified that currently rice can be irrigated with water that contains 25 percent of seawater and eventually the level of 50 percent may be possible but productivity is likely to be low. It was further explained that saline and alkaline soils create different challenges; salinity can diminish temporarily as a result of rains while alkalinity is a more permanent soil characteristic.

Concerning GMOs, it was asked whether the testing of GMOs should be done under a broader set of climatic conditions. Some noted that GMOs should be tested where they will be finally used. It was reminded that each country will ultimately make its own decisions concerning the regulation and

deployment of GMOs, and that a case-by-case approach is often the best one. It was further noted that cisgenics should also be considered as an approach for crop improvement.

It was noted that while much research has been done, it is not yet clear how much biotechnology has increased the yields of rice and maize in the hands of the farmers. It was also stressed that dissemination of technologies and germplasm for farmers is crucial for making the impact happen in the field. The speakers recognized that the impacts need to be better documented and noted that there are successful examples of deploying improved germplasm to farmers. IRRI, for example, collaborates with over 650 seed companies and non-governmental organizations (NGOs) through which the improved rice varieties have reached ten million farmers.

Some participants commented that agricultural development since the 1960s had destabilized production systems and caused erosion of genetic diversity. Several speakers emphasized that genetic diversity is used for breeding and that progress is being made. They also responded that the alleged destabilization of production systems is not true and that it is only a perception. Many speakers also stressed that it is necessary to use biotechnology as the global challenge is to feed nine billion people. It was further noted that continued research efforts are needed as the performance of crop varieties fades away over time and new pathogens and insects will always emerge.

During the discussions, it was mentioned that 2016 is the International Year of Pulses. There are some 20 000 accessions of pulses stored in different gene banks but it is unclear how many of these have been evaluated. It was noted that there is considerable duplication of the same germplasm in the gene banks so the amount of diversity is actually not that high in these collections. Furthermore, breeding programmes are often based on relatively few accessions.

The Chair concluded the session by thanking the other 'theme leader' Olivier Le Gall, the FAO officers, the three rapporteurs as well as the speakers and the participants for a lively discussion and sharing of their thoughts and experiences.



3.2.2 Developing rice varieties with enhanced adaptation to lowland farming systems: Case studies from South Asia

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The ever-increasing global demand for food makes it necessary to produce more rice from less favourable areas. These areas, however, have low productivity because of the prevalence of abiotic stresses like floods, drought and excess salt, the effects of which are becoming progressively more severe because of climate change. Recent scientific advances are providing opportunities to fast-track breeding of tolerant rice varieties that maintain their productivity under these conditions and to help meet the increasing demands for food, to combat poverty and secure sufficient food supplies.

Early floods can lead to poor crop establishment, especially in areas where direct seeding (DS) is practised. Farmers are increasingly adopting DS as the preferred method in both rainfed and irrigated rice ecosystems because of labour scarcity and reduced expense. However, large-scale adoption of DS requires rice varieties that can germinate in flooded or waterlogged soils, as rice is extremely sensitive to flooding during germination and early seedling growth. Developing high-yielding varieties that can withstand such conditions can accelerate the adoption of DS in both irrigated and rainfed areas. A few rice accessions that tolerate anaerobic conditions during germination were identified and used to study molecular and physiological mechanisms associated with tolerance. A few quantitative trait loci (QTLs) were mapped and one cloned. Breeding lines with tolerance under field conditions were developed and are being evaluated at various locations in Asia.

Complete flooding (submergence) is constraining rice production in over 16 million ha of rainfed lowlands in Asia and large areas in Africa, and its effects have worsened over the recent past leading to concomitant poverty and food insecurity in the heavily populated flood-prone areas. Significant progress was made in developing tolerant varieties through conventional and molecular breeding approaches. An important turning point in breeding for this ecosystem was the discovery of the *SUB1* QTL in the mid-1990s and its subsequent cloning. *SUB1* confers tolerance of complete submergence for 7–18 days, with no undesirable consequences, and is effective at almost all growth stages. Its usefulness was validated in farmers' fields with yield advantages of 1 to over 3 tonnes/ha, depending on the duration and depth of submergence and floodwater conditions, but with similar yields in the absence of submergence. Numerous *Sub1* varieties were developed and commercialized formally in several countries. These varieties are spreading fast in Asia since the release of the first variety in India in 2009 and are currently grown by about 4 million farmers in over 2.5 million ha.

Further research is targeting additional QTLs to strengthen *SUB1* and to combine it with tolerance of other abiotic stresses.

Longer-term stagnant flood (SF) causes severe reductions in yield, and farmers in affected areas are mostly using traditional varieties that are partially tolerant but have low yield and grain quality because modern tolerant varieties are not widely available. We identified several landraces and elite lines with reasonable tolerance of SF, and some of them were used to study the basis of tolerance. Stagnant floods reduce survival and tillering and suppresses vegetative growth leading to lower grain yield and quality. Several breeding lines were developed and are being evaluated; and mapping populations are being analysed to identify QTLs associated with tolerance for use in breeding.

Drought reduces rice yield in over 23 million ha in South Asia. Significant genetic variability for yield under drought in rice led to the search for major QTLs for grain yield. Several tolerant donors were identified and crossed with high-yielding but drought-sensitive varieties, and several drought-tolerant varieties were released recently in South Asia, demonstrating significant impacts on rice productivity in drought affected areas. Numerous mapping populations were developed over the past decade and 14 large effect QTLs were identified, seven of them showing effectiveness in several genetic backgrounds and in diverse upland and lowland environments, with yield advantages of 0.5–1.5 tonnes/ha over original varieties. The effectiveness of marker-assisted backcross breeding for improving drought tolerance in rice was demonstrated with the recent release of the first variety, IR64-drought, in 2014.

Salinity limits rice productivity in large irrigated and rainfed areas, particularly in tropical coastal deltas where rice dominates the cropping systems. These areas are most vulnerable due to increasing storm incidences and sea level rise caused by global warming. The productivity of saline soils is low, with yields averaging below 1.5 tonnes/ha, but can be doubled when salt tolerant varieties are used. Numerous tolerant donors were identified over the past few decades and used extensively in breeding tolerant varieties. Some of these new varieties were recently released, with large yield gains in affected areas. QTLs associated with tolerance were identified; the largest of which is *Saltol* on chromosome 1. This QTL was transferred recently into several popular varieties. Additional QTLs for tolerance at both seedling and reproductive stages are being targeted to combine them with *Saltol* for higher tolerance. Ultimately, we aim to combine alleles associated with tolerance of different abiotic stresses to provide more resilient varieties for less favourable areas in Asia and Africa, to help keep up with the increasing demands for rice and to cope with climate change adversities.



3.2.3 Harnessing agricultural biotechnology for resilience to climate change: A lesson from water efficient maize for Africa (WEMA) project

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Maize is among the most important food crops in the world, and together with rice and wheat, provides at least 30 percent of the food calories to more than 4.5 billion people in 94 developing countries. Compared with other regions, maize yield is extremely variable in sub-Saharan Africa (SSA), though maize is the most important staple food for more than 300 million people. For example, between 2005 and 2008 the average maize yield was estimated at 1.8 tonnes per hectare compared with 2.5 tonnes/ha in the Philippines, 3.1 tonnes/ha in Mexico, and 3.9 tonnes/ha in Thailand. Although several factors, including low soil nitrogen, foliar diseases, insect pests and socio-economic factors, do contribute to this low production, drought has been cited as one of the major factors that frequently limits maize production in the SSA region.

To address the problem, the WEMA project was launched in 2008 with the objective of enhancing food security in SSA through developing and deploying drought-tolerant and insect pest protected maize, developed using conventional breeding, molecular breeding and transgenic biotechnology approaches. The WEMA project is a public–private partnership among AATF, CIMMYT, Monsanto and five national agricultural research systems (NARS) in Kenya, Mozambique, South Africa, Uganda and United Republic of Tanzania. It is supported by the Bill and Melinda Gates Foundation, the Howard G. Buffett Foundation, and the United States Agency for International Development (USAID) for ten years (Phase I 2008–2013, Phase II 2014–2017). This presentation highlights the achievements, challenges, and lessons learnt from the project.

Advanced conventional pedigree breeding techniques, using managed drought stress selection environments and a large testing network (60 sites), are used to generate stable high-yielding hybrids. In a typical year, WEMA scientists evaluated 30 000 inbred lines and 15 000 hybrids, many of

them grown under managed drought stress and optimum moisture environments. To date, 26 000 doubled haploids (DH) lines have been developed by CIMMYT and Monsanto from crosses of Monsanto, CIMMYT and NARS inbred lines. The development and use of DH lines has increased rates of genetic gain and empowered NARS breeders who were able to access DH lines for the first time. New germplasm combinations using temperate germplasm introgressed into tropical germplasm are producing elite hybrids with high yield potential. Since 2008, WEMA partners have used DH technology and pedigree breeding to develop 59 drought tolerant hybrids recommended for commercialization in four WEMA countries (Kenya, South Africa, Uganda and United Republic of Tanzania). Currently, 23 seed companies have been engaged through sub-licensing, to produce and market the released WEMA hybrids. Overall, 35 drought tolerant hybrids are in on-farm demonstrations and five hybrids are in commercial production in four countries with projected production of 1 600 tons of certified seed in 2016.

To facilitate the development and use of improved tropical maize germplasm, the project adopted several approaches for breeding for drought stress tolerance including marker-assisted recurrent selection (MARS), genomic selection (GS) and pedigree selection. The project scientists conducted the largest genomics-assisted breeding work that includes analysis of the efficiency of MARS and GS over pedigree-based selection in tropical maize. Genetic gain studies have been completed for 18 tropical populations: ten under MARS and eight under GS. MARS and GS provided up to four times higher grain yield than pedigree-based selection, without significantly affecting plant height and anthesis date in most populations. Also, hybrids developed through MARS produced 19 percent higher grain yield than the commercial checks. The high genetic gain of hybrids developed using molecular breeding was highly remarkable considering that the commercial checks used for the studies were the best available in the region. In addition, more than 1 000 fixed lines developed through molecular breeding have been tested in multilocation trials. This improved germplasm will facilitate a flow of drought tolerant hybrids for several years to come. Several hybrids derived using lines developed through molecular breeding are currently under national performance trials, a step towards commercialization in SSA.

Combined analyses of confined field trials (CFTs) of transgenic drought tolerant (DT MON87460) maize data using 34 hybrids with the same base genetics and evaluated in three WEMA countries for three or more years, showed that five traited hybrids gave 8–14 percent greater yield than the non-traited versions, indicating a strong positive gene effect with ample scope for selection and breeding in germplasm of similar genetic background as these hybrids. MON87460 was approved for commercialization in South Africa in May 2015. In 2011 the transgenic *Bacillus thuringiensis* (Bt) event MON810 was added to the transgenic component of the project and provides insect pest resistance to all the WEMA countries except South Africa. For South Africa, a second transgene, MON89034, coding for different protein, has been added and is already approved for commercialization. Existing regulatory systems supported the testing of MON810 transgene in Kenya and Uganda and the efficacy of single trait events has been demonstrated. Efficacy trials were carried out on Bt MON810 in controlling the spotted stem borer (*Chilo partellus*) in the field and the African stem borer (*Busseola fusca*) in the laboratory in maize in Kenya (CFT I – CFT III) and in Uganda (CFT II). For example, results of CFT II in Kenya showed that 75 percent of the hybrids evaluated had significantly greater yields ranging from 26 to 113 percent with the Bt trait than without the trait. Similarly, results of CFT II in Uganda showed that all the seven Bt maize



hybrids had significantly greater yields of 49–201 percent due to the Bt trait compared with the non-traited hybrids.

Full deregulation of the MON810 transgene is likely to occur in Kenya and Uganda in 2016. Field testing of transgenics in Mozambique and United Republic of Tanzania will commence in 2016 as approval has been obtained for testing the transgenics in confined field trials. Field testing of stacked DT and Bt commenced in South Africa in 2015, and will commence in Kenya, Mozambique, and Uganda in 2016. Widely adapted inbreds have been converted to DT and Bt traits, and will be utilized to develop transgenic products.

3.2.4 Molecular breeding in legumes for resource-poor farmers: Chickpea for Ethiopia and India

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Breeding for climate resilience as well as other high-value traits in pulse legumes will be greatly accelerated if we can expand the range of adaptations accessible to breeders. We address this need in chickpea, the world's second most important pulse legume, by harnessing the capacity of chickpea's wild relatives to survive in harsh environments. Chickpea is a global commodity of critical importance to food security in low income, food deficit countries of sub-Saharan Africa (Ethiopia, Kenya, Malawi, Sudan and United Republic of Tanzania) and South Asia (India, Myanmar and Pakistan), and also of importance in advanced developing economies (Turkey), and developed countries (Australia, Canada and the United States of America). Effective use of wild germplasm in chickpea improvement requires new and systematic surveys of genotypes from natural environments, identification of adaptive alleles to environmental extremes, and incorporation of the diversity of wild alleles into phenology-normalized backgrounds for trait analysis and breeding.

Achieving these objectives requires a close marriage of cutting-edge science (e.g. genomics, modelling and high-throughput precision phenotyping), with appropriately structured pre-breeding and breeding activities. The current project involves multiple donor agencies in several countries, built around a core Feed the Future grant from the USAID that is focused on chickpea improvement for Ethiopia and India.

Chickpea (*Cicer arietinum*), like most cultivated crops, has exceedingly narrow genetic and phenotypic diversity. Whole genome sequencing reveals a remarkably strong domestication bottleneck through which ~95 percent of genomic variation was lost from modern elite cultivars. This has profound implications for breeding of climate-resilient crop varieties. The dearth of adaptive variation likely limits our ability to both adapt the crop to a scenario of changing environments and to expand the cultivation of domesticated species into environments beyond those under which historical domestication occurred. Thus breeding only within cultivated germplasm is likely to have diminishing returns, raising an urgent need for new sources of diversity.

Wild species are a key but underutilized resource for crop improvement and harnessing their potential represents a primary challenge for twenty-first century agriculture. The challenge, which is the explicit focus of numerous international efforts under the Global Crop Diversity Trust (one of our



sponsors), is particularly acute in the developing world where extreme climatic conditions, marginal soils and reduced inputs limit productivity, create increased risk, and diminish livelihoods through reduced income and malnutrition. The impact of a properly implemented and well-utilized resource of wild germplasm would extend beyond the developing world, because many of the crop phenotypes of importance in the developing world (e.g. tolerance to heat and drought, reduced dependence on inputs [e.g. nitrogen, phosphate, pesticides, water], and increased seed nutrient density) are also key to meeting the global demands for crops that incorporate traits for climate-resilience, increased sustainability, and increased nutritional value.

The potential for genetic gains from use of wild crop relatives is well documented. Nevertheless, wild crop relatives of chickpea have been used sparingly and in an ad hoc manner in chickpea improvement. Among the impediments to the use of wild material is the dramatic phenological difference between wild and cultivated forms, in particular with respect to flowering time. Phenological differences complicate crossing and preclude the ability to systematically evaluate wild alleles in an agricultural context. Moreover, traditional approaches of genetic crossing and phenotypic assessment are laborious, severely limiting the scale at which studies can be undertaken.

With these challenges in mind, we have built and are characterizing a large and systematic collection of wild *Cicer* species from a representative range of natural environments, including gradients in rainfall, temperature, soil chemistry and altitude. Genomic technologies have been used to characterize genetic diversity among ~1 100 accessions and to nominate particular plant accessions as targets of pre-breeding, phenotyping and breeding. Three *de novo* whole genome assemblies have been produced to provide reference genomes for cultivated *Cicer arietinum*, wild *C. reticulatum* and wild *C. echinospermum*. The remaining accessions are being sequenced under a prioritized, hierarchical strategy of high-, medium- and low-read depths to facilitate allele and trait discovery using a combination of computation of genomic features and phenotyping/modelling of trait-marker associations in nested association mapping and bi-parental populations.

A large programme of genetic crossing is being used to introduce wild genetic diversity into phenology-normalized backgrounds. The base populations involve 20 diverse wild donor accessions crossed into five cultivated elite varieties. A collection of ~8 000 segregating lineages is being increased in the field for F₃ seed and early generation phenotyping. In parallel, we are pursuing a programme of intercrossing to increase recombination and genotyping to normalize flowering time and plant architecture. The resulting populations are expected to exhibit relatively uniform phenology and thus be suitable for large-scale phenotyping, which we are beginning using a combination of automated field platforms, greenhouses and controlled environment chambers. Initial climate resilience traits under analysis include those related to drought, heat and cold tolerance.

Abiotic stress in chickpea is inextricably tied to both beneficial and pathogenic micro-organisms. For example, legumes' unique advantage of symbiotic nitrogen fixation is strongly impacted by abiotic stress, and thus developing plant varieties and bacteria symbiont genotypes that maintain symbiosis under stressful conditions is an additional objective. Similarly, the agronomic cycle in chickpea is driven by trade-offs between abiotic stress and plant disease. Planting of chickpea is delayed until after the rainy season ends because moisture promotes soil seedling disease and foliar *Ascochyta* blight. Conversely, planting or maturing too late exposes the crop to terminal drought, heat stress

and *Fusarium* wilt, leading us to initiate efforts on targeted plant disease phenotypes. Finally, the importance of microbial communities (the “microbiome”) in promoting the health and stability of both animal and plant systems is increasingly recognized, though it remains poorly understood. We have initiated a programme to understand the dynamics of chickpea’s microbiome, with the long-term objective of developing microbial treatments to mitigate abiotic stress, nutrient deficiency and plant disease.

The outcomes of this project are intended to be high-yielding, climate-resilient chickpea varieties within the context of user-preferred traits: seed quality and nutrient density, reduced inputs due to climate resilient nitrogen fixation, and biotic stress resistance among them. We have a clear focus on research-for-development, with all upstream activities (i.e. germplasm collection, genomics and population development) predicated on the need to facilitate downstream phenotyping and breeding activities. In the course of this work we aim to identify and introduce newly collected wild alleles into diverse high-performing elite cultivars that increase crop productivity, food and nutritional security for smallholder farmers.



3.2.5 Genomic approaches for dissecting fitness traits in forest tree landscapes

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Forests present a wide variability among living organisms and the ecological complexes of which they are a part. Approximately 30 percent of the Earth's land surface (four billion ha in 2015) is covered by forest landscapes (FAO, 2016). The bulk of that landscape (93 percent or 3.7 billion ha in 2015) is natural forest. Most natural forests are either naturally regenerated forest (65 percent) or primary forest (the remaining 35 percent) of native species and harbour up to 90 percent of the world's terrestrial biodiversity where there are no clearly visible indications of disturbance of the ecological processes by direct human-related activities. However, natural forests continue to disappear at an alarming rate as a result of disturbance and degradation of the ecological processes, fragmentation and other stressors that can be linked to the indirect effects of human activities (Steffen *et al.*, 2011). The global emission of large quantities of carbon dioxide (CO₂) and other gases with "greenhouse effects" in the air can disturb the energy balance at the Earth's surface and the intensity of weather events. Globalization and climate change can alter seasonal air temperatures, rainfall patterns, and the life cycles of pathogens which have co-evolved with forest tree hosts and facilitate the spread of non-native and invasive pathogens to areas where native tree species lack specific defences against them.

To meet the challenge of conserving forest biodiversity, services and resilience in this rapidly changing world, it is necessary to understand how ecological assemblages in a forest landscape have formed and respond to novel environmental factors. Darwin provided some key ideas for understanding the fate of ecosystems. He stated that species "favoured by any slight change of climate" will increase in numbers, whereas other, less-favoured species "must decrease". Darwin clearly believed that the "natural selection" process explains the increase in frequency of individuals carrying adaptive alleles as well as why individuals or species are adapted to their environments.

The modern synthesis of Mendelian genetics with Darwinian evolution, developed in the 1930s and 1940s, provided the conceptual framework for a basic population genetics model (reviewed in Provine, 2001) to measure the fitness of individual genotypes, genetic diversity, and to understand its change paths when mutation, migration-gene flow, genetic drift and natural selection evolutionary forces act in ecosystems. Examples of fitness-related traits displaying Mendelian inheritance are known for forest tree species, e.g. the simply inherited resistance to blister rust in *Pinus lambertiana* (Kinloch, Parks and Fowler, 1970). However, the majority of traits of both economic and ecological significance in forest trees are complex including life history traits (i.e.

generation length, mating system, pollination mechanism, fecundity, seed dispersal, growth rate) and resistance to abiotic stresses.

Since the early 1970s, biochemical markers identified by electrophoretic techniques have been used in the first attempt to dissect, at the molecular level, the fitness components of forest trees in homogeneous environments. Those markers of the nuclear or organellar genome were limited in number and soon revealed, with few exceptions, their adaptive-neutrality. On the other hand, they helped in making inferences on demographic patterns and colonization dynamics in several conifers, European oaks and *Castanea sativa*, but rarely (*Fagus sylvatica* and *Pinus sylvestris*) elucidated fitness components in tree populations. Similar limitations affected early genetic DNA markers (restriction fragment length polymorphism [RFLP], random amplified polymorphic DNA [RAPD], amplified fragment length polymorphism [AFLP], and simple sequence repeats [SSR]), which were difficult to reproduce (RAPD) or expensive to detect (RFLP, AFLP, SSR).

The recent development of next-generation sequencing platforms has helped to revolutionize population genetics by providing rich databases for SNP genetic markers. SNPs are generated from resequencing candidate genes for the phenotype of interest in a small (< 100) panel of individual trees of model species and from expressed sequence tag (EST) sequencing projects. Recently, *de novo* multiplexing sequencing of the reduced representation library of a tree genome using restriction enzymes and PCR amplification of the library of fragments, speeded up genome-wide SNP identification, fine mapping, and genotyping. SNPs are used primarily in genome-wide association mapping (GWAM), also known as linkage disequilibrium mapping, to overcome limitations of pedigree-based QTL mapping by taking advantage of both linkage disequilibrium and historical recombination present within the tree species gene pool. For example, in conifers, a QTL interval spans ~15 cM (Khan and Korban, 2012). This suggests that the majority of identified QTLs, particularly those with minor to moderate effects, are specific to the mapping population and without fine-mapping are of limited utility in metapopulation genetic studies. GWAM has the potential to identify the genetic architecture of traits when candidate genes for the phenotype of interest are unavailable. It has been used to map genetic regions affecting the release of seeds over a long period of time in response to an environmental trigger (i.e. wildfire), a phenomenon known as serotiny. The intensity of the serotiny phenotype varied in accordance to the genotype at 11 QTLs identified by GWAM which explained 50 percent of the phenotypic variation in serotiny in three populations of lodgepole pines (*Pinus contorta*). Much of that variation was related to geographically variable natural selection arising from fire frequency and seed predation.

Forest tree species and seed predator interactions have been documented in a wide variety of systems, including *Greya* moths and the *Lithophragma* woodland plants they pollinate and oviposit in, and crossbill finches (*Loxia*) preying on the seeds of lodgepole pine. The most clear example of geographic variation in species assemblage that cause difference in forest tree fitness and direction of disruptive selection involve competition between squirrels (*Sciurus* sp.) and crossbills (*Loxia curvirostra*) for *Pinus ponderosa* cone seeds. *S. aberti* squirrel feed mainly on the inner bark of ponderosa pine twigs found on the Rocky Mountains in the United States of America, and exert selection on resin characteristics but not directly on cone structure. In the absence of *S. aberti* squirrel, captive crossbills had significantly longer seed extraction times when feeding on cones. But cone scale provides resistance to crossbills spreading cone scales apart, and increased scale thickness evolved in response to crossbill predation.



Grey squirrels (*S. griseus*) have a selective impact on western ponderosa pine by preferring seeds from cones with a high ratio of seed mass to cone mass which tends also to be small. Selection exerted by grey squirrels favoured trees with large cones and a low ratio of seed mass to cone mass, and these are the traits that characterize cones in which grey squirrels are present and crossbill finches absent. Significant quadratic relationships exist between standardized relative tree fitness and size-related traits.

The above examples on variation patterns of serotiny and cone size related to geographical differentiation of the intensity and trend of ecological processes and natural selection, suggest significant roles for the spatial scale and genomics to quantify micro-evolutionary processes in natural forest landscapes. Conceptually, the forest landscape may be seen as layers of landscapes whether they describe fitness (fitness landscape), genome architecture (landscape genomics), the spatial distribution of environmental variables and population genetics parameters (landscape genetics), and the relationships between spatial patterns, geo-climatic variations, and ecological processes (landscape ecology). Integration of spatially explicit ecological analyses and genomic approaches will result in more comprehensive sampling of ecological landscapes providing a more diverse set of inferences regarding fitness landscapes.

Perhaps the broadest implication of the work on serotiny is thus the focus on phenotypes measured in natural populations in the light of their fitness, genomic, and ecological landscapes. This directly complements and extends the work performed in natural forest tree populations, common garden experimentation in the field, and growth chamber comparison of forest regeneration materials, which is where precise estimates of heritability and genetic effects can be obtained. When such experimentation is coupled with genomics and integrated with emerging infrared technologies, the first metaphorical and geographically based fitness landscapes may indeed be covered by trees.

Future directions for forest tree genomics and forest fitness landscape research will take advantage of the rapid advances in “-omics” technologies. Three priority research areas for genomic research in trees can be highlighted.

First, identification of “functional” traits targeted by natural selection: The informativeness of high-throughput phenotyping technologies in test plantations and laboratory environments may be increased when “functional traits” affecting fitness are evaluated. Recently, it has been demonstrated that principal component analysis of plant traits with ecological meaning (i.e. adult plant height, dry mass per unit of fresh stem volume, leaf dry mass accounting for investment in xylem tissue per unit leaf area, and diaspore mass) in forest tree communities reveals patterns of functional trait variation that allow one species to survive natural selection, physiological challenges and competitive exclusion (Díaz *et al.*, 2016). The procedure applied to geographically scattered forest landscapes sharing a common set of congeneric tree species, promises the identification of those traits and species that have successful fitness features in forestry.

Second, increased discovery of candidate genes for fitness traits: The identification of polymorphic “functional traits” within species will help to dissect traits related to fitness. Genomics research directed towards finding the candidate genes coding for the polymorphic “functional traits”, will provide the population genetic parameters to measure and predict evolutionary changes in forests disturbed by

stressors affecting those traits. For example, climate explained meaningful proportions of variation in leaf and xylem traits across the globe. In arid habitats, natural selection has favoured strategies that increase certain “functional” expressions such as the embolism resistance of xylem, investment in xylem tissue per unit leaf area, as well as the density of xylem tissue. It is likely that genes for these same traits could confer drought resistance in forest tree species and help adaptation under global warming.

Fourier transform infrared spectroscopy, a chemical fingerprinting technique of the metabolome, has been used to identify *Quercus agrifolia* plants resistant to *Phytophthora ramorum*, the causal agent of sudden oak death, prior to infection (Conrad and Bonello, 2016). Concentrations of quercetin flavonol and ellagic acid phenolic dilactone were found to be highly significant biomarkers of resistance. Therefore, chemical fingerprinting can be used to identify resistance in a natural population of forest trees prior to infection with a pathogen. GWAM and expression analysis of genes involved in the biosynthetic pathways of biomarkers will provide information on candidate genes to be followed in the fitness landscape for increased adaptation to diseases in forestry. Fourier transform infrared spectroscopy may be a useful approach for dissecting traits affecting fitness under directional selection due to biotic stressors and to manage forests impacted by sudden oak death, as well as in other situations (*U. minor* following infection with *O. novo-ulmi*; *Quercus suber* roots following infection with the pathogen *Phytophthora cinnamomi*; *Pinus pinaster* after inoculation with the pathogen *Fusarium circinatum*) where emerging or existing forest pests and diseases are of concern.

Third, deep genomics to explore the fitness landscape: Deep genomic surveys may be used to explore the metaphoric fitness landscape for alleles at the candidate genes discovered by chemical fingerprinting and involved in biotic and abiotic stress resistance in forest trees. Usually those resistances, as for antibiotic resistance in prokaryotes, carry a fitness cost that must be overcome in order for resistance to persist over the long term. Functional defects associated with resistance mutations may be compensated by mutations at other genes that overcome the cost of resistance. Compensatory mutations are expected to be rare relative to generally beneficial mutations that increase fitness, irrespective of resistance trait. If the cost of resistance is large, compensatory mutations will increase sharply in frequency. This prediction can be tested by determining the linkage disequilibrium decay for polymorphic SNPs in genomic regions harbouring expression QTLs and structural genes associated with the resistance phenotype and its biomarkers.

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3.2.6 Using genomics to understand and manage adaptation to climate change in forest trees

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Introduction

Forest geneticists have long recognized that natural populations of forest trees differ genetically for adaptive traits along climatic gradients. Such patterns were first documented centuries ago for temperate tree species in provenance trials, common garden experiments containing trees grown from seed collected in different locations. These observations led to forestry practices and policies supporting the use of local populations as seed sources for reforestation and as base populations for breeding programmes.

Strong and mounting evidence of the effects of anthropogenic climate change on the health of forests globally has resulted in a stronger imperative to manage adaptation to climate in reforestation, better matching genotypes with new climates. Tree populations are lagging behind their historic climatic conditions as climates shift. In a stable climate, forest geneticists need to define the geographic areas over which populations did not differ much in climate adaptation, but for new climates they need to understand the specific tree traits that vary with climate and the specific climatic factors to which tree populations are most closely adapted.

Traditional field-based provenance trials can be valuable for predicting the effects of climate change on long-term health and productivity, but they have limitations. They often do not sample a wide enough range of populations, and are often not planted on sufficiently variable sites, to predict responses to projected climate change. The sampling designs often do not allow for the decomposition of climatic variation into seasonal temperature and moisture regimes to determine the effects of average or extreme climate on reforestation risks. Finally, phenotyping in field trials is often limited to survival and growth, with assessment of heat, cold or drought stress-related traits not feasible. Both genomic methods and short-term seedling common garden experiments generate information on genetic variation in climate adaptation more quickly than long-term provenance trials, and provide different types of information.

Seedling common garden experiments

Seedling common garden experiments in controlled environment growth chambers, greenhouses or outdoors can be used to characterize responses to climate-related stresses such as heatwaves, drought

events and freezing events, and phenotype-environment associations, correlations between traits and climatic variables. Seedlings can be particularly sensitive to extreme climate events. Phenological traits such as the timing of active growth (e.g. bud break timing) and dormancy (e.g. terminal shoot bud set timing) can be phenotyped. Samples of seedlings can be used for artificial freeze tests or for assessing water use efficiency through stable carbon isotope ratios. Allocation of biomass to roots versus shoots can also be assessed through destructive sampling.

Genomic methods for detecting and managing climate-related adaptation

SNP genotyping methods: The most common type of genomic marker is a SNP. SNPs can be generated for many anonymous locations within the genome through using methods such as genotyping-by-sequencing and restriction site-associated DNA sequencing (RADseq). These methods are relatively inexpensive, but can lead to uneven data coverage among individuals and greater bioinformatic challenges than some other methods. Targeted sequence capture yields higher quality SNP datasets for known genes but requires more resources. Once SNPs and their flanking regions are identified, they can be used to design SNP genotyping arrays if sufficient demand exists for such tools.

Genotype-environment association (GEA) analysis: GEA are correlations between the frequency of individual SNPs and environmental factors associated with provenances such as climatic variables. Population structure and demographic history can lead to false-positive associations and so must be accounted for in analyses. GEA methods have several advantages. First, phenotypic data are not required to detect patterns of local adaptation to climate among populations; instead variation in DNA can be directly used. As a result, they can detect patterns of adaptation associated with traits that have not been phenotyped (e.g. variation in response to biotic factors or age-related traits). Finally, they can identify the particular aspects of climate that are most important, e.g. specific temperature and precipitation variables that are associated with the strongest patterns of adaptation.

Genome-wide association studies (GWAS): GWAS approaches test relationships between genotypes and adaptive phenotypes. Like GEA, this approach also controls for population structure. If SNPs can be identified that are associated with key adaptive traits such as drought hardiness, then these could be used either to screen populations for assisted gene flow or to screen genotypes within breeding populations for climate resilience.

Experience from the AdapTree project

The AdapTree project in western Canada has used phenotype-environment associations, GEA and GWAS methods to assess climate adaptation in two widespread, economically and ecologically important conifers – lodgepole pine (*Pinus contorta*) and interior spruce (*Picea glauca*, *P. engelmannii* and their natural hybrids). Approximately one million SNPs were genotyped for ~23 000 genes, as well as non-coding regions, for trees from hundreds of populations in each species. GEA analysis identified hundreds of SNPs in each species that were associated with climatic variables (after population structure was taken into account), and there was considerable overlap in patterns of local adaptation and in some genes involved between the two species. The primary climatic drivers of local adaptation were low temperatures, with fewer SNPs associated with precipitation or with high temperatures. These results were supported by results from seedling common gardens, where cold



injury in artificial freeze tests had the strongest geographic patterns of variation of all traits and was correlated with low temperature-related climatic variables. Heat and drought stress-related traits showed relatively little variation among populations.

These results suggest that assisted migration and assisted gene flow could be used to translocate more productive warm-adapted genotypes from milder climates to colder locations as climates warm, and that this should not increase the risk of drought injury relative to using local seed sources. However, care should be taken to avoid translocations that would substantially increase the risk of cold injury to young seedlings. This project has also evaluated the extent and nature of climate adaptation in natural versus breeding populations in order to design climate-based seed transfer strategies for selected genotypes.

3.3.1 **Report of the parallel session**

Facing the challenges of climate change: Adaptation in the livestock and fishery sectors⁵

Summaries of the six presentations

Panya Sae-Lim: Climate change in all its manifestations may affect all aquaculture systems. A number of opportunities include: improved locations and geographical area, prolonged growth period and consequently fish growth rate, breeding of new-farmed species and use of spatial planning. Two main challenges were described: 1) utilizing selective breeding (e.g. rainbow trout) for species best adapted to temperature changes induced by climate change; 2) outbreaks of fish pathogens and parasites facilitated by changes in water temperature. Three adaptive strategies proposed include: 1) selection for “robustness” in aquaculture; 2) use of genetically improved species; and 3) selective breeding.

Alexandra Adams: The presentation consisted of a brief narrative regarding climate change and aquaculture; development of diagnostics tests; and vaccine development. It concluded with some final thoughts on the potential development of novel rapid diagnostic tests for laboratory and field use. While many methods for vaccine development exist they are quite difficult for parasitic diseases. Thus it will not be possible to develop vaccines against all diseases. Some challenges include understanding mucosal immunity, high cost of final product and the route from research to commercialization which can be long and expensive. Thus, alternatives to vaccines also need to be considered so that antibiotic and chemical usage does not increase. Climate change will affect the movement and spread of diseases in the aquatic environment, thus the need for relevant and rapid tests and vaccines to be in place. Continued education and training are also important – some regions of the world do not currently have wide acceptance of the use of vaccines as a fish health control method.

Paul Boettcher: For smallholder livestock keepers, climate change could be a big challenge in the future. The use of best-adapted breeds will satisfy the increased consumption of livestock products. The use of biotechnologies should be complementary to traditional technologies. Through biotechnology, e.g. artificial insemination, the livestock keepers adapt their genetic resources quicker, and will require formal selection programmes in order to increase the rate of genetic change and adaptation. Other technologies which hold promise for the future, are genomic selection (e.g. multi-marker DNA assays) and genome editing or CRISPR which introduce beneficial gene variants into the gene pool; both will rely on reproductive biotechnologies.

Ulrich Meyer: Plants are the starting point for the whole human food chain. Plant breeding and crop production play important roles. Increased production of feed with improved quality may only to a small extent be based on further expansion of agriculturally productive land. Steady increase in

⁵ This report was prepared by the FAO rapporteurs for the climate change theme - Jarkko Koskela, Paul Boettcher and Melba Reantoso.



productivity requires specialized knowledge and depends on numerous factors to improve production systems. In this regard, the use of agricultural biotechnologies in the future will contribute to improve feed availability and quality. There are available agricultural biotechnologies used by plant breeders for genetic improvement of plant varieties, including improving the nutrient content of edible plant parts, nitrogen and water efficiency and better pest resistance, providing feed plants with lower concentrations of anti-nutritive substances, low concentration of nutritive value-determining components such as amino acids, minerals, vitamins and vitamin precursors. Biotechnology can also improve feed quality through the use of different feed additives like amino acids, enzymes and silage additives through fermentation technologies.

Jean de Foucauld: The advantages and benefits of vaccination are more widely recognized and understood now especially when comparing the actual market cost which is usually less than 1 percent of the production cost. Development of vaccines should satisfy four basic parameters: quality, reproducibility, stability and adequate cost. Quality has two aspects: producing according to acceptable standards and manufacturing according to a process allowing expression of safety, efficacy and stability. Climate change, along with other factors, triggers new and fast-moving disease patterns against which vaccines can make the difference. New vaccine technologies using genetic engineering are now really mature and already saving billions of animals every year; new ideas are ready to be implemented but more effort is needed for some key unmet needs. Development, registration and production of vaccines can be managed only by very skilled teams/companies which are not so many in the world. Vaccine registration procedures and timing might be challenging on many occasions especially when new technologies are involved and needs are urgent. Accessing customers in some markets is sometimes very difficult and unfair market competition can happen when vaccine supply is tight. A better network of veterinarians, technicians and distributors, close to the final customers are needed in many countries.

Farai Catherine Muchadeyi: Landscape genomics combines phenotypic and genotypic information as well as data on the local environment of spatially referenced individuals or populations across different landscapes to identify genomic regions that are involved in local adaptation. The potential of landscape genomics in characterizing genetic adaptation of South African indigenous goats was investigated. Goats in South Africa represents an important resource for smallholder communal farmers. The country has a highly heterogeneous livestock production landscape ranging from wet and highly fertile to dry and desert-like agroecological zones. The study highlighted the level of genetic diversity in South African indigenous goats as well as the utility of the genome-wide SNP marker panels in genetic studies of these populations with potential use in identification of gene loci under selection that could be used in genetic improvement programmes.

Session discussion points and conclusions

Questions raised during this session included the following: benefits, costs, affordability and accessibility, and delivery of various biotechnologies to smallholder farmers.

Biotechnology should be seen as a common good for farmers, communities and societies. The potential benefits of biotechnology (e.g. increased production, long-term protection from disease, more efficient use of resources [feed, energy and land, including marginal agricultural zones], more

efficient farming systems, better adaptation to climate change), and long-term return of investment generally outweigh the initial cost of development.

The research and development stage may be lengthy and expensive (e.g. subunit vaccines, genomic vaccines) but the final products can often be made available for use by smallholders at a price they can afford.

Breeding programmes, for example, can start at a small scale and then gradually expand. Investments may vary depending on the end goal. It is clear that having good germplasm is not sufficient. Successful breeding programmes require continuous government support, long-term sustainability and private sector investment. An integrated value chain approach is needed supported by appropriate policies and regulations, along with consideration of production technology, good management practices, better feed, good sanitary and health services, access to markets etc.

Adoption of biotechnologies, especially by smallholder farmers, will be facilitated if they are seen as meeting the needs of farmers and if they build on traditional practices and indigenous knowledge. As biotechnologies are developed, good communication and knowledge sharing between farmers and researchers is essential. This can pave the way for changing farmers' perceptions, as through science farmers may better understand the resources they have and how they may be improved. At the same time, it is important for researchers to understand the context in which the farmers are working. This improved communication and mutual understanding will contribute to research more targeted to the needs of farmers and the quicker and more extensive adoption of the research results.

Climate change poses opportunities and challenges. Selective breeding, artificial insemination, fermentation technologies for animal nutrition, use of vaccines for long-term protection against disease and for minimizing antimicrobial usage, landscape genomics – all of these can help farmers be resilient and to better adapt to climate change, thus, improving yields for better food security for the human population.



3.3.2 Selective breeding in aquaculture for future environments under climate change

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Aquaculture is the fastest growing food production sector that contributes significantly to global food security. Based on FAO reports, aquaculture production has to increase by 42.9 percent to meet the future global demand for aquatic foods in 2020. According to Intergovernmental Panel on Climate Change (IPCC) and FAO reports, climate change may result in global warming, sea level rise, changes of ocean productivity, freshwater shortage and more frequent extreme climate events. Consequently, climate change may affect aquaculture to various extents depending on climatic zones, geographical areas (inland or coastal), type of aquaculture systems and species farmed.

Climate change may introduce opportunities as well as several challenges.

Opportunities may arise at certain locations and geographical areas; for instance, a rise of temperature may prolong growth period, increase fish growth rate, allow new and more efficient farming systems, and new-farmed species. Spatial planning will enable the identification of locations with optimal conditions for farming.

There are major *challenges* caused by climate change.

First, current fish material adapted to the prevailing environmental conditions, may be suboptimal under future conditions. Similarly, breeding programmes selecting for genotypes with current superior performance may not be the optimal genotypes in the future. Genotype-by-environment interaction (G x E) is a phenomenon by which animals respond differently to changes in environment. The presence of G x E indicates that there is genetic variation in environmental sensitivity and it is possible to select for fish that can adapt to the changing environments. For instance, rainbow trout (*Oncorhynchus mykiss*), a very popular farmed salmonid worldwide, has a narrow optimal temperature range. Strong G x E in growth performance of rainbow trout in different temperatures has been reported; hence, utilization of selective breeding can be advantageous for breeding rainbow trout that are best adapted to the temperature changes induced by climate change.

Second, climate change may facilitate outbreaks of existing pathogens or parasites. Moreover, change in water temperature may promote dispersal of new diseases. Disease prevalence increases with physical stress, e.g. associated with a change in temperature, due to reduction in host resistance

and increasing growth of pathogens. Many diseases of farmed fish can potentially become a greater problem at higher temperatures. Thus, mortality rates will increase and production from aquaculture will reduce. In Australia, farmed abalone (*Haliotis laevis*) has experienced 25 percent summer mortality due to elevated water temperature, leading to AU\$1.75 million loss of profit.

To cope with the above challenges, adaptive measures must be addressed through both a reduction of environmental impacts from greenhouse gas (GHG) emissions and selective breeding strategies.

Adaptive strategies. Three major adaptive strategies are identified.

First, fish species are often poikilothermic and may therefore be particularly vulnerable to temperature changes. This will make low sensitivity to temperature more important for fish than for livestock and other terrestrial species. Hence, general “robustness” will become a key trait in aquaculture, whereby fish will be less vulnerable to current and new diseases and parasites while at the same time thriving in a wider range of temperatures. Breeding goals may change toward prioritizing robustness. Nevertheless, knowledge of, and implementation of genetic adaptation to fish breeding is limited and has not received much attention.

Second, the limited adoption of breeding programmes in aquaculture (< 10 percent) is a major concern. Aquaculture based on wild stocks that are not adapted to the farm environment, or farmed animals from breeding programmes without proper selection and/or control of inbreeding, will lead to poor performance and survival compared with genetically improved or well-managed stocks. This implies low aquaculture production and inefficient use of resources for feed and land. Consequently, a higher carbon footprint with a negative impact on climate change per kg fish produced is expected. Aquaculture should use genetically improved and robust species not suffering from inbreeding depression. This will imply using fish materials from well-managed selective breeding programmes with proper breeding goals and a controlled rate of inbreeding. Policy-makers should provide incentives and public support to boost selective breeding programmes in aquaculture for more robust fish tolerating climatic changes.

Third, although aquatic organisms do not emit GHGs as ruminants do, aquaculture activities such as input power, transport, and feed production contribute to GHG emissions. Life cycle analysis is a method to quantify the use of resources and emission of pollutants in the entire production chain for a product. Selective breeding for increased production is expected to enhance efficiency of resource utilization (feed, energy and land) of a production system through correlated changes in feed efficiency or shorter production period. Applications of life cycle analysis to define breeding goals that maximize production while minimizing environmental impacts can be one solution, as already demonstrated in African catfish.

Conclusions. Climate change poses opportunities and challenges to aquaculture production. Selective breeding is a long-term, cost-effective strategy that can best minimize the detrimental effects of climate change on aquaculture. Empirical studies are required to estimate the potential for increasing robustness of fish by selection methods. Applying selective breeding to develop robust animals will become more important under climate change, and dissemination of genetically improved stocks will in turn efficiently increase aquaculture production and reduce environmental load, including



GHG emissions. Established selective breeding programmes are a prerequisite to applying genomic information for further genetic improvement of aquaculture production. Hence, stakeholders should support the adoption and development of selective breeding by disseminating genetically improved materials and knowledge of selective breeding at all levels of the aquaculture sector worldwide to ensure food security for the growing human population under climate change.

3.3.3 Development of diagnostic tools and vaccines for aquatic animals

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Introduction

Currently, aquaculture contributes approximately 50 percent of global food fish consumption. Disease, however, is still regarded as a major constraint to aquaculture production. Control of disease is complex and relies on a combination of pathogen detection, disease diagnosis, treatment, prevention and general health management. Speed of pathogen detection is crucial to prevent the spread of disease. Clearly, climate change will affect the movement and spread of diseases in the aquatic environment; having relevant rapid tests in place as well as appropriate vaccines to prevent the spread of disease is therefore vital for the future sustainability of aquaculture.

Climate change and aquaculture

There is concern that climate change may increase the risk of disease to aquaculture through alterations in the distribution, prevalence and virulence of pathogens (bacteria, viruses, fungi and parasites) and changes in the susceptibility of the host species. The impact of climate change will vary across the distinct climatic regions (tropical, subtropical and temperate) and different environments (freshwater, marine and brackish water) of the world where aquaculture is practised. Aquaculture is predominantly present in tropical and subtropical climatic regions with Asia accounting for more than 80 percent of global aquaculture production, and some key aquatic diseases in Asia have been identified as potentially climate sensitive. Global warming, rise in sea level, changes in ocean productivity and circulation pattern, water stress, changes in monsoon patterns and occurrence of extreme weather events are all features of climate change that are likely to impact on aquaculture species. Any increase and/or decrease in temperature of their aquatic habitat will have a significant influence on their body metabolism and this could include influencing susceptibility/resistance to disease. Depending on the climatic zone, the impacts on aquaculture could be both positive and negative.

Development of rapid diagnostic tests

There has been significant progress in the development of rapid pathogen detection methods for aquaculture over many years, and in the last five years the pace has increased even more, as methods developed for clinical and veterinary medicine are rapidly adapted and optimized. Pathogen detection



methods for use in aquaculture need to be robust yet sensitive, as well as affordable and requirements will depend on whether methods are to be performed in the laboratory or in the field. This presentation provides a review of recent advances made in pathogen detection technologies, including antibody-based, nucleic acid and nanotechnologies, taking into consideration the limitations of both existing and novel methods, and how applicable some of the new methods are to aquaculture.

Fish vaccine development

The number of fish vaccines commercially available has grown in recent years but there are still numerous diseases where no vaccines are available, or cases where existing vaccines do not perform well. The most crucial step in developing an effective vaccine is identification of “potentially” protective antigens and confirming their protective response in the host species by efficacy testing. The most effective approach taken depends on the type of pathogen and the final end use envisaged for the vaccine (e.g. cost, fish species, and immersion versus injection vaccination). Technologies such as recombinant and DNA vaccines are powerful tools for future vaccine development as these enable the separation of potential protective antigens from suppressive ones. These are being developed because the simpler approach of using inactivated whole cell vaccines did not succeed for many important diseases, and attempts at attenuated vaccines in general have not been encouraged from a safety point of view. A number of case studies are presented, such as identifying isolates from given serotypes to include in traditional whole cell vaccines and describing technologies for the identification of specific antigens for recombinant or peptide vaccines. The potential of developing vaccines that differentiate between infected and vaccinated animals (DIVA vaccines) for use in fish is also discussed, where a vaccine is developed in tandem with a diagnostic test to differentiate vaccinated from infected animals.

Final thoughts and conclusions

Climate change will affect the movement and spread of diseases in the aquatic environment, thus having relevant rapid tests in place as well as appropriate vaccines to prevent the spread of disease is vital for the future sustainability of aquaculture. It will, however, not be possible to develop effective vaccines against all diseases and in some cases vaccines may be considered too expensive to use. Thus, alternatives to vaccines also need to be considered so that antibiotic and chemical usage does not increase. Continued education and training is also important for combating the future effects of climate change on aquaculture with regard to disease as some regions of the world do not currently have wide acceptance of the use of vaccines as a fish health control method.

3.3.4 Biotechnologies for animal breeding and coping with climate change

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Climate has historically played an important role in the development of animal genetic diversity. The origins of most livestock species can be traced to a few domestication centres across the world. Over the recent millennia, as humans migrated away from these centres, they took their livestock with them and created new breeds, leading to a set of markedly diverse populations that now numbers more than 8 000 breeds.

Each of these breeds has been adapted to the demands of its local conditions, whether those demands were environmental, markets-based or cultural. The individual animals best suited for a given situation were naturally or formally selected to have more offspring and the gene variants associated with survival became more common, providing the biological basis for different breeds. Where market forces allowed it, such as in Europe and North America, livestock keepers controlled the environment so that economic drivers and formal selection influenced survival more than climatic conditions. In most of the world, however, differences in temperature, rainfall, endemic diseases and feed resources have been the main factors determining the characteristics of specific breeds.

Over the decades, the forces guiding the formation of breeds have been pretty stable. The same collection of favourable gene variants has tended to be maintained across the years, meaning that most breeds have continued to be viable, particularly from the biological standpoint, without much outside intervention. Internal genetic adjustments to environmental changes could be made within the natural generation intervals of the species.

That situation seems bound to change, however. According to some forecasts, the future changes expected to the climate may occur too fast to allow livestock populations to keep up within their natural reproductive rhythm. In developing countries, the capital required to invest in housing and other infrastructure to control the environment may not be sufficient to allow this option, especially for smallholders. Moreover, for many breeds, especially traditional local breeds, increasing demands for livestock products and competition for resources predicate that traits associated with productivity will also merit stronger attention than in the past, putting increased pressure on breeds' capability to adapt. To account for all these forces, formal selection programmes will be desperately needed.



Biotechnologies, and reproductive biotechnologies in particular, can play a key role in allowing animal genetic resources to meet the demands of the future, including climate change. Artificial insemination (AI) is an especially powerful tool for this objective. The genetic gains made through formal selection programmes are achieved by obtaining multiple offspring from the best males and obtaining few, if any, offspring from the inferior males. For most livestock species, males can naturally mate with 20 to 50 females per year. AI affords males the possibility to mate with hundreds and even thousands of females, greatly increasing the genetic progress if males can be selected accurately. When few can be chosen from among many, chances also increase that the males used for breeding can be genetically superior not only for traits favouring survival in continually more difficult climatic conditions, but also for increased output and production efficiency. AI is especially beneficial for smallholders, as truly superior males are statistically rare. The probability to produce such an outlier from a small group of breeding animals is extremely scant. For smallholders, AI also provides access to a wider gene pool and eliminates costs of raising male animals. AI also allows access by smallholders to the benefits of other technologies, such as genomics and sexed semen, although the potential benefits of these technologies depend on the situation. Embryo transfer is a biotechnology that allows females to have more offspring, but it is much less powerful and more costly than AI and practically out of reach for smallholders.

If climatic changes are too fast or breeds lack the genetic diversity to adapt through biotechnology-enhanced selection, new sources of variation, via cross-breeding or breed-replacement may be necessary. In general, climate change is not expected to render many environments inhospitable for livestock, but rather simply different and often harsher. The new climate in one location will often resemble the past climate in another. Thus, in theory, genetic resources formerly adapted to one area can simply be moved to a new location that matches their potential. Moving of live animals is very costly, however, and may involve strict veterinary regulations if national borders are crossed. AI can be also be a powerful tool in dealing with this situation. Semen can be moved long distances much more quickly and simply, less expensively and in much greater quantities than can live animals. Furthermore, unless animals are being imported to restock after a climate-related disaster, the genes of the incoming population are the primary resource of interest, not the animals themselves.

In general, climate change is not likely to be so fast that complete breed replacement is necessary. The original breed is also likely to have particular characteristics and provide locally demanded services that are not available in alternative breeds. Therefore, a scenario more likely than breed replacement is the use of cross-breeding to gradually introduce characteristics of the non-local breed through a process called “adaptive introgression”. In this process, AI would be used to introduce the adaptively favourable gene variants from the outside breed and several generations of selection would follow to increase the frequency of these favourable genes, while keeping the desired characteristics of the original breed. Used with AI, genomic biotechnologies also have the potential to enhance such a strategy by increasing the efficiency of introduction of genes known to be associated with adaptation to a given environmental constraint or with increased productivity.

The methods proposed here will clearly alter the genetic constitution of the populations in question, risking or even promoting the loss of valuable genetic resources. Conservation should therefore be implemented in concert with any such actions. Reproductive biotechnologies would be a cornerstone of such activities, combined with cryogenic biotechnologies to preserve material in gene

banks. Semen is the most common material stored in gene banks, but embryo-related technologies can be more economically justifiable in cryoconservation than in genetic improvement or selective adaptation programmes.

Unfortunately, major obstacles exist in the implementation of AI and other reproductive technologies for the adaptation to climate change, especially for smallholders and developing countries. These biotechnologies will only be effective when complemented with the application of other simpler technologies. Biotechnological interventions can only be successful if applied in the context of a formal breeding programme. FAO (2015) indicates clearly that many countries have a significant deficit in the capacity to apply such programmes. Although most countries indicate they have access to AI and related biotechnologies, few developing countries report having the basic elements of breeding programmes, such as animal identification, performance recording and genetic evaluation systems needed to identify the best animals. Without these basic tools, application of AI will not only be ineffective, it will needlessly and dangerously reduce the genetic diversity. Information is the basis for effective breeding programmes and tends to be severely lacking.

The utilization of reproductive biotechnologies for distribution of genetic material also requires substantial infrastructure. Information systems are needed to collect, collate and analyse the data upon which to base selection. Storage and wide-scale distribution of semen requires a continuous and affordable source of liquid nitrogen, a resource that is exceedingly rare in many countries with large number of smallholder livestock keepers. Cross-breeding requires knowledge and the proper inputs to support husbandry of the new genotypes.

In conclusion, a changing climate is simply an additional obstacle confronting smallholders in breeding animals to support sustainable livestock production. Biotechnologies, particularly AI, have great potential for this challenge. However, the implementation of biotechnologies is input-intensive and their full power can only be harnessed when complemented with traditional technologies. Support for livestock development must approach livestock genetic improvement by considering adaptation as a single trait in a holistic objective that includes increased productivity, enhanced efficiency and maintenance of genetic diversity.

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3.3.5 Use of biotechnologies to improve feed quantity and quality: Adaptation to the changing climate from the animal nutrition perspective

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Achieving food security is one of the most important challenges with a view to the future and taking into account the continued increase of the world's population. An additional major challenge for food production is the threatening or already existing impact of climate change. Increased extreme weather events like hurricanes, heavy rainfall, flooding, heat waves and drought are likely to occur in different regions of the world and may affect both the growth conditions of cereal and forage crops and livestock production.

Plants can be regarded as the starting point for the whole human food chain. Therefore, to achieve food security, plant breeding and crop production play an important role. High yields of highly-digestible phyto-genic biomass produced with low external inputs of non-renewable resources and low emissions of GHGs during cultivation are required. In addition, the plants should have low concentrations of undesirable substances and high resistance against biotic and abiotic stressors including the ability of adaptation to potential impacts of climate change.

Food of animal origin is characterized by a high bio-availability of most nutrients and is a source of some important trace elements and vitamins. The consumption of meat, fish, milk, eggs and other protein and energy sources may contribute substantially to covering the human requirements for amino acids and energy. A rapid increase in the demand for food of animal origin is expected in the foreseeable future. In this context, it should be noted that the conversion of energy and protein from feed into food of animal origin is relatively low with about 3 percent for the conversion of energy into beef. It may vary, however, up to about 40 percent for the conversion of energy into milk and of protein into chicken meat. As a result, the production of livestock feed must grow disproportionately higher to meet the growing demand.

Increased production of feed with improved quality may only to a small extent be based on the further expansion of agriculturally productive land. The major part of the necessary additional livestock feed should result from an increased productivity per unit of land and reduced post-harvest losses. This approach appears applicable throughout the world and could be of particular relevance for smallholders in developing countries. A steady increase in productivity requires specialized

knowledge and depends on a variety of factors to improve production systems. In this regard, agricultural biotechnologies play an important role.

Agricultural biotechnologies represent a number of technological applications used in food and agriculture. Some of these technologies are used by plant breeders for the genetic improvement of plant varieties. This includes, amongst others, improvement of the nutrient content of edible plant parts, higher nitrogen and water efficiency and better pest resistance. In addition, the adaptation of plants to the expected adverse impacts of climate change represents a particular challenge.

Feeds are usually characterized according to their composition. The most important feed groups are roughages, concentrates and co-products from agriculture, food and the biofuel industry. Feeds from these different groups contain various concentrations of crude nutrients, but also further desired and undesired substances. An additional objective of plant breeding which may be achieved by the use of agricultural biotechnologies is providing feed plants with, for example, lower concentrations of anti-nutritive substances, low concentrations of substances that influence availability of nutrients such as lignin, phytate, enzyme inhibitors and tannins, and plants with a higher concentration of nutritive value-determining components such as amino acids, minerals, vitamins and vitamin precursors.

Feed additives are used to supplement feed with essential or non-essential substances in order to increase the nutrient digestibility of the diets or to cover the demand of the animals. Therefore, the impact of biotechnologies to improve feed quality also includes the use of different feed additives like amino acids, enzymes and silage additives which are partly produced by fermentation technologies based on biotechnological applications.

In conclusion it can be stated that the use of agricultural biotechnologies to improve feed quantity and quality may contribute to solving the important global challenge of food security through the sustainable use of limited natural resources, the avoidance of environmental pollution including the reduction of GHG emission, and the adaption to climate change.



3.3.6 Development of livestock vaccines and market access

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To follow the development of the population in the world, healthy livestock breeding systems are needed, sparing the resources needed to feed the animals, increasing the value they represent for many farmers and feeding more people. In this, vaccines have a critical role to play. The advantages and benefits of vaccination are increasingly recognized and understood, especially when comparing them with their costs which are usually less than 1 percent of the total production costs.

The purpose of this presentation is not to detail the mechanisms through which new or existing diseases are linked to climate changes as this is already well documented. After mentioning a few examples on how innovation can fight these diseases, the focus is on the downstream processes that make this innovation a practical and available tool for the target customers. Taking a global perspective on vaccine solutions is necessary, particularly since countries and farmers have to keep adapting to the consequences of climate change. There are currently too many cases where the solutions exist in the laboratory but cannot be applied on time in the field. Hopefully, highlighting the key success factors allowing the field application of these technological advances will help to focus the effort of all stakeholders towards success.

Vaccine innovation in the laboratory has been extremely rich since the 1980s. This led to the arrival of vaccines using these new technologies since the twenty-first century with a few notable pioneers already present in the 1990s. Some of these vaccines aim at diseases impacted by climate change like West Nile virus infection and avian influenza. More are to come, based on innovative technologies already known like vector platforms and subunit antigens, but also on newer ones like non-replicative non-inactivated virus particles. Work on other diseases like trypanosomosis and other parasitic diseases is still ongoing and proving to be quite difficult. Research effort should continuously be encouraged in these fields.

Thanks to all this high standard research work, proofs of concept for candidate vaccines are usually well established. But from successful research to the dose being injected into the livestock, there are many complex steps requiring highly experienced teams, from authorities to companies. And this is the reason why it takes in some instances so long for these solutions to access their target markets.

⁶ Speaking on behalf of HealthforAnimals (<http://healthforanimals.org/>)



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The first of these steps is vaccine development. It consists of establishing the manufacturing process, validating it, and testing the vaccine for its shelf-life, safety and efficacy. This step is followed by the registration process, industrialization and finally marketing of the vaccine.

The design of the production process of the candidate vaccine should be such that it can fulfil the main goals common to all veterinary vaccines: quality, safety, efficacy and adequate cost. Quality has two aspects: producing according to acceptable standards (good manufacturing practice [GMP], United States Department of Agriculture [USDA]); manufacturing according to a process allowing expression of the main safety, efficacy and stability features singled out during the feasibility phase.

Once pilot batches have been produced satisfactorily, they are then tested according to a “regulatory” analytical and clinical programme covering, amongst other points: validation of the planned manufacturing process, shelf-life study and clinical trials to confirm the safety and efficacy claims.

Marketing authorization: a registration dossier is then prepared by gathering the data from all this work, suitable for the target markets. It is sent to the target countries with additional documentation proving that the applicant works according to acceptable standards; it is also very common that authorities from the target countries require proof that the vaccine is registered in the country of origin. This is a cause of great concern when a company decides to develop a vaccine for which there is no market in the country/region where manufacturing takes place. Solutions are possible but this is not accepted everywhere. Moreover, when “novel technology” vaccines involve live genetically engineered product, specific procedures are needed.



Once the registration dossier has been assessed, questions have been answered and the marketing authorization granted, we are far from the end. Meanwhile, the company undergoes the industrialization process to ensure that what was planned in development happens in the industrial world, meeting quality and price targets.

Last but not least, market access: this is driven by different aspects including: capacity of vaccine production, vaccine supply chain, competition between “easy and difficult” markets. In many markets where these vaccines are needed, although customers are ready to pay the right price for it, there are great difficulties to establish the adequate supply chain for reaching the final customers. Some key points to solve these issues include: more veterinary product retailers, better cold chains, more trained veterinarians and vaccination technicians, better vaccination equipment, fighting counterfeit products. A tight market supply situation will lead to unfair competition between “easier-to-access” markets and the ones where it is difficult to reach the customers.

Looking at the extraordinary development of “novel technology” vaccines and the increasing needs for livestock vaccines everywhere in the world, it is a strategic goal for governments, global organizations, pharmaceutical companies and their associations like HealthforAnimals, to help increase the supply of vaccines and improve market access in regions where it is not satisfactory. Initiatives taken in this direction have had some successes, involving charitable organizations, companies and HealthforAnimals in Africa and on the Indian subcontinent. More ambitious projects are needed to find ways to expand manufacturing capacities, to harmonize regulatory barriers, to train more veterinarians and vaccination technicians and to work on supply chain issues.

In conclusion, the good news is that science has already brought and will bring more solutions to current and emerging diseases, including the ones affected by climate change. But very significant effort by all stakeholders should be placed on the complex industrial, regulatory and market access tasks.

3.3.7 The potential of landscape genomics approaches in characterizing genetic adaptation of indigenous goat genetic resources: A South African perspective

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In most developing countries, goats make a significant contribution to poverty alleviation and improving household food security and livelihoods of many smallholder farmers in marginal areas. Several goat ecotypes have been historically described as adapted to the harsh environmental conditions and low-input production systems. In South Africa, the ecotypes are the main genetic resource in the development of the current commercial meat-type Boer, Savanna, and Kalahari Red breeds. The genetic diversity and relations of the South African goat populations are, however, not fully understood. Communal and feral goats thrive under a host of harsh environmental, climatic and nutritional conditions, and numerous impediments to gene flow. They are characterized by non-descript and hyper-variable production systems as well as heterogeneity in phenotypic and genotypic landscapes and are adapted to the agroecological zones in which they occur. Local adaptation is driven by natural selection that targets specific genomic regions. Understanding the genetic mechanisms underlying local adaptation in these marginal populations is crucial for goat improvement strategies and conservation of adapted genetic resources. However, the exact genomic architecture of these goat populations remains unknown and the effect of natural and/or artificial selection on the diversity is not fully understood. Until recently, demographic, production and evolutionary events that impact on the local adaptation of indigenous goats have not been fully unravelled in South Africa and worldwide.

Landscape genomics combines the phenotypic and genotypic information as well as data on the local environment of spatially referenced individuals or populations across different landscapes to identify genomic regions that are involved in local adaptation. The hypothesis behind landscape genomics is that certain alleles and genotypes are adapted to a specific environment that is defined by climatic conditions, disease and disease pathogens, and feed availability profiles, which are referred to as the environmental/production landscape. Only markers that show higher genetic differentiation and subsequently skew allele frequencies related to environmental variation are targeted for genomic association analysis. Landscape genomics has found use in studying indigenous livestock populations that are raised in low-input production systems where record keeping is limited and populations are highly fragmented thereby complicating use of conventional genome-wide association studies. The potential of landscape genomics in characterizing genetic adaptation of South African indigenous goats has therefore been investigated.



South Africa has a highly heterogeneous livestock production landscape that ranges from wet and highly fertile to dry and desert-like agroecological zones. The first step of analysis surveyed the goat production systems in the different provinces and characterized the management systems and production challenges faced by farmers in raising their animals. Morphological traits linked to genetic differentiation of goat populations by farming communities were investigated. The goat production system is mainly scavenging with limited interventions provided by farmers. Goats were therefore exposed to the full variability of nutritional, climatic conditions and disease challenges that differed amongst agroecological zones. Qualitative traits such as characteristics of coat, horn, ears, and wattles were recorded for village goats. The analysis clustered populations into well-defined groupings.

Heartwater is endemic to most parts of South Africa, and livestock farmed in these regions are constantly under threat from this disease. The majority of indigenous goat populations are raised for subsistence production in rural areas and tick control is less frequent and erratic, unlike in the commercial sector. The study identified and quantified the effects of geographic regions, and animal- and production system- associated risk factors for *E. ruminantium*. It also explored the relationship between these risk factors and prevalence of heartwater in South African goats. Highest seroprevalence for antibodies to *E. ruminantium* was observed in goats from endemic regions (76.09 percent), and from smallholder production systems (89.54 percent). High seroprevalence was also observed in non-descript indigenous goats (85.04 percent), adult goats (69.62 percent), in does (67.46 percent) and goats infested with ticks (85.79 percent). A logistic model showed a gradient of increasing risk for commercial meat type Savanna (odds ratio [OR] = 3.681; confidence interval [CI] = 1.335–10.149) and indigenous (OR = 3.466; CI = 1.57–7.645) compared with Boer goats and for goats from the smallholder production system (OR = 2.582; CI = 1.182–5.639) and those with ticks (OR = 3.587; CI = 2.105–6.112). Results from this study showed that *E. ruminantium* infections were prevalent but were widely and unevenly distributed throughout South Africa.

An investigation into the genetic diversity, population structure and breed relations of the goat populations was undertaken. The three locally developed meat type breeds of the Boer (n = 33), Savanna (n = 31), and Kalahari Red (n = 40), a feral breed of Tankwa (n = 25), and unimproved non-descript village ecotypes (n = 110) from four goat-producing provinces of the Eastern Cape, Kwazulu-Natal, Limpopo and North West were genotyped using the Illumina Goat 50K SNP Bead Chip assay. Within-individual variation accounted for approximately 91.69 percent of the total genetic variation. Average linkage disequilibrium (r^2) was highest in the Tankwa (0.25 ± 0.26), followed by commercial breeds and lowest in the village ecotypes where it ranged from 0.09 ± 0.12 to 0.11 ± 0.14 . Pairwise F_{ST} , principal component analysis and the ADMIXTURE program identified Tankwa as a genetically distinct population and supported clustering of the populations according to breed affiliation and production system. Genome-wide F_{ST} identified 101 SNPs potentially under positive selection in the Tankwa compared with the farmed goat populations. This study highlighted the high level of genetic diversity in the South African indigenous goats as well as the utility of the genome-wide SNP marker panels in genetic studies of these populations with potential use in identification of gene loci under selection that could be used in genetic improvement programs.

3.4.1 **Report of the parallel session**

How can biotechnologies contribute to adaptation with mitigation co-benefits?⁷

The following are synopses of presentations given by the following speakers

Daniel Sumner: Both science and economics specify clear linkages between agricultural and food biotechnology and climate change. Climate change may cause poor farmers in poor places to be especially vulnerable to nutritional inadequacy and potential severity of nutritional inadequacy increases for situations associated with increased variability in climate. Climate change may have positive effects in some geographical areas, which doubles the negative impact in areas subject to detrimental impacts. If those suffering refuse to use biotechnology and other changes, the impacts will be even more severe. Policies should not hinder the advantaged, but support adoption of science for the disadvantaged. Any policies must consider the unavoidable fact that over time there will be fewer farmers and more people that are only consumers.

Stephan Weise: Farmers commonly lack the information necessary to adapt, particularly as regards genetic resources. The “Seeds for Needs” initiative (11 countries) studies how agricultural biodiversity can minimize the risks associated with climate change. Ethiopia is highlighted. Productivity of staple crops is declining. Resources in the national gene bank are being studied. Geographic information system (GIS) methodology was used to screen barley and durum wheat accessions in the gene bank. Crowdsourcing was used to gather information of farmer satisfaction with distributed materials. A community seedbank was also established. Molecular studies were undertaken on durum wheat to evaluate its genetic diversity, which was shown to be particularly large relative to that from other locations. The information gathered will be used in breeding programmes.

Guntur Venkata Subbarao: The biological oxidation of ammonium to nitrate, termed nitrification, is detrimental, as nitrate is prone to pollution through leaching and to denitrification to nitrous oxide, a powerful greenhouse gas (GHG). Atmospheric nitrous oxide has increased with increased use of nitrogen fertilizer, as 70 percent of the nitrogen is lost as nitrate. Certain plants, especially tropical pasture grasses, have the natural ability to produce and release biological nitrification inhibitors to suppress nitrifier activity and soil nitrification. Rotation of pasture grasses having high biological nitrification inhibition (BNI) capacity with maize seems beneficial. Molecular studies are underway to identify markers of BNI production. Genetic exploitation of the BNI trait to produce BNI-enabled crops and pastures could be a powerful genetic mitigation technology, but everything is still in the theoretical and research stage.

Henning Steinfeld: The process of enteric fermentation in the rumen is highly beneficial for humans because it converts human-inedible plants into food and fibre, but it is also a major producer of

⁷ This report was prepared by the FAO rapporteurs for the climate change theme - Jarkko Koskela, Paul Boettcher and Melba Reantos.



methane, a potent GHG. Livestock produce almost 40 percent of global methane. Various approaches can be applied to decrease enteric methane, but economics do not always favour their use and technology transfer is a constraint. Biotechnologies to decrease methane output include probiotics, vaccination and genetic modification of rumen organisms. To tap the potential of biotechnology and other methane-reducing interventions, investments in technological transfer and input and product market development are required, alongside with possible emission offset incentives.

Paulo Kageyama: Molecular studies show high diversity of plants, as well as insect and micro-organism species in tropical forests. Plants have adapted to produce biochemicals to resist these potentially harmful organisms. These biochemicals could be used in agricultural systems. Conventional and organic tomato production were compared. Conventional production resulted in greater yield and economic return, with greater concentrations of pesticides. Coffee production systems combining different levels of forest tree biodiversity with coffee were compared with mono-cropping systems. Pest attacks decreased with greater plant diversity; the system with greatest economic returns was the one with a medium level of biodiversity in the coffee agroforestry system. In conclusion, maintenance of a certain level of biodiversity is beneficial.

Hervé Saint-Macary: The 4per1000 initiative seeks to use carbon sequestration in soil to offset current anthropogenic carbon dioxide emissions. A rise in global soil carbon sequestration could be obtained through a large increase in global net primary productivity, partly obtained by restoring degraded lands. Research needs concern: 1) knowledge on the baseline of sequestration (or loss) of soil carbon; 2) definition and co-construction of agronomic strategies and practices at various scales (individual to collective); 3) the transfer and adoption of these strategies and the development of demonstration sites; 4) the design, experimentation and assessment of institutional arrangements and public policies that aim at promoting and rewarding relevant practices; and 5) metrics and methods for monitoring, reporting and verifying carbon sequestration.

The following topics were addressed and conclusions reached during the discussion period following the six presentations

Agricultural biotechnologies currently, and will continue to, help to feed the world and help smallholders (and all farmers) to adapt to and mitigate climate change.

To achieve GHG reductions foreseen as necessary to attenuate the effects of climate change and agreed to in international agreements, all citizens and countries must contribute to climate change mitigation. This contribution will be relative rather than absolute. Poorer countries and people will almost certainly produce more GHGs as they grow economically, but will ideally emit less GHGs than industrialized countries did during similar stages of economic development. Rich countries will work to reduce their current levels of GHGs to compensate. Biotechnology can play a role in both of these instances.

Reduction of denitrification is the only logical approach to control nitrogen loss from fertilization. Other approaches, such as repeated applications of small amounts of nitrogen fertilizer are not feasible in most production systems.



Agricultural land sequesters less carbon than forests, but techniques and approaches can be applied to limit carbon release and stabilize sequestration in agricultural systems.

Research on high biodiversity agricultural systems is inherently complex. Collecting high-quality and precise data is difficult. This fact may constrain the ability to undertake such studies and hamper the publishing and dissemination of results from studies on this technique.

Some approaches to decrease methane emissions in the dairy sector can lead to negative economic consequences, hindering their adoption. This is an example of the reality that economic incentives will need to play a significant role in mitigation approaches and application of GHG-reducing technologies.



3.4.2 Economics of agricultural biotechnology, food and nutritional security, and climate change adaptation and mitigation

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Climate change is a natural concern as we explore the broad theme of “The Role of Agricultural Biotechnologies in Sustainable Food Systems and Nutrition”. Both science and economics specify clear linkages between agricultural and food biotechnology and climate change. One natural question is: how can biotechnologies contribute to adaptation to anticipated and realized climate change? A second is: how can biotechnology, which may be adopted in part to help adapt to climate change, also help reduce the GHG emissions that drive climate change? Thus, how can biotechnology reduce the rate and extent of climate change? Within these broad questions, I focus on some economics of how agricultural biotechnology is likely to affect food and nutritional security in the context of climate change adaptation and mitigation.

This presentation examines economic issues surrounding relevant science and technology, including incentives for and consequences of adoption of technology by farmers; regulation of and incentives for investments in science of biotechnology; and impacts of incentives for use of biotechnology related especially to food demand. That is, consumer information and perception affect market-derived demand for biotechnology as they affect demand for food produced using modern scientific tools.

Economics considers costs to reach goals, and here the goals of sustainable food systems and sustainable nutrition security are paramount. Economics of adaptation to climate change, adaptation to climate change policies, and the economics of agricultural and food system contributions to the rate of climate change and mitigation all affect the roles of biotechnology in farming and the rest of the food system.

Nutritional security requires attention to food production and distribution. But, economics focuses attention on incomes of the poor relative to the price of nutritious food, where we define income inclusively to mean command over resources needed to access food. We define the price of food inclusively to mean the resources that must be sacrificed to acquire and consume a nutritious diet. In this context, security necessarily refers to stochastic distributions, and nutritional security is tied to the probability of satisfying nutritional criteria, typically for those at the lower end of the nutrition adequacy distribution in a population.

Main economic points of the presentation

1. Climate change may cause poor farmers in poor places to be especially vulnerable to nutritional inadequacy. Many of the poor of the world are farmers and global warming threatens to reduce their productivity and hence reduce their incomes and lower their production of and access to food.
2. Climate change that causes increased variability of weather outcomes (a less clear implication of climate change models and evidence) increases vulnerability and the probability of periodic severe nutritional inadequacy.
3. Climate change will likely improve productivity in some places, and models and evidence suggest that farm productivity may rise more in places with already wealthy and highly productive farms. If that happens, farmers in poor regions (often nearer the equator) are doubly disadvantaged. Their own productivity may deteriorate, so they produce less food from their own farms, while the price of food they sell may decline as productivity of their northern (or southern) competitors rises.
4. Biotechnology has much to offer for both poor and rich farmers, and especially poor consumers, but only if it is allowed to play its role in improving productivity and allowing more benign environmental outcomes. That is, adaption to climate change, reduction of GHG emissions, and responses to GHG and other environmental incentives and constraints can all be enhanced by drawing on the most effective science available.
5. However, if the rich accept biotechnology while the farmers in poor places reject biotechnology, the poor will be triply disadvantaged by climate change as they struggle to sustainably achieve nutritional security.
6. The goal and promise of more and better agricultural science is that fewer resources are required to make more food available and accessible to the poor. If prices fall because of more productivity on rich farms, but farmers in poor regions do not have matching productivity gains, they lose again. They lose not just from climate change, but also because richer farmers adapt better to the challenges and opportunities of climate change and climate change regulations and incentives.
7. The policy implication is not to block science for rich farms. Rather, it is to remove constraints and enhance incentives for the development and adoption of science and technology applicable to vulnerable farms and farmers in poor regions that are likely to face larger challenges from climate change in any case.
8. Finally, we should remember that a central consequence of successful agricultural development is almost always fewer farms and farmers. Thus, agricultural success means more people who are not farmers, but rather are purely food consumers who gain from lower farm prices. They have better diets and more secure nutritional outcomes as a result of larger food supplies no matter what the source.



3.4.3 Biodiversity: Key to helping farmers adapt to climate change

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The challenge

Climate change is estimated to reduce agricultural production by 2 percent every decade until 2050, with yields of major crops declining by an average of 8 percent in Africa and South Asia (IPCC, 2014). As extreme weather events become more frequent and unpredictable, smallholder farming communities will continue to be the hardest hit. Diversification of crops and varieties is one way to give farmers more options to cope with the effects of climate change. But farmers do not always have the information or planting material to choose what diversity best suits their conditions. How can we tap into the vast genetic diversity that exists in different countries to address farmer needs in a timely manner?

Bioversity International's "Seeds for Needs" initiative works with more than 20 000 smallholder farmers in 11 countries to research how agricultural biodiversity can minimize the risks associated with climate change. Our focus is on deploying existing diversity to farmers from wherever it is found (gene banks, plant breeding programmes, farmers' own fields). The farmers are directly involved in the process.

Research highlights – Seeds for Needs in Ethiopia

Production systems in Ethiopia are largely dominated by cereals: barley, teff, durum and bread wheat are some of the most important crops, and are key to achieve food security. Yet, due to climatic changes the productivity of these crops is declining. Farmers need solutions now, and might not be able to wait until breeders have gone through the long process of crop improvement.

The traits farmers need could be found in the vast genetic diversity conserved at the national gene bank of the Ethiopian Biodiversity Institute. The aim of the initiative is to identify landraces of durum wheat and barley with the potential to adapt to changing climatic conditions, and make them available to farmers and breeders. We developed an approach in which farmers and scientists work

⁸ This work is done within the framework of the Climate Change Agriculture and Food Security CGIAR Program and in partnership with: Institute of Life Sciences, Scuola Superiore Sant'Anna, Pisa, Italy; Department of Dryland Crop and Horticultural Sciences, Mekelle University, Ethiopia; Sirinka Agricultural Research Center, Sirinka, Ethiopia; Amhara Regional Agricultural Research Institute, Ethiopia; Ethiopian Biodiversity Institute, Ethiopia; and Department of Agricultural Sciences, University of Bologna, Bologna, Italy.

together, integrating scientific knowledge with farmers' knowledge and needs, to help farmers in their effort to adapt to climate change, and contribute to improve their food security and livelihoods.

After screening barley and durum wheat accessions in the gene bank using geographic information system (GIS) methodology, we selected the varieties that could grow well in different climatic conditions in three regions. We then asked farmers to evaluate the selected varieties using a participatory approach. The key challenge was to link, in a scientifically sound way, two different sets of information: the detailed agronomic and morphological data of the varieties, with the farmers' preferences. This information could be of great interest to breeders, who could better target their efforts to meet farmers' needs. Linking these sets of information helped us further narrow down the number of varieties for farmers to test under their own conditions. To better understand the linkage between climatic conditions, performance and preference of varieties, we wanted to cover the broadest possible geographic areas and have as many farmers as possible to test the seeds. Hence, we used a crowdsourcing approach that allowed us to easily reach farmers and get their feedback. In the crowdsourcing approach, farmers receive three varieties to blind test from a portfolio of 20 and one control variety. These mini trials allow us to involve more farmers than a typical multilocational trial.

The initiative included 12 villages, covering about 350 km². To know the climatic conditions in all villages, we used sensors called iButtons[®] that monitor temperature and humidity eight times/day. In each village, we installed a plot where all the varieties used in the trial are planted together, so farmers can observe and evaluate the diversity. By combining weather data with the performance of the varieties, we were able to link farmers' feedback with scientific data. Once farmers have an understanding of how different varieties perform, they need to have access to this diversity, which is not commercially available. Consulting with farmers, we identified a sustainable solution to overcome this challenge: the creation of a community seed bank. Farmers built the infrastructure and the community seed bank was opened in May 2014.

As one of the main climate stresses faced by farmers is drought, we concentrated our efforts on identifying drought-resistant varieties. Several varieties that are more resistant to drought than the one commercially released by breeders with the same goal were already identified.

Meanwhile, we conducted a study at the genetic level for the durum wheat accessions, to have a better understanding of the genetic diversity we are using. This analysis revealed that we introduced new valuable genetic traits for climate change adaptation to farmers. Most importantly, we are trying to identify where the traits preferred by farmers are located in the genome.

We evaluated hundreds of domesticated, locally adapted varieties (landraces) of durum wheat – many identified and conserved by local farmers – and performed detailed genetic characterizations at the molecular level. More specifically, we tested, through QTL mapping, 81 587 markers scoring 30 155 SNPs and used them to survey the diversity, structure, and genome-specific variation in the panel. We showed the uniqueness of the Ethiopian germplasm using a siding collection of Mediterranean durum wheat accessions. We phenotyped the Ethiopian panel for ten agronomic traits in two highly diversified Ethiopian environments for two consecutive years and used this information to conduct a genome-wide association study. We identified several loci underpinning agronomic traits of interest, both confirming loci already reported and describing new promising genomic regions. We discovered



that the variety in outwardly expressed traits such as plant growth, morphology, resistance to pests and productivity correlated specifically with diversity at the genome level. The results indicate an especially high level of genetic diversity for Ethiopian durum wheat compared with durum wheat cultivated elsewhere, suggesting that it could provide an important, as yet unexplored source of durum wheat diversity (Mengistu *et al.*, 2016).

This information is also useful for a breeding programme being conducted by the Sirinka Agricultural Research Station in Ethiopia, aiming at creating new lines using the best material identified by scientists and farmers.

Reference

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3.4.4 Biological nitrification inhibition (BNI) in plants: Implications for improving nitrogen use efficiency and reducing nitrous oxide emissions from agricultural systems

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The biological oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), termed as nitrification, is carried out by two groups of soil micro-organisms – ammonia oxidizing bacteria and ammonia oxidizing archaea. Cationic- NH_4^+ is strongly bound to the soil and is available for crop uptake. In contrast, the anionic NO_3^- does not bind to the soil and is prone to leaching and causes pollution of water bodies. Several heterotrophic soil bacteria denitrify nitrate under anaerobic or partially anaerobic conditions, producing nitrous oxide (N_2O), a powerful GHG with global warming potential 300 times more than carbon dioxide (CO_2), and the third-largest contributor, after CO_2 and methane, to global warming. Nitrification and denitrification are the only known biological processes that generate N_2O ; concentrations of N_2O in the atmosphere are rising since the advent of the green revolution (from 290 parts per billion in the 1960s to 320 in 2000); nearly 70 percent of global N_2O emissions come from agricultural systems.

Green revolution, nitrogen (N) fertilizer use and N_2O emissions – the functional link

Fertilizer-responsive high-yielding wheat, rice and maize varieties largely are responsible for the green revolution, that doubled global food production (between 1960 to 2000); but global N-fertilizer consumption has increased from 10 teragrams (Tg) to 120 Tg/year during this period. A 12-fold increase in N-fertilizer consumption for a two-fold increase in global food production led to a dramatic decline in nitrogen use efficiency (NUE; kg of grain produced per kg of N-fertilizer applied), reaching < 30 percent recovery of applied N by crops at present. Nearly 1.36 billion barrels of diesel energy are needed to produce 120 Tg of N-fertilizer; about 70 percent of N-fertilizer applied to agricultural systems is lost to nitrate leaching and denitrification; the economic cost from the lost N-fertilizer is estimated at US\$90 billion annually. Global N-fertilizer consumption will reach 300



Tg by 2050 and global N₂O emissions will double from present levels and reach 19 Tg N₂O-N per year (8.98 Gt CO₂ eq per year), if we carry on with business as usual.

There is an urgency to develop next-generation mitigation technologies to reduce N₂O emissions from agricultural food production systems as the IPCC set a target to cut global GHG emissions by 80 percent by 2050. Controlling soil nitrification is thus critical to reverse the present trend in declining NUE by improving N retention and reducing N leakage from N₂O emissions and NO₃⁻ leaching.

Biological nitrification inhibition – A genetic-mitigation technology to curb N₂O emissions from agricultural systems

Certain plants have the natural ability to produce and release biological nitrification inhibitors to suppress nitrifier activity and soil nitrification, a plant function termed “biological nitrification inhibition” (BNI). Tropical pasture grasses such as *Brachiaria humidicola* (Bh) have the strongest BNI capacity and release “brachialactone”, a powerful nitrification inhibitor from roots. Our initial estimations suggest that sufficient biological nitrification inhibitors can be produced and added from Bh root systems (from root exudation and from root turnover) that can potentially reduce soil nitrification. This hypothesis was field-tested where it was demonstrated that Bh pastures not only suppress nitrifier activity and NO₃ formation in soils but also reduce N₂O emissions. Currently, JIRCAS in partnership with CIAT is evaluating whether biological nitrification inhibitors added from Bh root systems can improve NUE of a following maize crop in an agropastoral system. We tested the hypothesis that a reduced soil nitrifier activity from a high BNI-capacity Bh pasture grass can improve N recovery thereby improving NUE of a follow-up non-BNI maize crop. The last four years of field evaluation suggest that maize yields have improved substantially (from 60 to 100 percent) in BNI fields compared with non-BNI fields under moderate N inputs (60 to 120 kg N/ha); N recovery and soil N retention were substantially higher in BNI fields compared with non-BNI fields, suggesting the potential value of exploiting BNI function in an agropastoral system.

In addition, JIRCAS, with participation from ICRISAT and CIMMYT, is evaluating and characterizing the BNI capacity in sorghum and wheat root systems to assess the potential for genetic exploitation of the BNI trait in major staple food crops. Sorgoleone, a powerful hydrophobic BNI compound is exuded from roots and contributes to the BNI-capacity in sorghum. Current research is focused on identification of molecular markers linked to the sorgoleone release trait for deploying high BNI capacity into next-generation sorghum varieties. Cultivated wheat lacks adequate BNI capacity in their root systems and current efforts are directed towards introducing high BNI capacity from one of its wild relatives (*Leymus racemosus*), using chromosome engineering techniques. As plant root systems produce a cocktail of biological nitrification inhibitors with varied chemical structures and multi-modes of inhibitory action on *Nitrosomonas* (the nitrifying soil bacteria), exploiting BNI function (using both genetic and agronomic strategies) may be more effective than using chemical nitrification inhibitors to control soil nitrifier activity. Genetic exploitation of the BNI trait to produce BNI-enabled crops and pastures could be a powerful genetic mitigation technology for the next green revolution that must improve NUE and reduce N₂O emissions.

Low-nitrifying food production systems are critical components of climate-smart agriculture

Low-nitrifying and low N₂O-emitting agricultural production systems are important pillars to support climate-smart agriculture. Genetic mitigation technology, where BNI-enabled root systems of staple crops/pastures will become components of low N₂O-emitting food production systems, should be integrated with genetic adaptation strategies to address climate change for developing climate-smart agriculture in the twenty-first century.

A paradigm shift is needed in nitrogen management to meet COP21 GHG emission reductions from agricultural systems

The 21st Conference of the Parties of the United Nations Framework Convention on Climate Change (COP21) set the goal for cutting GHG emissions by 80 percent to limit global temperature increases to below 2°C by 2050. Termed the “Paris-Agreement”, this created a climate fund of US\$100 billion per year, operational from 2020 to facilitate development of novel mitigation technologies that are carbon-neutral, and N₂O-neutral as well. A paradigm shift towards low-nitrifying production systems is needed; exploiting BNI function could become a powerful genetic mitigation technology to achieve the goal of reducing N₂O emissions to lower the N footprint from agriculture by 2050.



3.4.5 Mitigation of enteric methane emissions from ruminants: The role of biotechnology

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Animal biotechnology has been practiced in one form or another since the beginning of the domestication of animals. Many of the classically used tools such as nutrition, reproduction, animal breeding and genetics have played an important role in the proliferation of desirable and economically important traits that have enabled ruminants to respond to human demand for food.

Modern livestock production has relied on biotechnology for the development of improved feedstuffs and feed ingredients, vaccines, high-quality genetics, and improved reproduction traits, disease diagnosis – all aspects that have combined to improve the sector's contribution to global food supply.

The domestication of ruminants represents one of the earliest forms of human application of biotechnology to produce food. This has been made possible through the process of enteric fermentation that takes place in the rumen – the site where rumen micro-organisms digest carbohydrates, proteins and fibre under anaerobic conditions.

Ruminants and microbes have evolved together, filling a niche based on the conversion of complex plant carbohydrates to energy that is beneficial to both the host animal and the microbial population in the rumen. The production of ruminant products, such as milk and meat depends on the microbial fermentation of feed into products such as microbial protein and volatile fatty acids, which are transformed by the ruminant tissues into animal products, along with by-products such as hydrogen (H_2), carbon dioxide (CO_2), ammonia (NH_3) and heat. This microbial transformation in the rumen allows ruminant species such as cattle, buffalo, sheep and goats to use fibrous feeds for production.

The process of enteric fermentation in the rumen is thus highly beneficial for humans because it converts low quality, coarse and fibrous plants into food and fibre, but it is also a major producer of methane, a potent GHG. Methane (CH_4) production is a natural and inevitable outcome of the fermentation process that prevents the accumulation of the hydrogen end product released by rumen microbes during the fermentation of feeds.

Methane emissions are the second largest cause of global warming after CO_2 , accounting for 16 percent of global emissions. From 1750 to today, the concentration of methane in the atmosphere has increased by 150 percent (from 700 to 1 760 parts per billion). By weight, CH_4 is 84 and 28 times more potent than CO_2 over a 20-year and 100-year period respectively.

The agricultural sector contributes about 50 percent of the global human-induced CH₄ emissions, of which 78 percent are from livestock (manure and enteric fermentation). Methane from enteric fermentation is the single largest global source of anthropogenic CH₄, responsible for 30 percent and 70 percent of global CH₄ emissions and CH₄ emissions from agriculture, respectively. At global level, CH₄ production from enteric fermentation contributes 5.5 percent (equivalent to 2.7 gigatonnes [Gt] CO₂ eq.) to the global anthropogenic GHG emissions. Using methane's 20-year global warming potential – a measure of the short-term climate impact of different GHGs – more than triples the share of enteric CH₄ to over 18 percent of global GHG, from slightly less than 6 percent at the 100-year time frame. Cattle account for 77 percent of the global enteric emissions (2.1 Gt), buffalo for 14 percent (0.37 Gt) and small ruminants (sheep and goats) for the remainder (0.26 Gt). Global enteric CH₄ emissions are projected to increase by 20 percent in response to growing demand between 2010 and 2030; this would add over 388 Mt CO₂ eq. in 2030.

Methane production through enteric fermentation is not only of global concern for its contribution to global warming, but also for its wastage of feed energy, an inefficiency that limits the production performance of ruminants. As a result of this process, ruminants lose between 2–12 percent of the gross dietary energy in the form of CH₄ depending on the quality and quantity of diet. Thus, it is essential to look for options to reduce CH₄ emissions through improving feed conversion efficiency, which also translates into economic benefits for millions of producers dependent on ruminant production for their livelihoods.

In the last few decades, there has been a rapid growth of knowledge in the functioning of the rumen as well as research into mitigation technologies to reduce the enteric CH₄ emissions from ruminants. Several options are available ranging from nutritional strategies (such as feed processing to enhance digestibility, inclusion of concentrates in diets, improving the quality of forages), to the use of feed additives (ionophores, organic acids, fats and oils, plant extracts), and to modern technologies such as defaunation, immunization, genetic modification of rumen micro-organisms, conventional and advanced (molecular genetics) plant and animal breeding.

Currently, nutritional strategies and interventions focusing on the optimization of feed rations are some of the most developed and readily available for immediate application in the field. These are often low-cost, low-risk, low-tech, resilience-enhancing and provide productivity gains. Nevertheless, despite the obvious benefits, these technologies have been adopted much more slowly. In low-input low-output systems, ruminants are usually reared because they do not necessarily require resource ownership as they often depend on free access and communally owned grazing resources, while providing high returns at low or no cost (in the form of milk, meat, draught power, manure, etc.) relative to other investment options. In addition, several other factors restrict action on enteric fermentation including the heterogeneity of management practices, the cost of mitigation and inherent price volatility of options dependent on diet manipulation.

For systems operating at very low levels of efficiency, many of the nutritional strategies outlined involve employment of existing technology. With such strategies, the main constraint is technology transfer, diffusion and deployment. Policies that aim at incentivization of technologies with a high to intermediate level of scientific certainty and with the potential both to generate relatively rapid productivity gains and economic benefits, are required.



On the other hand, the inhibition of enteric CH₄ in ruminants through the use of technologies such as dietary additives have not delivered a clear and positive answer in reducing CH₄ emissions in ruminants, highlighting the difficulties in their application. Many of these strategies still require further research to allow application. The scope to use specific dietary additives in ruminants is much greater in developed regions than in the developing world because of cost, applicability (i.e. it is much easier to administer products to animals in confined systems than in free-ranging or nomadic systems). In addition to this, the high upfront cost and the knowledge gaps surrounding their impacts remain major obstacles.

Finally, there are many novel and advanced biotechnologies in their early stages of development, such as the use of probiotics, vaccination and genetic modification of the rumen. For these technologies, further research and development is needed before they can be widely employed.

The potential applications of biotechnology in ruminant production are endless. With the current challenges facing the sector, it is possible to envisage a future where livestock production will rely increasingly on existing and emerging biotechnological advances to produce food. Today, modern and advanced biotechnologies are a reality and are rapidly finding their way into research and development. Consequently, there are high expectations about the developments in biotechnology and the potential benefits it can offer in enhancing productivity, improving livelihoods while protecting the environment. To tap this potential, investments in technological transfer and input and product market development are required, alongside possible emission offset incentives.

3.4.6 Use of biodiversity as a biotechnological tool for carbon sequestration in the tropics

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The Laboratory for the Genetics of Tree Species at the University of São Paulo, Brazil (LARGEA/USP) is studying the complex biodiversity and the genetic structure of tropical tree populations, with a view to using these on two applied projects in the field: 1) restoration of degraded riparian areas around hydroelectric dams for carbon sequestration; and 2) agroforestry systems with high biodiversity for smallholder farmers, protecting the system against pests and diseases, and producing healthy food.

Basic research using molecular genetics is showing that there are around 500 plant species per hectare in tropical forests (Atlantic Forest), with 100 times more species of insects and micro-organisms (50 000 species/ha). The majority of these organisms are normally enemies to plants and can eat them. Why is the biodiversity so high? The plants in these natural forests have evolved to be protected against insects and micro-organisms, producing secondary chemical compounds to survive in nature, and this can be used as a biotechnological tool in the construction of agroecosystems.

The genetic structure of the Atlantic Tropical Forest in Brazil has been studied by LARGEA/USP for the past 30 years, using molecular genetic methods to determine genetic variation within and among populations, gene flow, and the breeding systems of more than 50 representative tree species of natural tropical forests. This basic information is very important for a deep understanding of the biodiversity of natural tropical forests, and input for restoration and agroforestry system projects.

The two main applied projects of LARGEA/USP are using biodiversity as the basis. In the first project, trees of 100 different species were planted to give a biodiversity of 100 tree species per hectare in a restoration project for degraded riparian areas, in cooperation with hydroelectric companies in the State of São Paulo, Brazil. In the second, the project was in association with the “Landless Movement” of Brazil, the most well-organized smallholder communities, developing agroforestry systems with high biodiversity, for producing healthier food.

The main result of the restoration project of LARGEA/USP was the planting of 500 hectares per year (during a period of 30 years) with the previously mentioned biodiversity (100 tree species/ha) for carbon sequestration. This project was under the UN Framework Convention on Climate Change (UNFCCC). The most recent PhD thesis presented by a student of LARGEA/USP within this theme addresses: “Emergy evaluation of ecological restoration around hydroelectric dams in



Pontal – Brazil”. This thesis presents an evaluation, through effects on the same parameters of nature and economics, of 26 years of restoration under the same planting methodology.

For examples from the second applied project of the laboratory, we can highlight a 2011 MSc thesis comparing, under the same ecological conditions, the cultivation of tomato by three conventional producers (using applications of pesticides and chemical fertilizers) against three smallholder farmers operating under an organic system (biodiversity surrounding the culture), without the use of industrial chemical products in Apiaí (Brazil). The final results were surprising: the productivity for the organic system was 65 percent (130 boxes of 20 kg of tomatoes per 1 000 plants) of that for the conventional system (200 boxes per 1 000 plants), while the economic returns to the farmers under the two systems were about the same (1 000 versus 800 Brazilian real per 1 000 plants, for the conventional and organic farmers, respectively). The most important aspect to highlight is that the smallholder farmers did not use pesticides. Therefore, neither the farmers nor the consumers of their products were exposed to the danger of being poisoned by the 36 applications of pesticides used by the conventional farmers during the 2.5-month cycle of the tomato culture. The essential aspect is that the tomatoes produced by the organic farmers were free of pesticides, and represented healthier food. The project illustrates the use of biodiversity as a biotechnological tool for the production of healthier food by smallholders within settlements of agrarian reform in Brazil.

The second example of an agroforestry system studied in our laboratory is coffee cultivation. A PhD student (P. Lopes) presented a thesis comparing coffee cultivation under different levels of native tree biodiversity with monocultures of coffee in settlements in Pontal do Paranapanema, Brazil. Three levels of biodiversity were used in the coffee agroforestry systems: 1) high – 36 different native tree species in addition to the coffee plants; 2) medium level – 23 native tree species plus coffee; and 3) low – 12 native tree species, together with 4) the control – pure monoculture of coffee.

The results supported the hypothesis that attacks on the coffee plants by the most important pest in the region, *Leucoptera coffeella* – the so-called “bicho mineiro” – could be reduced by adopting an agroforestry system with biodiversity provided by native tree species. The average levels of attack, expressed as percentages, observed for the different coffee agroforestry systems were: 31.24 percent, 45.47 percent, 58.15 percent, and 88.35 percent, for the high, medium, low biodiversity, and the coffee monoculture treatments respectively. Estimates of the economic returns for the different coffee systems were respectively 1 100, 2 813, 2 250 and 1 452 Brazilian real for the agroforestry systems of high, medium and low biodiversity, and for the coffee monoculture. The best economic performance, representing a balance between biodiversity and productivity, was achieved by the second treatment, corresponding to medium biodiversity.

Final considerations:

- 1) In agriculture and silviculture in the tropics, advanced technology and the large-scale use of monocultures are destroying the biodiversity, causing increases in pests and diseases. To maintain productivity, the agroindustry has turned to more and more use of pesticides and chemical fertilizers together with the introduction of GMOs.
- 2) The adverse impacts of these production models on the environment and human health are clearly observed, including in reports commissioned by the World Health Organization

(WHO). In contrast, smallholder farmers have adopted agroforestry systems for the production of healthier food, avoiding the use and high costs of dangerous industrial chemical products.

- 3) We have presented the important application of biodiversity for the maintenance of equilibrium in agroecosystems and the production of healthier food for society.



3.4.7 Carbon sequestration in agricultural soils: The “4 per mil” programme

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The proposal, made by the French authorities ahead of COP21, to store annually four per mil of the soil organic carbon stock to offset current anthropogenic CO₂ emissions is now part of the Lima Paris Agenda for Action (LPAA) and it is confronted to state-of-the art scientific understanding.

The adoption of best agronomic and forestry practices can allow a significant carbon sequestration rate, reaching locally up to 4 per mil (0.4 percent) of the soil organic carbon stock for some of the documented examples. However, these examples are unevenly distributed with, in particular, little data for tropical soils. Assuming a global soil organic carbon stock of ca. 820 Gt C (over a meaningful depth for carbon (C) sequestration, i.e. 0–40 cm), the 0.4 percent target would result in a carbon sequestration that could peak at 3.5 billion tons C per year (Gt C/year) when considering soils from all biomes.

A rise in global soil carbon sequestration could be obtained through a large increase in global net primary productivity partly obtained by restoring degraded lands (ca. 24 percent of the total land area) that are widespread in all biomes and in most world regions. Further, assuming that net CO₂ emissions from land use change could be halted, the land carbon sink that could peak in the 2030–2040s thereby substantially offsetting the current growth in atmospheric CO₂.

Positive impacts of increasing carbon contents of soils on food security and ecosystem services can be anticipated, including increased biomass production for bioenergy, reduction in erodibility as well as climate change adaptation, thereby contributing to sustainable development goals. The additional soil organic carbon stock would need to be preserved until the end of the century – and as far as possible beyond – through a combination of soil conservation practices and of land adaptation to climate change.

Research is needed on: 1) knowledge on the baseline of sequestration (or loss) of soil carbon and on current soil carbon stocks; 2) the definition and co-construction of agronomic strategies and practices at various scales (individual to collective) targeting the “0.4 percent” objective; 3) the transfer and adoption of these strategies and the development of demonstration sites; 4) the design, experimentation and assessment of institutional arrangements and public policies, including financial mechanisms,

that aim at promoting and rewarding relevant practices; 5) metrics and methods for monitoring, reporting and verifying carbon sequestration, if possible on the basis of a net-net accounting.

As mentioned, an increase in the global net productivity is one way to achieve the goal. However the final sequestration of carbon is determined by the net biome productivity. Estimations are that the global primary production of carbon is 123 Gt of C per year. Compared with this, the net biome productivity is 2.9 Gt. The ratio between these two values is very low and biotechnologies could be mobilized to improve them in various ways: for example, improvement of the photosynthesis process, modification of the shoot/root ratio, biomass quality monitoring, perennality of crops, improvement of knowledge on the soil-rhizosphere-plant interface.

In this presentation, these various ways will be discussed and, when relevant, the example of sorghum will be used to illustrate ongoing research and possible implementation for various environments.



Chapter 4

Parallel sessions: Sustainable food systems and nutrition



4.1 Report of outcomes from the three parallel sessions dedicated to the theme of sustainable food systems and nutrition

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Our first session was on “Improving productivity through enhanced resource use efficiency”, the second on “Post-production value addition and food safety” and the third on “Nutrition and food quality”. So you can see that over the three days we covered a huge range of different opportunities for agricultural biotechnologies to make a difference. Our focus throughout was on smallholders.

In the first session, we looked at the application of biotechnologies not just to staple crops, but also to vegetables and livestock and this was a theme throughout our three sessions, where we were saying that it is not just about the staple crops. There is the potential for biotechnology to actually redress some of the balance in terms of the relatively cheap price of the staple crops compared with vegetables, livestock and fish. Trees were also an important part of our sessions and they do contribute to nutrition, as I will briefly cover.

The aim was to look at the application of technologies to those commodities to achieve sustainable intensification, meaning higher yields per hectare or greater efficiency of use of inputs such as water. So we started with a presentation on that key crop, rice, and heard about a project from China, where there are 27 partners, on “Green Super Rice” which hopefully can use less pesticides, less fertilizer, is water-saving, drought-resistant and, at the same time, high-yielding and of superior quality. And this shows the ambition you can have with biotechnologies. Genes have been identified to improve nitrogen use efficiency and tolerance to phosphorus deficiency. Partnerships were important here, but you will see the importance of partners throughout our other sessions as well.

The next presentation was on vegetables. I was very keen to get vegetables into this series of sessions because, as became clear during these three days and as many people have already stated in the literature, the emphasis on staple crops means there has been less research on fruits and vegetables and, from a nutrition point of view, fruits and vegetables should be getting greater focus. The whole concept of diversification of diets was much discussed in the third session, this morning.

One thing that came up in this talk about vegetables was about looking along the value chain and the potential for employment opportunities for youth. We need to put more effort into the value chain, adding value as you go from production through to consumption. Another important point from this talk was the importance of understanding farmers’ needs.

Our next talk was on aquaculture and genetic improvement. As in the opening plenary session, we heard about the potential of biotechnology to control sex ratios. Issues raised in the talk were the use of genomic analysis and the importance of context. That is another theme that came up throughout the sessions; matching our technologies with the needs of different countries and different contexts.

The fourth talk was on bridging the biotechnology–livestock productivity gap in East Africa. We went through dairy cows, pigs and goats in a very interesting talk and, again, we had this concept of matching the breed to the farm context. In pigs we were looking at disease resistance and in goats we heard about the potential for identifying prolific does. But again there was the message: investing in breeding alone, using biotechnologies alone, will not work without paying attention to other issues such as basic management or hygiene.

In terms of trees, I learned in the fifth talk there is a tree species *Allanblackia* whose oil is used for margarine. Also we heard about the nutritive value of food from the forests and the diversity in terms of nutritional context and the use of marker-assisted or genomic selection to match seed to site.

So out of that session, common messages were:

- Biotechnologies exist which can help smallholder farmers.
- Genetics alone does not guarantee increased productivity.
- There is no “one size fits all” solution. We have to match the nature of the improvement, the focus of that type of improvement, to the site and context.
- Potential for different sectors to learn from each other.
- Importance of partnerships in defining research questions and conducting research. But what do smallholder farmers get from research?

The second session, on Tuesday, was on post-production value addition and food safety. It was in two parts. The first was on enhancing value in the post-production phase. We heard about feed additives generated by fermentation, a traditional biotechnology that has been around for a long time, and the opportunities it presents through, for example, efforts to reduce the use of antibiotics in livestock production. The potential for genomics to actually advance the selection of feed additives – to target them more closely – was also discussed.

In the second talk, biotechnologies to increase storability and shelf-life of fruit were discussed. The short shelf-life of fruit causes marketing issues that can be a problem for smallholder farmers trying to get into this area. What I learned is that harvesting early to improve transport has a negative effect on taste and that comes back to another common theme about acceptability. If we target too tightly, then there can be unintended consequences which are negative. We also heard about gene editing, which has the potential to switch individual biochemical reactions on or off, such as ethylene production, particularly important in relation to ripening. We were, very importantly, also reminded that while there is a lot of excitement about all the potential here, there is quite a long time line to take biotechnologies through to the field.

The third talk was about biotechnology tools and capabilities. We heard about the African Orphan Crops Consortium, also mentioned elsewhere in the symposium, which is a good example of the type of partnership we could build on more. And, going back to orphan crops, we heard again about the



need to avoid focusing just on the staples but to broaden the focus. If we want to deal with nutrition, if we want to have value addition, we need to be working on more than just the staples. We also heard about the growth and potential of the clustered, regularly interspaced, short palindromic repeats (CRISPR) technology.

The second part of the session was on using biotechnologies to ensure food safety. The first talk was about milk fermentation, where some of the traditional technologies, not just genetically modified organisms (GMOs), were covered. We also heard a talk about Aflasafe, used to reduce aflatoxins in crops. It is a good success story because Aflasafe is a product that works and developing countries, at least some of the governments, are actually investing in its production in their countries. It is fine to get investment in something where you can actually see immediately the response. But, I think it is very significant that there is investment in reducing aflatoxins which cannot be seen and whose impact is often not seen for some time except, as was brought to our attention, in the poultry industry where you immediately see the impact on productivity of the birds.

The final talk was about diagnostics for tuberculosis in cattle in Brazil. Issues covered included problems associated with regulation; differences between testing methods; and the practicality of actually bringing cattle in from the range twice, if you have a complex test.

Common messages from the second session were:

- Biotechnologies exist which can help to enhance post-production value.
- Genomics and gene editing provide new opportunities.
- Biotechnologies on their own are not a “silver bullet”. We need communication on all those other aspects which are going to help biotechnologies actually deliver, such as on hygiene/best management practices.
- Time scale from innovation to impact in the field can be 15–20 years.
- GMO discussion needs: we need to have a participatory approach; option of a high-profile champion; use of evidence-based results; separation of the discussion from commercial benefits.
- Importance of policy and regulation and multistakeholder investment.
- Need to consider nutrition, resilience and yield simultaneously.

The focus of the third session was on nutrition and food quality. The first talk was an excellent introduction in terms of giving us the context of the two billion people who suffer from hidden hunger and micronutrient deficiencies. We also heard about the economic cost of obesity and the global figures were similar to those for smoking. Hidden hunger and micronutrient deficiencies are so important for the development of young children. Biotechnology can increase food production, increase nutritional content and, here, biotechnology was mentioned as a potential rallying point across disciplines. One of my key passions is about trying to get scientific disciplines working together.

The second talk was on biotechnologies applied to improve the quality of wheat and rice. We heard about the potential of golden rice, but saw photos of a field trial actually being trashed and heard what that meant to the PhD student involved. Current examples of what can be achieved in rice include beta-carotene, high iron and folate in grains – the potential again is there. One of the key things though is market acceptability. There is no point in producing all these crops if people will

not actually buy them. One of the things about rice is the importance of aroma in terms of peoples' acceptance of it. So that is important in terms of food quality.

The third talk was on biofortification of staples. We heard about the success already achieved with some of the biofortified crops such as vitamin A fortified orange sweet potato and also maize. Again, acceptability came into that in terms of different countries having different preferences for orange or white maize, and making it clear that if it is going to be acceptable to the farmers, yields should not be sacrificed to biofortification.

The final talk was on biotechnology to improve nutrition through fish. So, the focus was on aquatic species that need feed. Again, fermentation biotechnology, already out there, is important. Micro-algae or genetically modified yeast can contribute to replacing fish oil in aquaculture feed. This is very important in terms of long-term sustainability so we are not just catching fish to feed fish. Fermentation biotechnology is also important in improving the shelf-life and nutritional value of fish which, again, comes back to taste acceptability and the importance of fish sauces in some parts of the world.

Common messages from the third session were:

- Biotechnology is not new. Fermentation technologies are a traditional way of dealing with many nutritional issues both on the quality side and in terms of food safety.
- Importance of acceptability of new products to consumers – regarding their colour, taste, quality, perception of risk – and to farmers – regarding the economic importance of yield.
- The potential for biotechnology to redress the balance of past high investments in staples through a focus on other healthy crops, as a result of the increasing appreciation and recognition of the importance of a diverse diet.
- Cost of regulations or deregulations to enable new products. If we are moving from more traditional technologies to high-tech ones like transgenics, that cost-effectiveness needs to be built in.
- Dialogue early and with multiple stakeholders – recognizing “language” differences and providing definitions. This point came up throughout the symposium: dialogue early and with multiple stakeholders. I use the word “dialogue” deliberately; it often came up as “communication”, but a key thing is to listen as well as to actually get a message across. And also to recognize that if a scientist talks to policy-makers they use different languages. Scientists have to make the effort to get their messages across in a way that policy-makers, the public and farmers understand. It is not enough to say we have a technology let us push it out there. We need to listen and we need to learn.

I hope that I have covered all points from the sessions. Thank you very much.



4.2.1 *Report of the parallel session*

Improving productivity through enhanced resource use efficiency⁹

The world will need to improve the efficiency of food production systems in order to feed over nine billion people by 2050. Recognizing the important contributions genetic biotechnologies make to improved resource use efficiency, this session contained a diverse collection of presentations on Green Super Rice (GSR) in China, groundnut development in Malaysia, genetic improvement of fish in tropical areas, livestock in East Africa and forest genetics in Africa. It was chaired by Sergio Feingold, co-chaired by Thuy Nguyen and moderated by Dominic Glover.

Sibin Yu presented a case study on GSR in China where genomic design, traditional selection and marker-assisted selection (MAS) helped identify desirable genes towards the development of new varieties of rice with increased disease resistance, water use efficiency, nutrient use efficiency and growth. A network of research institutes, universities and private industry was created and has developed numerous lines and cultivars for distribution outside of China to Africa and South Asia.

Although major crops have helped improve food security, underutilized crops are important but often have not been the subject of genetic improvement programmes. Sean Mayes described how underutilized groundnut can be improved by the use of genetic markers to assess pollen transfer, genetic diversity and seed quality. By examining related and ancestral species, the research chain and farmers' needs, and by recognizing that many farming systems are low-input or on marginal lands, hundreds of lines of groundnut were developed for worldwide distribution.

David Penman highlighted the numerous genetic technologies that have the potential to improve resource use efficiency in tropical fish. Genetic technologies to improve growth and to control maturation and sex determination include chromosome set manipulation and mono-sex production to take advantage of sexual dimorphism in desirable farming traits, e.g. male tilapia grow faster than females and female rainbow trout grow better than males. Genetic mapping, sex-linked markers, DNA markers and quantitative trait loci (QTLs) are being used to identify superior breeders in both farmed and wild populations while more precise gene editing allows for more targeted modification of the fish genome. Cryopreservation of fish sperm has not had wide application, but can facilitate breeding programmes.

Denis Mujibi presented three case studies from East Africa where cross-breeding is a common strategy. Single nucleotide polymorphism (SNP) markers were used to match cross-breds with their production environment in dairy cattle. Genes from local breeds performed well under local conditions and a high percentage of exotic genes from supposedly improved breeds did not perform significantly better in low- and medium-input systems. SNPs were further used to identify the genetic basis for resistance to African swine fever (ASF). Indigenous pigs were shown to be resistant to ASF; the more

⁹ This report was prepared by the FAO rapporteurs - Devin Bartley and Julie Belanger

“African” genes a pig contained the higher the resistance. Fecundity in goats is an important farming trait, but the genetic basis for fecundity and the goat’s general adaptability to diverse and marginal environments are poorly understood. MAS is being planned to help understand the genetic basis for these traits.

Judy Loo highlighted the special characteristics, advantages, disadvantages and the many uses of trees. Trees are largely undomesticated and genomic selection, genetic modification, cloning and QTLs have only been applied to a handful of species. A case study from Kenya and the African Orphan Crops Consortium highlighted the *Allanblackia* species complex, which is targeted by the industry for its edible oil, timber and medicine. Partnerships have been created to establish supply chains, and for domestication and breeding efforts with the objective to decrease time for seed production, improvements in propagation and in seed dormancy period. Challenges in public–private partnerships were highlighted. Genetic markers are being used in forest management to look at impacts of illegal logging on important traits and in forest restoration, e.g. to match source to site.

Discussion summary

Discussion topics included:

- Clarification of breeding strategies in GSR as to whether they included GMOs: In the case of GSR, conventional breeding of plants with desirable genes was used – genetic modification was not used.
- The probable acceptability of precision breeding and genetic modification for the African Orphan Crops Consortium.
- The value of reducing variability of cross-bred populations to reduce unknown diversity with unpredictable inheritance; productivity of the breed is the important factor.
- Partnerships between scientists and farmers should be sought, as farmers are often innovators/scientists themselves – they try the technologies and form farmer/research networks.
- The value of providing phenotypic information on breeds to link with genotypic data and the vital role farmers play in this process.
- How farmers will benefit or be repaid from biotechnology research when they share knowledge, seeds, wood, etc. with scientists? What in the case patents are developed?
 - Although past examples do not encourage confidence the session stressed that there should be a mutual learning experience with feedback and tangible benefits.
 - Farmers should get improved varieties and provide advice on management.
 - In the case of underutilized species, the knowledge comes from the farmers; therefore it is a moral obligation that sharing information should benefit them.
 - In intellectual property, protection for minor species may not be an issue because large companies may not be interested, but any intellectual property rights should be afforded to farmers.

The session demonstrated that:

- An integrated approach to the application of biotechnology is important.
- Genetic biotechnologies can speed up progress and are useful across sectors to help:
 - produce more food with less land, water and other inputs;
 - identify the genetic basis for important farming traits, e.g. disease resistance, nutrient uptake,



- drought tolerance and growth;
- manage wild and farmed populations;
- match species and genetic biotechnologies with the environment and growing system, noting that a different collection of genes will be needed for different growing conditions, e.g. high- and low-input systems, or optimal or marginal environments.
- Different sectors can learn from each other.
- It is important to ensure technologies are usable, appropriate to smallholders.
- Orphan crops, breeds and underutilized species, as well as undomesticated species, e.g. many fish and trees, are potential resources for the future.

Partnerships and cooperation are necessary between actors (civil society organizations, academia, private sector, governments, farmers, etc.) for breed development, testing and for wider dissemination of plants and animals with greater resource use efficiency. Finally, biotechnology is not a magic bullet but must be used in conjunction with other aspects of food production.

4.2.2 “Green Super Rice” to be resource saving and environment friendly

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Sustainable crop production is of predominant concern for food security. The global demand for crop production is expected to double by 2050 as the growing world population is estimated to be over 9.6 billion. This forecast would require the global increase of crop yield to be around 1.5 percent per year, which is a massive challenge in the face of climate change and diminishing resources. Increasing crop production to meet the demand must be achieved in a sustainable manner from less land and fewer inputs of pesticides, fertilizers, water and other resources.

Rice is the main staple food for more than half of the world's population, particularly in Asia where 90 percent of rice is consumed. In the past half century, the increase in rice production has made great contributions to global food security. However, crop production with high-yielding cultivars required high inputs of nutrients, water and labour. For example, in recent years, China has been consuming 55–60 million tonnes of chemical fertilizers annually, which accounts for more than one third of total fertilizers consumed globally. China has also been consuming 31 percent of the total pesticides produced worldwide. In addition, irrigation water is used annually in agriculture, accounting for 70.4 percent of the total water consumption in China, of which 70 percent is used for rice production alone. Excessive use of fertilizers, insecticides and water has resulted in severe problems such as the deterioration of soil, water and the environment, as well as in reduced crop productivity. To achieve continuous enhancement of crop production in a sustainable manner, Chinese scientists proposed the notion of “Green Super Rice” (GSR) with the key characteristics of “less input, more production and better environment”, as the goals for agricultural research and crop improvement.

GSR aims to produce more rice of good quality to meet the consumers' demands with higher resource use efficiency and resilience to climate change in crop production. GSR focuses on promoting resource saving and environmentally friendly rice production, while still achieving yield increases and quality improvements. Thus, the new varieties should possess the following characteristics: resistance to major insects and diseases in various rice producing regions, improved nutrient use efficiency, and resistance to drought and other stresses in areas. Furthermore, GSR is not only varieties with the above desirable traits, but also advocates an efficient and environment-friendly crop management. Labour-saving, mechanization and less intensive field management in crop production are now emerging as necessary with the rapid urbanization in China. Such changes require the GSR varieties to have those traits suitable for labour-saving and mechanized crop cultivation.



In the past decade, on the basis of the GSR concept and breeding strategies, we have made tremendous achievements in development and adoption of GSR in rice production in China. For the development of GSR, a combination of strategies has been formulated by integrating germplasm, genomic resources, molecular technology, traditional and genomic breeding with target traits of insect and disease resistances, N- and P-nutrient efficiency, drought tolerance, good quality and high yield. With the rapid advances in functional genomics, a large number of genes identified so far have provided a rich source for developing GSR cultivars. For example, several genes related to root growth are currently available for developing N and P nutrient use efficient rice. Many genes for drought tolerance hold promise for the development of water use efficiency cultivars. Accumulation of these desired genes by genomic design and marker-assisted or genome-based selection would result in progressive improvement of the rice varieties, eventually leading to GSR.

Currently, the Chinese government has launched the mega-project of GSR with the goal to benefit billion farmers to boost rice productivity by 8 percent in the target regions with 30 percent less input. A national network for the GSR project has been established, comprising more than 360 scientists from 21 research institutions, four universities and two seed companies with the strongest expertise in rice breeding and genetic research in China. By using the GSR strategies, the GSR network team has developed thousands of pre-breeding lines with resistance to major insects and diseases, improved drought tolerance, high N- and P-use efficiencies, and other desirable traits in many elite rice genetic backgrounds. The first version of GSR cultivars with stacked favourable genes has accelerated in recent years. Several hundred varieties with the green traits have been tested in many regions of China as well as in other countries.

Almost 100 GSR varieties are now widely available across various rice growing ecological areas in China, where they are helping farmers produce more rice using fewer inputs of pesticides, fertilizers and water, and thus increasing their incomes. So far, about 50 first-version GSR cultivars have been released by national or provincial Crop Variety Approval Committees. Utilization of these cultivars will result in increased rice productivity with much reduced inputs to ensure a great sustainability of rice production. With an international collaborative project supported by the Bill and Melinda Gates Foundation and the Ministry of Science and Technology of China, GSR practices have also spread to other countries in Asia and Africa. Some developed varieties are now being trialed and demonstrated in African and Southeast Asian countries.

Development and demonstration of GSR has set up a successful model with its emphasis on sustainable agricultural production. The notion of GSR has influenced the prioritization of research direction and changed agricultural policies in China. Further activities are underway including determination of key traits for GSR in each target region or country, integration of platform of green genes and pre-breeding lines for developing GSR, procedures for evaluating and releasing GSR varieties in target countries, establishment of efficient crop management for the development and adoption of GSR varieties, and capacity building for widespread application and dissemination of the GSR technologies in agricultural production.

4.2.3 Resource use efficiency in vegetables: Application of molecular breeding to bambara groundnut, an underutilized crop for low-input agriculture

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Intensive agriculture will continue to help in the quest for food and nutritional security. High inputs of nitrogen, growth regulators, irrigation, mechanization and monoculture of yield-selected genotypes have a valid role for the future. Nevertheless, multiple drivers have forced a partial re-think, with efforts underway to reintroduce resource use efficiency traits into major crops, while maintaining yields. Progress is being made at the pre-breeding level with the introduction of exotic germplasm from ancestors and relatives of current major crops. However, re-engineering “resilience” into major crops still leaves food and nutritional security vulnerable to abiotic and biotic stresses associated with extensive and intensive monoculture. In marginal environments often found in the global South (where subsistence or small-scale farming still produces the majority of the world's food), inputs, infrastructure and finance are often not available for high-input, high-return farming, while degraded soils may not support such agricultural systems.

A complementary approach is to evaluate the potential of many of the minor and underutilized crop species which have been grown under low-input agricultural systems for millennia. Such traits and crops may have potential to support agricultural resilience in the face of climate change. In addition, there is some evidence that the dietary nutritional value of such crops can be greater than many of the comparator major crops. However, underutilized crops often suffer from a range of factors which limit their potential. Often very little breeding work has been carried out, the pollination systems of the plants are poorly understood and relatively simple genetic problems remain unsolved. Yet, breeding “elite” cultivars (if that is the aim) is unlikely to be the critical step towards further uptake of such underutilized crops. Farmer requirements and preferences, the existence of markets, value-added products, validated nutritional data and sustainable agricultural systems to grow these species, are all required and their lack can significantly limit progress. Moreover, given that it is estimated that around 7 000 species of plants have been used at some point by humankind, a critical question is how to choose the crops that should be the focus of future collaborative efforts? A sensible approach is to identify crops which already have outstanding trait values, whether for drought tolerance,



nutritional content or another characteristic which makes these species potentially valuable. Even in their “unimproved” state such crops have some potential to complement or, in specific circumstances, replace major crops and are likely to exhibit good resource use efficiency after many centuries of selection in low-input systems.

Crops For the Future (CFF) is the world’s first research centre with a specific focus on underutilized and minor crops for food, feed, fuel and industrial uses. Based next to the University of Nottingham Malaysia Campus near Kuala Lumpur, Malaysia, it has adopted a research value chain approach, which requires disciplinary input from across the range of academic subjects impacting the growth and use of a crop; from biotechnology to socio-economics. BamYIELD (www.bamyield.org) is a programme within CFF which is focused on using bambara groundnut as an exemplar crop, with the lessons learned in this species being tested in other species. Bambara groundnut (*Vigna subterranea* (L) Verdc) is an African drought tolerant legume which is widely grown in sub-Saharan Africa by subsistence and small-scale farmers. As a legume, it also contributes nitrogen to the agricultural system and non-animal protein to the human diet. We are beginning to apply the approaches developed in winged bean (*Psophocarpus tetragonolobus*), *Amaranthus* ssp. and Proso millet (*Panicum miliaceum*).

Biotechnology and crop genetics

We have developed and used markers to assess pollen transfer, genetic diversity of accessions and for quality control as we develop breeding lines and carry out field work. We concluded that seed from a single plant represents an inbred line. With the International Institute of Tropical Agriculture (IITA), we are developing an extensive collection of lines (500) with genotypes which will be available worldwide to researchers and farmer groups. Working with DArT Pty Ltd, a genotype-by-sequence marker system has allowed us to map the order of markers on the chromosomes of bambara groundnut. Using this approach we have bred lower sensitivity to long day lengths into a number of lines – a trait which can be an issue for pod filling – for testing in 2016 in South Africa, Tunisia and the United Kingdom. The markers also allow us to compare marker and gene positions in related species such as the common bean, which has been far more extensively studied. A coordinated effort to supply germplasm for the African Orphan Crops Consortium through the BamNetwork (www.bambaragroundnut.org) will ensure that sequenced genomes are linked to known genetic lines available worldwide.

Breeding and agronomy

Matching the genotype to the environment is a critical aspect of introducing new crops to new environments. A grant from the third round of the Benefit-sharing Fund of the International Treaty on Plant Genetic Resources for Food and Agriculture will allow common protocols and a core of common genotypes to be trialled with local material in Ghana, Malaysia, Nigeria and Indonesia. This will generate robust data on the environmental influence on nutritional and processing traits. By including the major crop equivalents (peanut, cowpea) in the trials, we will also produce robust data to determine under what circumstances it makes sense to grow the underutilized crop, rather than the major crop. The network of field partners will also be used for selection and breeding work alongside developing collaborations with seed companies in Southeast Asia and Africa.

Meteorology and ecophysiology

Given the predictions of climate change, it is also important to understand how any introduction of a new crop is likely to be impacted by climatic change over time, as well as to know that it is suitable for planting now. Based on trial data from Gaborone (Botswana) we predicted that bambara groundnut has potential in Malaysia, both today and also in the future. We are now generating a comparable set of data in Malaysia alongside actually selecting genotypes within Malaysian field environments, to allow validation of the models. This approach can be applied worldwide.

Nutrition and bioproducts

Many underutilized crops are held back by a lack of nutritional and processing knowledge and how to produce value-added products. These can limit a crop to remaining purely a commodity. We have developed a number of potential products, including vacuum-fried and extruded products, soy-replacement drinks and supplemented wheat flour (which has a better balance of amino acids than either wheat or bambara groundnut flour alone). We are working (non-exclusively) with a major manufacturer in Southeast Asia to develop the supply chain needed for large scale supply of raw materials for such products, with the potential to expand approaches to multiple countries.

Social, economic and policy

Ultimately, the development of underutilized crops must contribute to social and economic benefits for producing communities. Currently, many of these communities are made up of subsistence farmers growing crops in small-scale low-input farming systems, with limited resources, little leverage over the supply chain and a very limited ability to effectively market and/or capture added value which could come from the processing of the raw materials. Work currently underway in United Republic of Tanzania is directly addressing the question of devising appropriate economic metrics for underutilized crops employing bambara groundnut as an exemplar. Further projects are being undertaken with partners in Ghana, Indonesia and Nigeria to develop and test approaches to increasing our understanding of the current role of bambara groundnut in smallholder systems and evaluating its current and potential contribution to smallholder welfare.



4.2.4 Resource use efficiency: Applications of biotechnology in genetic improvement in tropical aquaculture

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Aquaculture is the most rapidly growing food production sector, but modern aquaculture has a short history, of about 40–50 years. Many aquatic species are farmed (541 are reported in FAO production statistics) and others are being tested on a pilot-scale level; several are becoming major global aquaculture species, while some have fallen out of use. Among the dominant fish groups in world aquaculture are the tilapias and carps, which are mostly farmed in tropical and subtropical regions. Catfishes have also seen rapid recent growth in production. Seaweeds, clams and oysters are dominant groups in tropical marine aquaculture.

Several biotechnologies have been developed that have potential to assist genetic improvement and resource use efficiency in aquaculture. These include: chromosome set and sex ratio manipulation to overcome problems with differential growth of the sexes, early maturation and reproduction before harvest; DNA markers, linkage mapping and QTLs are useful in tracking pedigree and identifying genetically superior individuals; cryopreservation can assist with gene banking, storage and transport, and assessing genetic gain; and genetic modification allows for targeted genetic improvement based on the function of specific genes.

The first group (chromosome set and sex ratio manipulation) are appropriate for species-specific problems rather than having generic application for long-term genetic improvement. Thus, there is very little need for such techniques in most large carp species, which reach harvest size before maturation and show relatively little sexual dimorphism at this stage. However, in tilapias, the second ranking group in world aquaculture by production volume, maturation and reproduction before harvest constitute significant problems in most farming environments. Energy is wasted in reproduction and the resultant fry compete with the originally stocked fish, leading to wasted resources and reduced market prices due to lower harvest sizes.

The most commonly used way to overcome this is by dietary treatment of fry with 17 α -methyltestosterone, although this is banned in some countries. Triploidy, induced through the application of pressure or temperature shocks to newly fertilized eggs, renders most females sterile and prevents males from producing functional sperm, and has been shown to result in increased yields in experimental trials. However, it is not feasible to use this in commercial tilapia hatcheries due to their reproductive biology: females spawn small batches of eggs frequently and asynchronously, making it impossible to obtain large quantities of unfertilized eggs to induce



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triploidy. The production of genetically male tilapia (from crosses between YY males and XX females) has been commercialized on a small scale, but the management of this is complex, partly due to several generations of breeding to produce large numbers of YY males and partly due to the complexity of sex determination in tilapia. The recent discovery of a master sex-determining gene (*amhy*) may help to overcome these problems through the application of marker-assisted selection (MAS). Other species in which these techniques have potential include the African catfish (triploidy to reduce female egg mass at harvest), giant freshwater prawn (all-male production to take advantage of faster growth rate) and oysters (triploidy to reduce maturation and allow all-year marketing).

The second group (DNA markers, linkage mapping and QTLs) is linked to the rapidly developing science of genomics. The genomes of several important aquaculture species (including the Nile tilapia) have been sequenced in the last few years, and more are underway. Polymorphic DNA markers (microsatellites and, more recently, SNPs) have been used in studying the structure of the wild populations of many species (aquaculture still relies on wild fish as broodstock and in some cases for juveniles), for parentage assignment (can be achieved from communally reared mixed families, particularly important in mass spawning species and also to allow communal rearing of families in breeding programmes to reduce environmental effects on selected traits), and in the development of QTL mapping and MAS in aquaculture species. While high-value, high-latitude species have led the way in the application of such techniques (the first QTL to be applied in commercial breeding programmes in aquaculture was one for resistance to infectious pancreatic necrosis, a viral disease of Atlantic salmon; this only happened a few years ago), the potential for the application of DNA markers and MAS in tropical aquaculture species is there and starting to be realized.



Unlike mammals and many plants, gene banking in fish is currently only possible for sperm. The inability to cryopreserve eggs and/or embryos is a serious limitation. However, sperm cryopreservation has been used for gene banking at the start of several breeding programmes as a tool in assessing genetic gain (progeny from the current generation of selection can be compared with crosses between eggs from current generation females and cryopreserved sperm from earlier generation males), and as a way of transferring genetic material between aquaculture programmes. Cryopreservation has not, however, found large-scale use in routine seed production.

Genetic modification in fish was first achieved in the 1980s in China, but progress towards use in aquaculture has been limited due to the negative image of GM animals for consumption. Recently, the United States Food and Drug Administration (FDA) approved a long-running application by AquaBounty for Atlantic salmon with modified growth hormone expression. These fish are produced in a hatchery in Canada and currently grown on in tanks in Panama to reduce the risk of impact from accidental escapes. This case may act as watershed for other potential applications, although public acceptance remains in doubt and is likely to vary from country to country. These GM fish were produced by microinjection of many copies of the DNA construct into fertilized eggs, with random integration of a very low proportion, often creating mosaic insertion patterns. The recent emergence of highly targeted gene editing offers the potential for more accurate genetic modification, which is now being realized at an experimental level.

Although the current impact of biotechnology in genetic improvement in tropical aquaculture is limited, the increasing level of application in temperate aquaculture, the development of breeding programmes for tropical species, current research on tropical aquatic species and the decreasing costs of sequencing and genotyping all indicate increasing impact on production. As will be outlined in the presentation, it is to be expected that this will improve the efficiency of resource use.

4.2.5 Resource use efficiency in livestock: Bridging the biotechnology–livestock productivity gap in East Africa

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Introduction

Africa's indigenous cattle populations are the backbone of the continent's livestock industry, providing sources of income, nutrition and livelihoods to millions of people in marginal areas. However, unit productivity of these animals lags behind most other regions of the world. Recent studies predict significant contraction of mixed farming systems, which represent the majority of food producers in sub-Saharan Africa. Changes in the growing length, disease vector habitat as well as water distribution and availability, require that sustainable intensification of livestock productivity be given priority.

Biotechnology, and specifically genetic improvement, can play a significant role in increasing productivity of livestock in Africa. There is a wealth of information and tools available for such improvement, but they have been poorly utilized for most livestock species because of lack of infrastructure, high initial investment and the long time required for impacts to be made. We present three case studies that illustrate our efforts in applying genetic tools in improving livestock productivity in Africa.

Identification of appropriate cross-breeding levels for smallholder dairy enterprises

The use of cross-bred animals continues to be the basis of most dairy enterprises in Eastern Africa. However, the indiscriminate cross-breeding practised in these systems produces highly admixed animals resulting in huge differences in productivity. Additionally, since the breed composition is unknown, there is often a mismatch between production environment and animal breed type, a situation which cannot sustain the growth and expansion of the local dairy sector.

We have recently applied SNP markers in order to match breed composition with production environment for smallholder dairy cows. The results indicate that there is an optimal level for cross-breeding beyond which increased upgrading to exotic breeds does not result in additional yields. In high-input smallholder production systems, higher grade exotic breeds would be ideal to maximize returns. However, for mid- and lower-input systems, high grade cross-breds do not perform any different from lower grade crosses. In these systems, the overriding considerations would



be the percentage of exotic genes that an animal harbours, which needs to be balanced against the unfavourable effects of lower survival and higher disease incidence.

There are opportunities to identify bulls that sire more adapted offspring that produce higher yields. We intend to develop genomic tools that allow mass profiling of animals to identify and propagate tropically adapted high-yielding cows.

Unveiling the genetic basis of African swine fever virus tolerance

Diseases are responsible for enormous productivity losses in Africa. In hotspots where several livestock and zoonotic diseases are endemic, the net effect of disease can be very large, especially when disease control systems are poor. African swine fever (ASF) is a viral hemorrhagic disease of pigs (*Sus scrofa*) that results in complete mortality of infected animals. The disease is endemic in Africa and Sardinia where it is largely restricted. Spread of the disease into major pork producing regions of the world could lead to massive losses to farmers. There is anecdotal evidence that indigenous pigs in Africa are less susceptible to African swine fever virus (ASFv) infection compared to improved international breeds. Apparently healthy pigs have tested positive for the virus or viral antibodies, without clinical symptoms of the disease. However, the determinants of this tolerance are not known.

We used genome-wide SNP markers to investigate the genomic structure of indigenous and improved international breeds in comparison with wild pigs. Wild pigs are resistant to ASF. Results indicate that village pigs that tested negative for ASFv have significantly higher indigenous (“African”) ancestry (54 percent and above) compared with those testing positive, which had higher proportions of international commercial breeds. This has significant implications in disease surveillance and diagnosis of infection status. A genome-wide scan detected several regions having signals that indicate preferential selection for genes within those regions. These results point to a possible underlying genetic control to ASF tolerance.

Understanding of the genetic basis for ASFv tolerance will be a great boost in the management of ASF.

Harnessing fecundity in goats

Goats play an important role as a source of meat and income for large numbers of African families. The biology of the goat, particularly its small size (10–80 kg), short generation interval (15 months), prolificacy (up to five live births possible) and short age to market makes it a very attractive prospect for many households, and especially for women and youth. Owing to it being one of the hardiest animals adapted to a host of harsh environments, the goat has been integrated into the social fabric of Africa. The goat’s dominance and distribution is testament to the high regard it receives.

The specific genes underlying the capacity of the goat to adapt easily to diverse agroecologies are poorly understood. Current efforts are trying to reverse this lack of knowledge, and activities targeting genomics of disease and adaptation are already underway. One of the research projects underway is looking at improved fecundity in goats. Given the nature of goat production systems, reproduction equals production. Success of the enterprise depends on the number of kids raised, weaned and sold.

West African dwarf goats are extremely fecund. Super does that produce multiple kids have been observed, with twins and triplets being quite common. We are studying the genetic determinants underlying this trait with the aim of increasing the utility of high prolificacy. We intend to produce a marker panel applicable in a MAS framework to identify bucks that sire does that produce more triplets and quadruplets. Access to highly-fecund super does will not only increase incomes for families, but also improve household nutritional status.

Conclusion

Despite the promise that biotechnology presents, there are still many challenges to be contended with, including the high cost of genomic tools, marker systems that are biased towards exotic breeds and the lack of phenotypes to aid in associating performance in smallholder systems with genomic determinants. These limit the application, utility and potential benefits accruable from the use of genomic tools.



4.2.6 Resource use efficiency in forestry: Utilization of tree genetic resources

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What is different about trees?

Among the 80 000 or more species of trees, thousands are important for livelihoods, and for food, fuel, construction, fodder, medicine and other purposes. Tree species differ from agricultural crops in obvious and less obvious ways that affect the use and management of their genetic resources. Trees are large, long-lived organisms that are late maturing, highly diverse and still mostly undomesticated. Gene flow occurs over long distances and trees may produce millions of seeds throughout their lifetime. In addition, they are often managed in some form of the commons; on public land or in community forests.

Table 1. Evolutionary advantages and drawbacks of the tree growth form (from Petit and Hampe, 2006)

Advantage	Drawback
Great potential of biomass gain	High maintenance costs
High competition after successful establishment	Extremely high recruit mortality
Endurance to short-term resource depletion	Increased vulnerability to catastrophic events
Great lifetime fecundity	Delayed maturity
Little dependence on particular reproductive events	Trade-off between present reproductive output and future growth, survival and reproduction
Large pollen and seed production and release height facilitate gene dispersal	Low plant density complicates mating and increases pollen limitation
Local adaptation favoured by strong selection during early life stages	Local adaptation hindered by high gene flow
Low accumulation of mutations per unit of time	Increased mutation rate per generation
Strong inbreeding depression increases outcrossing rate and maintains genetic diversity	Lifelong accumulation of somatic mutations results in susceptibility to inbreeding depression

Tree species make direct contributions to food and nutritional security; for example if 11–13 food-producing tree species were cultivated on each farm in East Africa, a constant supply of vitamins A and C could be assured, including the period known as the hunger gap between harvests of agricultural crops.

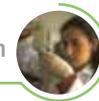
At the global scale, forestry investments are increasing; \$US80 billion worth of forestry investments were made in 2014 and investments are predicted to continue to rise with increasing returns. In part, this is driven by the need to tackle climate change and deforestation. Investors are not philanthropists, however; they must see returns, and some of the highest returns are such as those described by the Brazilian company, Fibria which is the biggest producer of Eucalyptus pulp. Using the latest biotechnologies, after four generations of cloned genetically improved Eucalyptus, pulp productivity has almost doubled and it continues to increase.

Biotechnology has many applications for trees, including the use of genetically modified *Populus* spp. in China, the increasing possibilities posed by genomic selection, sequencing entire genomes and resequencing, mass production of clones, application of molecular tools for management and improving returns on planting by choosing the right tree for the right place.

Taking advantage of the increasing availability of gene technologies for trees, the African Orphan Crops Consortium (AOCC) was conceptualized in 2010–2011 as “an uncommon public–private partnership under the leadership of Mars, the World Agroforestry Centre (ICRAF), the University of California, Davis (UCD) and the New Partnership for Africa’s Development (NEPAD)”. The vision of AOCC is “to improve the nutritional content, productivity and climatic adaptability of some of Africa’s most important food crops (including 47 tree species); providing a fundamental step in helping to eradicate chronic hunger, malnutrition and stunting in the children of Africa”, and it has been endorsed by African Heads of State at an African Union Assembly. ICRAF hosts the AOCC’s Genomics Laboratory and the African Plant Breeding Academy where 250 plant breeders will be trained over a five-year period.

A large number of orphan crops in Africa are under study, including several tree species. Genomes for 24 out of 101 species of African orphan crops, including baobab, are already being sequenced by the Beijing Genomics Institute. The ultimate aim is to use the genomic information to improve productivity and nutritional value. For example, just 20 grams of baobab fruit pulp provides twice the amount of calcium as spinach, three times the vitamin C of oranges and four times more potassium than bananas. Increasing production of baobab could significantly improve nutritional outcomes for many people. Twelve of the orphan crop species are undergoing resequencing.

Allanblackia is an important tree genus in Africa; oil from nine species has been used for centuries for cooking and medicine. ICRAF and partners conduct research on these species to establish supply chains and domesticate promising species and genotypes, aiming to reduce the time to fruiting and increase production of oil which is ideal for margarine. In September 2014, Becel Gold margarine, containing *Allanblackia* went on sale in Sweden. More than 10 000 farmers have planted *Allanblackia* with support from 15 rural resource centres that provide training and seedlings. About 250 local buyers provide a link with harvesters and local supply chains operate in the three countries.



Public–private partnerships (PPPs) have been and will continue to be crucial to allow *Allanblackia* to reach its full potential. In agroforestry research, PPPs are not always easy because of differing cultures and expectations between scientists, farmers and investors.

Genetic technologies are also employed in forest management and restoration. Studies carried out by Bioversity International scientists examine how selective logging affects genetic diversity and viability of populations of high value timber species using molecular markers. If tree density is reduced too much by logging, inbreeding increases, reducing seed viability and regeneration success. Genetic diversity may decrease, reducing the evolutionary potential for adaptation to changing conditions. For example, in the Maya Biosphere Reserve in Guatemala harvesting mahogany in community forests significantly increases incomes for members, often making the difference between subsisting below the official poverty and escaping poverty. The community forestry managers must demonstrate that harvesting operations are sustainable as a condition for maintaining their rights to the forest and molecular markers are employed for this purpose. Likewise, a study in the Congo Basin was designed to determine whether harvesting practices in high value hardwood concessions are sustainable; results showed that species vary in their population viability at low densities.

Both ICRAF and Bioversity are working on tools to help choose the right species and right seed source within species for planting. This is particularly urgent considering the massive amounts of seed that will be required to meet the demands for restoration.

Reference

Petit, R.J. & Hampe, A. 2006. Some evolutionary consequences of being a tree. *Annu. Rev. Ecol. Evol. Syst.*, 37: 187–214.

4.3.1 **Report of the parallel session** **Post-production value addition and food safety¹⁰**

Innovation in the agricultural sector is essential for feeding a growing world population as greater amounts of food and energy are needed; climate change has also altered the way we grow crops. Concerns over food safety, health and nutrition present new challenges to our societies. The world needs innovations now more than ever as growing demands on global food production supplies require new solutions for our farmers.

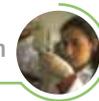
The session was organized in two sub-sessions, chaired by Sergio Feingold (INTA, Argentina) and Delia Grace (International Livestock Research Institute, Kenya) respectively. It focused on the issues arising post-harvest, which are as important as production issues, since the spoilage of food or feed (by bacteria or toxin contamination, or natural decay in the case of fruits) has serious implications, diminishing the total yield available. Moreover, these issues have a greater impact on smallholder farmers and their environment, where conditions for storability and shelf-life are often far from ideal. This is especially true for underutilized crops and tropical fruits, where market opportunities are limited by a very short shelf-life.

Addressing these issues, Cadaba Prasad presented the case of animal feed additives to add value to animal welfare and meat quality. An overview was provided on the use of biotechnology for: genomic-based knowledge of gut microbes to advance the selection of feed additives; potential combinations of prebiotics and probiotics to reduce the risk of intestinal diseases; antioxidants from microbial sources; and food additives for modifying gut bacteria for mitigating enteric methane emissions. However, more research is needed to obtain information on standardizing the preparation and delivery of microbial enzymes, probiotics and prebiotics to take full advantage of their potential for using food additives in animal feed to address animal welfare, food safety and environmental issues.

Traditional milk fermentation as a potential tool for sustainable improvement of food safety was discussed by Kohei Makita as an approach to address food-borne diseases. Staphylococcal food poisoning is one of the most common food-borne diseases in the world, and is caused by ingestion of staphylococcal enterotoxin produced in food by certain strains of *Staphylococcus aureus*. Participatory methods were used to investigate the use of fermentation and its efficacy in reducing staphylococcal poisoning. Models were then run on the information gathered. Traditional milk fermentation was found to reduce the risk of staphylococcal food poisoning by 93.7 percent in Debre Zeit, Ethiopia. The study showed the importance of supporting traditional food preparation. Indeed, complementing these methods with provision of efficient strains of fermentation bacteria would be one way to support this.

The use of diagnostic tools to detect pathogens that cause tuberculosis in cattle and prevent their transmission through dairy products to humans was presented by Flávio de Araújo. Mycobacterial species that cause tuberculosis in humans and animals belong to the *Mycobacterium tuberculosis*

¹⁰ This report was produced by the FAO rapporteurs - Arshiya Noorani, Devin Bartley and Julie Belanger



complex, including *M. bovis*. An overview of the different methods for detecting infected animals was presented, including intradermal tuberculin tests and interferon-gamma tests, using an enzyme-linked immunosorbent assay (ELISA). The increasing importance of DNA-based approaches, using polymerase chain reaction (PCR) for identification of *M. bovis* in tissue samples and milk, and sequencing the genomes of strains of *M. bovis*, was highlighted.

The session also discussed the use of biotechnologies to increase the storability and shelf-life of fruit. Eric van de Weg discussed the assessment of cultivar diversity of climacteric fruits (i.e. require ethylene for ripening, such as tomato, apple, banana, mango, peach, pears, avocado, and melon). The study showed the genetic basis for range of shelf-life and storability in apple and tomato cultivars. The huge potential that new gene editing technologies offer, in introducing changes to an ethylene gene, for example, was underlined. They may provide great opportunities for crops like mango and banana which are not easy to improve through classical breeding approaches.

Howard-Yana Shapiro discussed the need to focus on the minor crops and highlighted the work of the African Orphan Crops Consortium (AOCC), with diverse stakeholders. The AOCC is working on 101 minor crops of Africa, which are important as sources of micronutrients. The use of host-induced gene silencing for fungal pathogens could significantly reduce levels of aflatoxin contamination. He also described the many applications of gene editing using clustered, regularly interspaced, short palindromic repeats-CRISPR associated protein 9 (CRISPR-Cas9), including as a powerful technology against pathogens. He underlined the enormous potential the breakthrough technology represented.

The discussion on aflatoxins was continued by Ranajit Bandyopadhyay, who described use of the Aflasafe biocontrol product to reduce aflatoxin contamination. The approach focused on the use of native non-toxin producing strains of *Aspergillus flavus* to naturally outcompete aflatoxin-producing strains. Field testing of country-specific Aflasafe products in Burkina Faso, Kenya, Nigeria, Senegal, the Gambia and Zambia for several years has produced extremely positive results in reducing aflatoxin contamination of maize and groundnut consistently by 80 to 90 percent, and even as high as 99 percent. The biocontrol strains carry over through the value chain, discouraging contamination in storage and transport even when conditions favour fungal growth. The study showed how adapting and applying biocontrol solutions to address aflatoxin contamination in Africa could dramatically improve nutrition, health and livelihoods of millions of families while reducing commodity losses due to contamination.

Discussion summary

Discussion topics included:

- 1) Concern for targeted science for nutrition and resilience and yield. Feed additives, especially for ruminants, should be developed to address the need for decreasing GHG emissions, especially in the face of climate change.
- 2) There is a need for multistakeholder investments, such as in the AOCC to highlight the value of biotechnology to all sectors.
- 3) The shelf-life of Aflasafe, which is officially two years, and whether the non-toxic strains revert to



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- producing toxins: This is unlikely as the strains are clonal and recalcitrant.
- 4) Acceptability of genetic modification strategies and how to change public awareness that genetic modification does not equate to biotechnology.
 - One way forward would be to develop initiatives in a participatory manner, with greater dialogue and inputs needed from farmers. The dialogue between farmers and scientists needs to be iterative and continuous.
 - The fear of the new is present. Another option might be for a high-profile champion to convince the public of the safety of biotechnology.
 - The application of the precautionary principle exists but is not applied uniformly, for example to vaccines, rennet, wine yeast and medicine.
 - Need to highlight evidence-based results.
 - There is a need to also dissociate the commercial aspects of biotechnology from the technical aspects.
 - 5) What is the greatest challenge to getting biotechnology to smallholders?
 - The obstacles are often affecting change in policy and regulation, which can in turn be linked to other sectors such as international trade.
 - The knowledge gap is a major challenge. Scientists are not aware of alternative, often traditional, methods to reduce risks of contamination. Greater dialogue is needed among the policy-makers, researchers and smallholder farmers to promote exchange of information.
 - Another challenge concerns the formal versus informal production sectors. Regulation and technology transfer are often effective in the formal sector but many smallholder farmers are within the informal sector. Thus, there is a need to affect change through dialogue with policy-makers to promote awareness-raising and education across the board. Sensitization workshops held for regulators have been shown to be for the entire biotechnology development pathway.



- 6) The issues of food safety are problematic as they are often unseen, as in the case of the presence of aflatoxins.
 - Integration of various practices is essential and creating incentives for change are also needed through policy innovation. Linked to that is how to reach smallholders. Public interventions are necessary. For example, in Kenya the government funded initiatives in raising awareness of aflatoxin poisoning. Private sector interventions in Senegal were also effective.
 - Therefore, it must be borne in mind that no one size fits all.
- 7) There is a need for incentives (in terms of costs and benefits) for smallholder farms to increase the uptake of biotechnologies. When farmers are actually shown the benefits of biotechnological approaches, there have been major success stories and high levels of uptake.

4.3.2 Use of feed additives generated through fermentation technologies for livestock feed

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The primary aim of the livestock industry is to produce safe and high-quality animal products after due consideration of consumer awareness, public health, ethical issues and the environment. Feed additives occupy a significant niche amongst the list of scientific interventions that guide the enhancement of livestock production for augmenting the growing demands for animal products by the global population. However, application of some of those feed additives, such as antibiotics, raises grave concerns for both the animal industry as well as public health. As a result, several countries have already imposed bans on the addition of antibiotics to feed. This emphasizes the need to develop alternative strategies to enhance nutrient availability for achieving higher productivity and/or quality. Evidently, feed additives sourced through fermentation technologies seem to be the front runner to cater for the new and emerging challenges of the livestock sector.

Put simply, feed additives are defined as non-nutritive ingredients that stimulate selectively the growth or enhance the performances (quality/quantity) of animals through improvement of nutrient utilization and uptake. Presently, feed additives are also advocated for maintaining the health of animals. The use of feed additives is much greater in poultry and pig production than in ruminants. One of the simpler ways of producing feed additives is through microbial fermentation. The feed additives generated through microbial fermentation technologies can be classified broadly into prebiotics, probiotics, enzymes, yeast embedded minerals and amino acids.

Prebiotics

Prebiotics are non-digestible bio-active molecules that affect the host beneficially by stimulating selectively the growth and/or activity of one or a limited number of bacteria in the gastrointestinal tract of an animal. Although, most feed additives target only one or a limited number of functions, prebiotics target a range of different physiological functions such as increase in gut health, mineral absorption, immune stimulation and pathogen exclusion, and reduced cholesterol. Commercially available prebiotics are inulin, fructo-oligosaccharides, galacto-oligosaccharides, mannan-oligosaccharides, xylo-oligosaccharides etc.

Supplementation using prebiotics in the diets of poultry and swine enhance the population of beneficial gut microflora followed by decreasing pathogenic microflora in addition to improving mineral absorption, immunity and growth performance. As the demand for prebiotics is increasing, researchers around the world are enriching the “nutraceutical basket” with newer ones, and attempts to use agricultural residues like straws, coconut husk and grasses for production of prebiotics are gaining importance.



Probiotics

A probiotic is defined as “a live micro-organism which, when administered in adequate amounts, confers a health benefit on the host”. The beneficial effects of probiotics are manifested by regulation of intestinal microbial homeostasis, stabilization of the gastrointestinal barrier function, secretion of bacteriocin and immuno-modulatory effects. The probiotic organism may originate either from prokaryotic (bacteria) or eukaryotic (yeast) cells. The bacterial probiotics are *Lactobacillus*, *Enterococcus*, *Bacillus*, *Streptococcus* spp., among others. In the eukaryotic class of probiotics, the important genera are *Saccharomyces*, *Kluyveromyces* and *Aspergillus*. Among the several species of yeasts, *Saccharomyces boulardii* is a commonly used probiotic in both ruminant and non-ruminant species. Administration of a *Lactobacillus*-based probiotic reduced the population of *Salmonella enteridis* in challenged broiler chicks. Daily dosing of piglets with *Enterococcus faecium* as a probiotic supplement reduced the incidence of diarrhoea and improved daily weight gains.

Enzymes

The rearing of animals and the use of enzymes have been distinct parts of human life for many thousands of years but it is only recently that their use is increasing due to drastic reductions in the costs of enzyme production. The major enzymes that are being used in animal feeds are classified broadly into four categories namely: 1) fibre-degrading enzymes; 2) protein-degrading enzymes; 3) starch-degrading enzymes; and 4) phytic acid-degrading enzymes. As the name implies, each enzyme can act specifically on a particular substrate and ensure benefits to the animals either by unlocking the energy, by releasing amino acids, by complementing the animal's own enzyme activities or by releasing nutrients from unbreakable linkages such as phosphorus from phytate using phytase. Phytate removal by phytase also enhances the availability of minerals to animals.

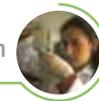
Yeast embedded micronutrients

Chromium (Cr) and selenium (Se) have been found to be essential for ruminants as well as monogastrics due to their anti-oxidation properties. They also improve immunity and reduce thermal stress. However, inorganic forms of these minerals are less bio-available and use of organic Cr and Se in the form of Cr-yeast and Se-yeast is being extensively studied due to their enhanced bio-availability. Cr-yeast has been found to both improve immunity and also reduce cholesterol content in eggs. Se-yeast supplementation in poultry during peak summer temperatures reduced the ill-effects of thermal stress and improved the anti-oxidant status.

Amino acid production through fermentation

Inefficient utilization of absorbed protein in ruminants and monogastrics can lead to high nitrogen losses. Matching the animal's dietary amino acid levels with their biological needs minimizes nitrogen excretion to the environment. Providing the essential amino acids (lysine, methionine, threonine, glutamic acid) would help in reducing the protein content in the feed leading to better utilization of nutrients, less wastage of nitrogen and reduced feeding cost.

Use of feed additives is limited in smallholder ruminant production systems because their effects are not consistent. Also, high cost prohibits their use. However, their use in smallholder poultry and pig production system is higher. Future research to understand better the conditions under which they produce consistent, long-term and greater effects would enhance their use in animal diets.



4.3.3 Use of biotechnologies to increase the storability and shelf-life of fruit

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Storability and shelf-life are major determinants of the economic value of fruit and determine the risk for loss of produce due to decay. Extended storability and shelf-life supports the delivery and consumption of high-quality fruit during a longer time period, thus improving market prices (avoiding dumping prices due to over-supply), food availability, income, job opportunities and economic sustainability, especially of small producers.

Improved storability and shelf-life have been successfully addressed through the breeding of new, well-adapted cultivars in a series of crops following classical breeding approaches. New biotechnology techniques that recently came available may further accelerate the coming availability of new cultivars, especially for tropical crops for which little breeding activity is currently ongoing.

For the application of biotechnology in breeding, especially climacteric fruit may have potential. In climacteric fruit, ripening is accompanied by a burst of ethylene production and respiration. The ethylene produced stimulates ripening. Being a gas, ethylene from a ripe fruit can also stimulate the ripening of other (unripe) fruit (e.g. at the household level, a ripe banana may be wrapped together with unripe mangoes). Tomatoes, apples, bananas, mangoes, peaches, avocados and melons, among others, are climacteric. Non-climacteric fruit like citrus, grapes, watermelons and strawberries do not produce ethylene and respiration bursts and do not need ethylene for ripening.

In view of storability, shelf-life and transport over long distances to, for example, export markets, climacteric fruit is harvested unripe: the earlier harvested, the better the storability. Later, close to the point of sale, ripening is forced by the external application of ethylene. This is common practice for crops like banana, mango and avocado. However, the early harvesting of unripe fruit has negative effects on flavour attributes including texture, juiciness, sweetness and aroma. When harvested too unripe, the fruit will never become as tasty as a tree-ripened fruit.

Thanks to breeding and biotechnology, the shelf-life of tomatoes has been extended from seven days to more than a month. Freshly-picked apples have a shelf-life of 2–4 weeks, depending on the cultivar. Apples can be stored for another two weeks and up to four months under temperature-controlled conditions, and even for up to 13 months when the atmosphere in the cold room is also controlled (low oxygen, high CO₂). This variation in storability results from variation in the genetic composition of cultivars. More precisely, it is based on natural variants of a very limited number of genes that are

involved in ethylene production or the ethylene perception pathway, or in the production of specific cell wall-degrading enzymes. In tomato, natural variants of three specific genes are involved. The taste of tomato is “repaired” by enhancing other taste-related pathways. In apple, seven such genes are involved which slow down ripening without compromising on taste.

Classical breeding approaches include the search for the desired trait in wild germplasm or raising the desired trait by the creation of gene variations through, for instance, radiation. Next, these new sources are used in crosses to raise new progenies, the best of which are selected and released as cultivars. Through time, diagnostic molecular markers have been developed to support breeding: these allow the desired trait to be traced more efficiently in the progenies.

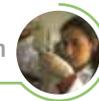
Classical genetic modification approaches have led to the approval of a limited number of GM cultivars in melon and tomato which target storability and shelf-life. They were introduced between 1992 and 1999 and none of them are on the market anymore. Besides lack of public acceptance, the techniques of that time were still crude so that too many other traits may have been affected negatively. Other fruit crops for which GM cultivars have been approved are apple (2015), eggplant (2013), plum (2007) and papaya (1998), all of which except plum are in commercial production. That of plum is held in stock deliberately until an outbreak of plum pox virus shows up in the United States of America.

Recently, new biotechnologies have been developed that are now turning out to be true game changers. They allow removal or change of just a few nucleotides of a gene in a very precise way. Such minor changes in an ethylene gene, for example, may have major effects on ethylene production and hence on storability and transportability, especially when applied on the promotor region of such a gene. This is because each promotor region has several on/off switches that determine the activity of the gene in a tissue and in a time-specific manner. In principle, this would make it possible to hamper or delay the production of ethylene in only that fruit which is close to maturation. At that time, the fruit is not only sensitive to external ethylene applications, but is also ready to produce all the specific components that give it its delicious taste. Moreover, in the near future, modifications brought about through this new procedure may not fall under GM regulation.

These technologies may offer great opportunities for crops like mango and banana which are not easy to improve through classical breeding approaches. Small-scale growers may be the first to benefit through immediately extended periods of sale, whereas large-scale export production will follow when production volumes allow this. Still, it may take 15–20 years from application to marketable fruit because of the various successive stages in production that have to be passed, from the actual application of this technology (years 1–3), to the cultivation of small *in vitro* plantlets to fruit-producing trees (years 3–6), selection of the best performing new plants (years 6–8), multiplication of the few initial copies of these best plants to 10 000s of trees, completion of the intellectual property and admission procedures (years 9–12), plantation of orchards (year 13) and first production of fruit (year 15). An excellent overview on new biotechnology and breeding techniques can be found in Schaart *et al.* (2015).

Reference

Schaart, J., Riemens, M., van de Wiel, C., Lotz, B. & Smulders, R. 2015. *Opportunities of new plant breeding techniques* [brochure]. Wageningen. (available at <http://edepot.wur.nl/357723>).



4.3.4 The promise of biotechnology tools to help control mycotoxins, especially aflatoxins

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Mycotoxins represent an ongoing threat to global food safety and security. Aflatoxins are a common food contaminant representing 20 chemically-related toxins produced by *Aspergillus flavus* and *Aspergillus parasiticus*. Twenty-five percent of food crops are contaminated by aflatoxin, exposing 4.5 billion people annually. The greatest impact is on the impoverished, malnourished and young. Although a global problem, sub-Saharan Africa has the greatest prevalence of mycotoxin-related health issues – premature deaths in women, stunting in children and a high prevalence of liver cancers. Mycotoxins appear to have a greater impact on those who are immune-compromised and may contribute to a worsening of this compromise. The impact of chronic low-level exposure has not been well documented. In the United States of America, food limits are 0.5 micrograms per kilogram.

Sixty percent of agriculture is produced by smallholder farmers who represent five out of six producers. Of those smallholders, most are struggling economically and half are women. Mycotoxin contamination threatens the food supply, reduces the amount of available food product and degrades its value. Estimates place food loss and waste at about 1.3 billion tons annually with 40 percent occurring in developing countries at post-harvest and processing. Mycotoxins, in particular aflatoxins, are present in many raw materials and are not destroyed by normal food processing.

Industry focus for controlling mycotoxins has been directed: 1) at the field level, with interventions such as improved agricultural practices, better crop varieties and specific treatments during production to control fungal growth and insects; 2) at harvest, by controlling moisture content, assuring crop maturity and reducing plant diseases; 3) at and during storage, by controlling temperature, moisture and insects, improving sampling methods and increased training of personnel to detect contamination; and 4) at and during manufacture, by maintaining clean and sanitized equipment, controlling process temperatures and humidity and improved processing of raw products. With the information available, little progress has been made beyond the rejection of raw materials and refusal to utilize contaminated raw products in human foods or animal feeds. Aflatoxin production is dependent on temperature, moisture, pH, low oxygen, high CO₂, and oxidatively-damaged lipids and available sugars.

New methods for controlling mycotoxins, and specifically aflatoxins, need development. Progress in the areas of gene editing, mechanisms of innate plant immunity, and specific applications of RNA

interference (RNAi) concepts provide an opportunity to approach the problem at an earlier point of production in the field. Definitions of RNAi and other biotechnology-related terms used in this summary are provided in Gaj, Gersbach and Barbas (2013).

Since the first reports of RNAi in 1998, a new understanding of how cells modulate gene expression using RNA has created numerous opportunities for modulating the host-pathogen relationship (Fire *et al.*, 1998). A number of naturally occurring systems have been identified that utilize RNAi as a basis for controlling gene expression in both plants and animals. Dicer, an endonuclease, cleaves double stranded RNAs (dsRNA) into small interfering RNAs (siRNA) and microRNAs which induce the RNA-induced gene silencing complex (RISC) and is essential for the induction of innate immunity in plants (R resistance) (Bernstein *et al.*, 2001; Baker *et al.*, 1997; Fang *et al.*, 2011). CRISPR/Cas9 controls the expression of plasmids and phage genes in microbes; CRISPR processes DNA and forms microRNAs through transcription to use siRNAs to control the expression of these newly introduced genes (Ishino *et al.*, 1987; Marrafini and Sontheimer, 2010). P-element induced wimpy (PIWI) testis silences transposons in eukaryotic stem cells by detecting and eliminating dsRNA (Cox *et al.*, 1998; Saito *et al.*, 2006).

A number of additional pathways use similar mechanisms ultimately for gene silencing. RISC represents a variety of systems that are triggered by dsRNAs and which are fragmented subsequently into short nucleotide sequences (10–20 nucleotides) and complexed with the Argonaute protein allowing for the identification of complimentary RNA transcripts, initiating the gene silencing process. Gene silencing occurs by blocking translation and stopping protein synthesis, degrading targeted mRNA, altering the reading frame or by degrading DNA (Hsu, Lander and Zhang, 2014).

Recently, guide RNAs that target specific complimentary sequences have been produced providing new methods for utilizing CRISPR/Cas9 and Argonaute protein within an organism through RNA-guided DNA endonucleases. Advances using zinc finger nucleases (ZFNs) and transcription activator-like effector nucleases (TALEN) are providing gene identification and sequence-specific DNA binding modules that are coupled to a non-specific DNA cleavage domain allowing gene editing and silencing. DNA cleavage may be double-stranded or single-stranded depending on the endonuclease (Gaj, Gersbach and Barbas, 2013).

A number of research teams have been working with RNAi systems to control host-pathogen interactions. Host-induced gene silencing (HIGS) has been used in a variety of leaf and grain crops to limit damage from fungal diseases, nematodes and insects. Several studies seek to inhibit specific pathogens. Transgenic plant varieties have been developed that produce siRNAs that target specific gene sequences unique to a specific pathogen's survival. The host produces the siRNA, which is taken up by the pathogen with the silencing of essential genes within the pathogen with no impact on the host. Demonstration studies have been conducted in lettuce against downy mildew, *Bremia lactucae*. In this study, two genes in the pathogen were successfully inhibited resulting in a significant reduction in fungal growth and sporulation (Govindarajulu *et al.*, 2015). Another recent study demonstrated the induction of resistance to *Fusarium* in Arabidopsis and barley using the dsRNA directed at the three gene forms of cytochrome P450 lanosterol C14 alpha demethylase (Koch *et al.*, 2013). Similar early demonstrations have been published indicating the effectiveness of RNAi on insects (Huvenne and Smaghe, 2010). The control of nematodes is also feasible using RNAi silencing (Huang *et al.*, 2006).



These studies clearly demonstrate a maturing area of science where toxin production by contaminating fungi can be controlled in food crops, improving the amount of food produced and safely consumed. Populations in the developing world will have significant health benefits in those who are in greatest need of relief.

HIGS is an emerging mechanism that needs development in the area of mycotoxin production and control. Focused studies on the potential of gene silencing of the twelve genes associated with toxin production in *Aspergillus flavus* are required if better food safety is to become a global reality. The morbidity and mortality of aflatoxicosis justifies the development of a progressive research programme to reduce mycotoxin contamination to near zero in the next 10 years. Motivation, not the maturity of the science or technology, seems the current limitation in mycotoxin eradication.

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4.3.5 Traditional milk fermentation as a potential tool for sustainable improvement of food safety

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Every year, 1.5 million people die due to diarrhoea, and animal-source foods are an important source of food-borne diseases (FBDs). FBDs include non-diarrhoeal serious zoonoses such as brucellosis and tuberculosis. A large proportion of FBDs occur in developing countries where informal markets dominate in the food supply and improvement of food safety through implementation of public services is a challenge in these settings. The objectives of the study were two-fold: to prove that participatory risk assessment can be applied to informally marketed foods; and to assess the risk of staphylococcal poisoning through consumption of raw milk and home-made yoghurt in Debre Zeit, Ethiopia.

Staphylococcal food poisoning is one of the most common FBDs in the world, and is caused by ingestion of staphylococcal enterotoxin (SE) produced in food by certain strains of *Staphylococcus aureus*. *S. aureus* starts producing enterotoxin in milk when the population density reaches about $10^{6.5}$ colony-forming units per millilitre (CFU/ml) of milk and thereafter the amount of SE increases linearly with time. A small amount of SE, 100–200 ng, can cause illness. Intoxication is characterized by the sudden onset of nausea, vomiting, abdominal cramps and diarrhoea. The optimum pH for *S. aureus* growth is 7 and the minimum pH is reported to be 4.9. In this summary, contribution of traditional milk fermentation to food safety found by the risk assessment is described.

The study sites were urban and peri-urban areas of Debre Zeit, Ethiopia. Rapid urban appraisals were combined with conventional interviews to identify and quantify formal and informal milk value chains and to collect information on consumers' food preparation and consumption behaviour. Milk was sampled in 170 dairy farms and five milk collection centres and microbiological tests were conducted. Published data on milk fermentation in Ethiopia were used to estimate the time when pH became lower than 4.9 after milking, to model the stop of growth of *S. aureus*. A published mathematical growth model of *S. aureus* was used to model the competition between SE production by *S. aureus* reaching $10^{6.5}$ CFU/ml, and stop of bacterial growth due to traditional milk fermentation reaching low pH values. The growth of *S. aureus* was dependent on the initial bacterial population in milk, temperature (storage of milk in room or refrigerator) and length of storage time before milk consumption. A system from production to consumption was stochastically modelled in @Risk, and Monte Carlo simulation was run for 10 000 iterations. Sensitivity analysis for all the uncertainty



parameters was run for 1 000 iterations.

Prevalence of *S. aureus* in five milk collection centres (72 percent, 18/25) was significantly higher than in bulk milk samples at dairy farms (43.5 percent, 74/170, $\chi^2 = 5.99$, $df = 1$, $p = 0.014$). No dairy farmers boiled milk for sale. Consumption of raw or fermented milk was common and there was no significant difference in the probability of boiling between farmers (68.2 percent, 116/170) and consumers (64.0 percent, 16/25, $\chi^2 = 0.038$, $df = 1$, $p = 0.85$). The annual incidence rate of staphylococcal poisoning was estimated to be 20.0 (90 percent CI: 13.9–26.9) per 1 000 people. When the effect of fermentation was removed from the model, the annual incidence rate increased to 315.8 (90 percent CI: 224.3–422.9) per 1 000 people, showing the importance of traditional food preparation methods in risk mitigation; traditional milk fermentation reduced the risk of staphylococcal food poisoning by 93.7 percent. Sensitivity analysis found two very sensitive factors: the initial population of *S. aureus* and the storage temperature of milk.

Improving the safety of milk and dairy products could be achieved through supporting appropriate traditional food preparation and consumption where an industrial risk mitigation system is not feasible. For example, provision of good strains of fermentation bacteria to farmers and consumers can be a highly effective and sustainable intervention for improving food safety. In industrialized settings, communication to avoid mixed use of refrigerator and natural fermentation of raw milk may be necessary. Improvement of milk hygiene was another important factor to reduce illness.

4.3.6 Aflasafe: A case study for aflatoxin reduction in crops

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Food quality and safety issues resulting from aflatoxin contamination are significant obstacles for improving nutrition and agricultural production while linking smallholder farmers to markets. Aflatoxin exposure is frequent and widespread in most African countries where the key staples maize and groundnuts are particularly vulnerable to aflatoxin contamination. Aflatoxin poses a significant public health risk in many tropical developing countries and is also a barrier to the growth of domestic, regional and international markets for food and feed. The most documented health impact of chronic exposure to aflatoxins is liver cancer. Broader health effects such as child stunting and immune suppression with higher rates of illness have also been associated with aflatoxin exposure. Aflatoxin-contaminated feeds decrease livestock productivity. Aflatoxin contamination has also led to the destruction of hundreds of thousands of tonnes of grains, contributing to huge losses of much-needed income, food and trade with health and food security consequences.

An innovative scientific solution in the form of a natural biocontrol has been developed by USDA-ARS. This breakthrough technology, already in wide use in the United States of America, reduces aflatoxins during both crop development and post-harvest storage, and throughout the value chain. Atoxicogenic strain based biological control is a natural, non-toxic technology that utilizes the ability of native atoxicogenic (incapable of producing aflatoxins) *Aspergillus flavus* to naturally outcompete their aflatoxin-producing cousins. IITA and partners have successfully adapted this competitive displacement technology for use on maize and groundnut in various African countries using native microflora, developing biocontrol products called Aflasafe. We describe progress made with the development of biocontrol of aflatoxins in Africa, the current status and prospects for further scaling up in maize and groundnut value chains.



Field testing of country-specific Aflasafe products in Burkina Faso, Kenya, Nigeria, Senegal, the Gambia and Zambia for several years has produced extremely positive results in reducing aflatoxin contamination of maize and groundnut, consistently by 80–90 percent, and even as high as 99 percent. The biocontrol strains carry over through the value chain, discouraging contamination in storage and transport even when conditions favour fungal growth. Positive influences of atoxigenic strain applications carry over between crops and provide multiyear benefits. A single application of atoxigenic strains may benefit not only the treated crop but also rotation crops and second season crops that miss a treatment. Additionally, because fungi can spread, as the safety of fungal communities within treated fields improves so does the safety of fungal communities in areas neighbouring treated fields. The excellent efficacy of biocontrol in reducing aflatoxin in these countries has led to the expansion of the programme to other countries in East (Burundi, Rwanda, Uganda and United Republic of Tanzania), West (Ghana) and Southern (Malawi, Mozambique and Zambia) Africa.

To make the biocontrol product available to farmers and other end users, a manufacturing plant (capacity 5 tonnes/hour) has begun to produce Aflasafe in Nigeria. A small-scale modular manufacturing plant is under construction in Kenya. A model for creating sustainable market demand for Aflasafe in maize value chains is being piloted under the AgResults Aflasafe Initiative in Nigeria where farmers have purchased Aflasafe to treat about 30 000 ha of maize crop (application time: 2–3 weeks before crop flowering; application rate: 10 kg/ha; cost of product: US\$12–US\$18.75/ha). Farmer groups that treated their maize crop with Aflasafe sold grains at a 13–15 percent premium to food and feed processing industries. These farmers also retained a portion of the treated crop for home consumption thereby improving the safety of food for their families.

The Kenyan Government is providing a Kenyan Aflasafe product to smallholder farmers to treat almost 23 000 ha in aflatoxin-prone areas as a public good in public health interest and to improve marketability of maize grains. Initial results are very encouraging – all the maize harvested from several hundred ha of treated maize crops in the government's food security initiative in the Hola/Bura/Galana irrigation scheme met the stringent European Union standard (four parts per billion). A Senegalese agribusiness firm provided 20 tonnes of Aflasafe to its contract growers in 2014 and 2015 to improve the safety and marketability of groundnuts procured from the farmers.

Smallholder farmers harvest, store and consume home-grown crops. The deployment of Aflasafe can profoundly improve safety of food of smallholder farm families and reduce post-harvest losses since the technology dramatically reduces the source of contamination in the field before harvest, during storage and until maize/groundnut is consumed. Reduced crop contamination could translate into improved food security and better access to domestic, regional and international markets that pay premium for aflatoxin standard-abiding maize and groundnuts. Scaling up of biocontrol has also the potential to revitalize exports and to increase smallholder farmers' opportunities to access premium export markets where aflatoxin-safe grain is a prerequisite for trade. For realizing health and income improvements, the biocontrol technology must be scaled up to reach the various players in the maize and groundnut value chains by developing sustainable product manufacturing and delivery mechanisms. Several challenges remain for scaling up. To address these challenges, the next phase of Aflasafe development is geared towards technology transfer to the private or public sector (as per situational analysis) and commercialization of the product in 11 countries.

4.3.7 Diagnostic tools to detect pathogens causing tuberculosis in cattle and prevent their transmission through dairy products to humans

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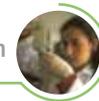
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Mycobacterial species that cause tuberculosis in humans and animals belong to the *Mycobacterium tuberculosis* complex (MTBC), including: *M. tuberculosis*, *M. africanum* and *M. canettii*, which are mainly human pathogens; *M. bovis* and *M. caprae*, which are mainly ruminant pathogens; *M. microti*, a pathogen of small rodents; *M. pinnipedii*, from marine mammals; *M. mungi*, from mongooses; and *M. orygis*, from oryx.

Members of the MTBC have been associated with food-borne transmission to humans. The consumption of contaminated raw dairy products has been recognized as a major cause of transmission of *M. bovis* to humans, generally associated with the development of extra pulmonary tuberculosis. Another MTBC species that infects man is *M. caprae*. Although the transmission to humans by raw dairy products has not been proven formally for *M. caprae*, the relatedness of the pathogens and the epidemiological settings suggest that this is probably the case.

Current bovine tuberculosis (bTB) eradication programmes are based on a screening and slaughter policy, using mainly the intradermal tuberculin test, which detects the cell-mediated immunity (CMI) to the injection of purified protein derivative (PPD), a mixture of proteins prepared after a heat treatment and lysis of *M. bovis* AN5 (bovine PPD) and *M. avium* D4ER or TB56. The single intradermal tuberculin test (SITT) and the caudal fold tuberculin test (CFTT) both use bovine tuberculin, while the comparative intradermal tuberculin test (CITT) uses both bovine and avian PPD. The CITT is used to differentiate between animals infected with *M. bovis* and those responding to bovine tuberculin as a result of exposure to other mycobacteria.

Advantages of the intradermal tuberculin tests and reasons for their wide use are low costs and low logistical demands, and a well-documented use. Limitations include difficulties in administration and interpretation of results, need for a second-step visit, low degree of standardization and imperfect test accuracy. False-negative reactions are also a concern, since infected cattle may remain in herds. In Brazil, there is strong evidence of a resurgence of bTB in accredited-free herds due to infected cattle not being responsive on CITT. Also, when results of intradermal tests are inconclusive, it is necessary to wait at least 60 days before repeating the SITT or applying a CITT. This mandatory interval requires cattle to be kept in quarantine and it increases the risk of spreading the disease to herd mates and potentially to humans.



The interferon-gamma (IFN- γ) assay also detects the CMI on tuberculosis-infected cattle. In this test, sensitized lymphocytes from infected cattle are incubated *in vitro* for 16–24 hours with PPD and the released IFN- γ is detected with a sandwich enzyme-linked immunosorbent assay (ELISA) that uses two monoclonal antibodies to bovine gamma interferon. In animals that are difficult or dangerous to handle, the advantage of the IFN- γ test over the skin test is that the animals need to be captured only once. Another advantage is that since lymphocyte stimulation is done *in vitro*, it is not necessary to wait 60–90 days to repeat the test when the initial test is inconclusive.

Bovine tuberculosis is an infection that triggers predominantly a CMI during early and intermediate phases of the infection. Therefore, the main diagnostic techniques used worldwide in eradication programmes are based on the detection of the CMI: intradermal tests and interferon-gamma (IFN- γ) assay. As the disease progresses, there is a decrease in CMI and the development of serological responses. The importance of antibodies for the diagnosis of bovine tuberculosis has been debated because of the variable sensitivity (18–73 percent) reached with serological assays in preliminary studies, although high specificity has been observed (88–96 percent)

Recent studies have re-established interest in serological assays as diagnostic tests to detect false-negative animals in the intradermal tests and the IFN- γ assay. In animals with experimental infection, the serological response has been shown to increase after performing intradermal tests (anamnestic effect), leading to an improvement of the sensitivity of these techniques. The serological response varies depending on the different antigens. The Brazilian Agricultural Research Corporation (Embrapa) has developed an ELISA for detection of *M. bovis* antibodies based on a fusion recombinant antigen with the hydrophilic domains of 6 kilodalton early secreted antigen test (ESAT-6), MPB70 and MPB83 proteins. This ELISA has been used to detect infected animals missed by the CITT.

In Brazil, the control of bTB is regulated by the Brazilian National Program for the Control and Eradication of Animal Brucellosis and Tuberculosis (PNCEBT). These regulations involve the slaughter of cattle with positive reactions to the intradermal tuberculin test (*ante-mortem* diagnosis) and the inspection of carcasses for gross lesions in abattoirs (*post-mortem* diagnosis). However, there is increasing pressure from beef markets for a definitive diagnosis of tuberculosis in cattle exhibiting lesions compatible with tuberculosis (LCT). Since 2012, the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA) determined that farms with cases of bovine/bubaline tuberculosis cannot export beef to the Customs Union of Belarus, Kazakhstan and Russia. All lots of animals from a farm with suspicious animals are sequestered and the LCT are submitted to an official laboratory for aetiological diagnosis.

The culture is considered to be the “gold standard” and definitive test for the confirmation of bovine tuberculosis. However, the microbiological diagnosis of *M. bovis* is an extremely slow procedure which may take as long as 2–3 months. An additional 2–3 weeks are required for the biochemical identification of isolates. Therefore, the need for more rapid diagnostic systems is evident. Molecular diagnostic systems, particularly those based on real-time PCR technology, are faster.

A nested-PCR technique was developed by our research group that showed a clinical sensitivity value of 76 percent with tissue samples from animals that exhibited positive results in the CITT, as well as from those with LCT that rendered positive cultures. A clinical specificity value of 100 percent was

detected with tissue samples from animals with CITT-negative results, with no visible lesions and negative cultures. Nested-PCR allowed the identification of *M. bovis* in tissues with a performance that was similar or superior to the culture. Individual results from the nested-PCR were obtained in a short period of time (two days), in contrast with the culture which took up to 90 days.

It is a priority to improve and simplify diagnosis of bTB. The excretion of mycobacteria in milk is intermittent, and up to 30 percent of infected cows eliminate it by milk. Because milk samples are very easy to collect, a new strategy based on PCR in bulk tank samples has been developed at INTA in order to detect herds infected with *M. bovis*. The touchdown (TD) modification programme of PCR was used to amplify *M. bovis* insertion sequence IS6110, since sensitivity increases significantly when compared with conventional PCR. In individual milk samples, 55 percent of PPD-positive cows were shown to be positive and 95 percent of PPD-negative cows were negative to TD-IS6110 respectively. Besides, in infected herds, 47 percent of samples were positive whereas in herds with official free-of-tuberculosis-certification (TFC), 62 percent were negative and 38 percent were positive by TD-IS6110 PCR, respectively. TD-IS6110 PCR in bulk tanks could be used as a vigilance strategy for negative skin test in herds with official TFC since the negative predictive value was 95 percent. This method has been incorporated since 2012 in the Plan of Control and Eradication of Tuberculosis of Santa Fe province, Argentina, which produces 41 percent of the total milk production of the country.

To the extent that programmes for the eradication of bTB advance, more effective genotyping techniques are required in order to trace back the remaining outbreaks. A research group which involves Embrapa Gad de Corte, INTA, Universidade Federal de Mato Grosso do Sul, LANAGRO-MG, Instituto Biológico and Universidade de São Paulo has been working on the sequencing of genomes of South American strains of *M. bovis* and comparing these with genomes from the United States of America, in conjunction with the USDA-ARS. These studies will give us a better understanding of bTB and its relationship to specific phenotypes of all strains investigated; they will also generate important data for local epidemiological studies.



4.4.1 **Report of the parallel session** **Nutrition and food quality¹¹**

This parallel session on nutrition and food quality was chaired by Margaret Gill (CGIAR Independent Science and Partnership Council, Rome, Italy). Anna Lartey set the stage by introducing the context of increasing population; changing economic conditions; climate change; current trends towards staple food production and consumption; low dietary diversity; hidden hunger and the double burden of nutrition and their impacts on human health; and the ways in which biotechnologies can be used to promote sustainable food systems. Biotechnologies can be used to enhance human nutrition by, for example, making foods more available by increasing food production and by enhancing the nutritional content of foods, or in transforming food and prolonging shelf-life through fermentation. In line with the Sustainable Development Goals agenda and the 2nd International Conference on Nutrition (ICN2), biotechnologies have to be considered to address current nutritional challenges, in collaboration with all disciplines.

In the context of population growth, climate change and increasing proportion of middle class, the application of biotechnologies, including cross-breeding, genetic transformation and genome editing, presents opportunities to improve the quality of rice and wheat. Melissa Fitzgerald reported that the demand for high-quality food (physical appearance, sensory quality and nutritional traits) would increase along with the need to develop new high-yielding varieties adapted to new climates and stresses (agronomic traits). Currently, the nutritional traits being investigated are for beta-carotene, zinc and folate in rice grains, and iron and carbohydrates with low digestibility for diabetics in both rice and wheat. One of the quality traits of rice is fragrance. Using metabolomic profiling and sensory evaluation, a number of compounds have been identified that determine the high-quality jasmine fragrance and the genetic regions (QTLs) for several of these compounds for use as markers in breeding programmes.

Howarth Bouis presented biofortification as an efficient and cost-effective solution contributing to addressing micronutrient malnutrition. Through conventional plant breeding or transgenic techniques, biofortification increases the density of minerals and vitamins in food. Challenges to the success of biofortification include ensuring acceptability and bio-availability (uptake of the nutrient across the gut). It has now been demonstrated that high mineral and vitamin traits can be combined with high yields and high profits. Peer reviewed published data demonstrate that biofortified foods improve nutritional status and reduce disease incidence and duration. Already more than 15 million people in 30 developing countries are growing and eating biofortified foods. To date, all released biofortified crops have been developed using conventional plant breeding techniques. Yet, transgenic techniques are very powerful tools for adding vitamins and minerals to food staples, as exemplified by the golden rice and transgenic iron and zinc-dense rice.

¹¹ This report was produced by the FAO rapporteurs - Julie Belanger, Arshiya Noorani and Devin Bartley

Albert Tacon presented examples of agricultural biotechnologies based on the use of micro-organisms for the improved nutrition of the aquaculture feeds used for the production of farmed aquatic species, the reduction of potential environmental impacts of aquaculture feeds and the improvement of the nutritional content of aquaculture produce for direct human consumption. He also discussed the traditional and current use of fermentation technologies for the processing and conservation of small lower-value fish within most Asian countries, including the common production of fish sauces for food seasoning as well as the more recent trend toward the fortification of farmed fish produce with supplemental nutrients for the benefit of consumers prior to harvesting.

One of the key messages from this session was that agricultural biotechnologies provide promising tools for contributing to improved nutrition and food quality. However, efforts are needed to convince consumers and influence policies in favour of their development and application. Communications must be well managed in presenting the facts, especially around food safety.

Discussion

The discussion addressed a number of interrelated key themes related to biotechnologies, nutrition and food quality.

Communication:

- Commercial information provided on certain products, such as probiotics, sometimes made it difficult for farmers and consumers to understand their real impact on nutrition.
- The perception from the crop sector that biotechnologies benefit private companies, not farmers or consumers, can negatively impact the perception of biotechnologies in other sectors. Communication is needed to show that biotechnologies can benefit consumers and farmers.
- Key terms, like biofortification, need to be defined early and clearly.
- What is the balance between safety of food derived from biotechnologies and risks represented by malnutrition?

Safety:

- Issues about safety should be discussed early in the development of the product and with all relevant groups.

Acceptability challenges:

- Regulation and potential benefits depend on the degree of acceptability and adoption of the products. If there is political opposition, costs are not likely to make it worthwhile.

Diversifying diets:

- Concerns were voiced about the replacement of dietary diversity by a few foods derived from biotechnologies.
- Diversified diets are recognized as a key solution to good nutrition.
- Foods derived from biotechnologies are part of the solution.
- Price of non-staple foods is high due to past under-investment in research. Investments in research are needed to improve productivity of non-staple foods.
- To help farmers, economic incentives would be needed to improve the profitability of growing non-staple foods.



4.4.2 Our foods, our diets, our health: Where do we go from here?

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By 2050, the world's population is expected to increase to about nine billion and this is expected to call for a 60 percent increase in food production. For developing countries where the bulk of the population growth will occur, food production needs will increase by 100 percent from current levels. Increase in cereal production will far outweigh other food crops. The production of fruits, vegetables and pulses over the past five years has increased little. While the prices of staple foods are dropping, the prices of non-staple foods such as fruits and vegetables, pulses and animal-source foods are increasing. Under the circumstance, for poor households it is cheaper to meet food needs on staple foods, even if less nutritious, than to use scarce resources on the more expensive non-staple foods.

Many developing countries are going through the nutrition transition characterized by improved economic conditions, but increased consumption of highly processed foods high in fat, sugar and salt. As economic conditions improve, many countries are moving into a state of the double burden of malnutrition – a situation where undernutrition including micronutrient deficiency co-exist with overweight and obesity. The food environment is changing globally. Access to healthy diets affordable to the majority of the population is becoming an issue. The consequence is the slow progress made in addressing malnutrition. Although significant progress has been made in reducing hunger from over one billion people affected in 1990–1992 to under 800 million in 2015, the progress made in reducing stunting and micronutrient deficiency has been slow. Micronutrient deficiency affects about 30 percent of the world's population. Anaemia, a major contributor to maternal death, affects over 500 million women of reproductive age. The other side of malnutrition has crept up on us. About 1.9 billion are overweight or obese; this is about 30 percent of the global population. The economic burden of obesity and its associated non-communicable diseases is estimated to be US\$2.0 trillion, comparable to that of armed conflicts and smoking (US\$2.1 trillion each). Not surprisingly, concerns about broken food systems dominate the discourse around our diets.

The 2nd International Conference on Nutrition (ICN2), hosted by FAO and WHO in November 2014, drew the world's attention to actions needed to promote sustainable food systems. Among these are:

- the need to review national policies and investments and integrate nutrition objectives into food and agriculture policy, programme design and implementation to enable healthy diets (recommendation 8);

- strengthen local food production and processing, especially by smallholder and family farmers, giving special attention to women's empowerment, while recognizing that efficient and effective trade is key to achieving nutrition objectives (recommendation 9);
- promote the diversification of crops including underutilized traditional crops, more production of fruits and vegetables, and appropriate production of animal-source products as needed, applying sustainable food production and natural resource management practices (recommendation 10);
- improve storage, preservation, transport and distribution technologies and infrastructure to reduce seasonal food insecurity, food and nutrient loss and waste (recommendation 11);
- establish and strengthen institutions, policies, programmes and services to enhance the resilience of the food supply (recommendation 12);
- develop, adopt and adapt, where appropriate, international guidelines on healthy diets (recommendation 13);
- encourage gradual reduction of saturated fat, sugar and salt and trans-fat from foods and beverages to prevent excessive intake by consumers and improve nutrient content of foods, as needed (recommendation 14);
- explore voluntary instruments to promote healthy diets (recommendation 15);
- establish food or nutrient-based standards to make healthy diets accessible (recommendation 16).

The knowledge and technologies to tackle the current nutritional and food system problems exist. One of these tools is biotechnology. This tool can be used to enhance human nutrition by making foods more available and by enhancing the nutritional content of foods. There are many examples where modern biotechnology has been used to improve the nutrient content of foods such as orange-flesh sweet potatoes, iron- and zinc-rich millet, and vitamin A-rich cassava. Biotechnology in the form of fermentation has been employed in traditional cultures to transform food and prolong shelf-life. Modern science has opened up a wide range of techniques for the application of biotechnology to agriculture and nutrition. The evidence around the potential of biotechnology to improve nutrition has built up. It is up to us to use it well to our advantage.



4.4.3 Application of biotechnologies to improve the quality of rice and wheat

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Background

Rice and wheat account for most of the global grain harvest and together these two grains supply around half of all calories consumed by the entire human population. Human consumption accounts for 85 percent of all rice produced and 72 percent of wheat produced, illustrating 1) the importance of these two crops for human sustenance; and 2) the need to ensure that production is able to overcome future challenges.

Current trends of population growth, middle class expansion and climate change have consequences for crop improvement programmes and agricultural production into the future. Social science also informs us that as developing countries undergo economic transition, the demand for high-quality food will increase. High quality can include physical appearance, sensory quality and nutritional traits. Breeding programmes have already embraced the challenge of developing new high-yielding varieties adapted to new climates, and scientists are searching for the genes and physiological pathways that lead to crops reaching and exceeding yield potential and maintaining this yield under stress. However, with demand for quality increasing, success of a new variety of any cereal is more likely to be measured by consumer acceptance of the food derived from the harvested grain, rather than adoption by farmers of the plant and its suite of agronomic traits.

Biotechnology

“Climate change, Urbanization, Biotechnology. Those three narratives still taking shape, are developing a long arc likely to dominate this century” (Brand, 2010).

Biotechnology applies scientific and engineering principles to living organisms in order to produce products and services of value to society. Biotechnology encompasses features from many different disciplines such as chemistry, mathematics, physics, engineering, microbiology and genetics. It can drive transformational changes for agricultural production, food security and nutrition security for our future generations. Much biotechnological research reveals genes with important functions, and biotechnology enables those genes to be mobilized into different varieties either through conventional breeding and marker-assisted selection or through more rapid techniques, such as genetic transformation or the newer technique of genome editing. Transformation leads to the

insertion of a gene into the DNA of another variety or organism, and genome editing refers to the insertion, deletion or replacement of DNA within the genome of an organism.

Equipping the genome of rice or wheat with a valuable gene by either transformation or genome editing is a translational outcome of biotechnology research because it places the research outcome into farmers' fields for maintaining yield and therefore income; if the new gene increases the nutritional content of the grains, then the value is found in the diets of people with chronic micronutrient deficiency or those with Type II diabetes. Currently, the nutritional traits being investigated are for micronutrients of beta-carotene, zinc and folate in rice grain, and in both rice and wheat iron and carbohydrates with low digestibility for diabetics. Not all consumers accept that value can be derived from using the tools of biotechnology to modify the genome of animals or plants that are intended to be food. This is powerfully illustrated by the destruction of field trials of plants genetically modified to express traits for health and nutrition, which means that it will take a lot longer to place these nutritionally beneficial foods into the food bowls of the people most affected by these chronic nutritional conditions. In order to avoid such devastating impacts in the future, it is important to: 1) understand what drives the fear, and 2) initiate a dialogue supported by science to explain the value of equipping plants with a valuable gene when evolution did not.

As with improving plants with genes for agronomic traits, a new variety is unlikely to be accepted with a nutritional trait unless it also meets quality traits for the cooked rice or the processed wheat.

Using biotechnology to discover genes for quality

The expansion of middle classes is most strongly seen in the rice-consuming countries of Asia. One of the quality traits of rice that all consumers rate important is fragrance, and this is demonstrated by the cost of fragrant rice in all markets. The compound giving fragrance is 2 acetyl-1-pyrroline (2AP), and the gene leading to the presence of the compound is known. Both jasmine and basmati rice contain 2AP, and no other compounds have been identified that combine with 2AP to give the characteristic jasmine or basmati aroma, and no genes have been discovered that lead to different amounts of 2AP.

Using metabolomic profiling and sensory evaluation, we have identified a number of compounds that determine the high quality jasmine fragrance, compounds that associate negatively with fragrance, genetic regions (QTLs) for several compounds, and three QTLs that associate with the concentration of 2AP. Using different tools of biotechnology, these QTLs can be delivered as markers to breeding programmes to enable them to use conventional breeding with genetic selection. Using that pathway, breeders must keep track of the new QTLs as well as the host of other agronomic and quality traits, so a new, highly-fragrant variety will take many years to reach a market. If consumers can be persuaded to accept genetic engineering technologies, and Brand's long arc can be shortened, a new, highly fragrant version of currently accepted varieties could be fast-tracked to market by editing the genomes to insert or replace the genes required for high fragrance for the many rice consumers that value fragrance highly, and for the new varieties with nutritional benefit.

Reference

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4.4.4 Biofortification of staple food crops: Justification, progress and future activities

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An estimated two billion people in the developing world suffer from the effects of micronutrient malnutrition, caused primarily by poor quality diets which are characterized by high food staple (e.g. rice) intakes. Inadequate intakes of essential vitamins and minerals lower disease resistance, increase mortality, compromise cognitive development, stunt growth and lower work productivity. Pre-school children and mothers of reproductive age are most vulnerable due to their higher requirements.

The density of minerals and vitamins in food staples eaten widely by the poor may be increased either through conventional plant breeding or through use of transgenic techniques, a process known as biofortification. For example, HarvestPlus seeks to develop and distribute varieties of food staples (rice, wheat, maize, cassava, pearl millet, beans, sweet potato) which are high in iron, zinc and provitamin A through an interdisciplinary, global alliance of scientific institutions and implementing agencies in developing and developed countries.

Biofortified crops offer a rural-based intervention that, by design, initially reach these more remote populations which comprise a majority of the undernourished in many countries, and then extend to urban populations as production surpluses are marketed. In this way, biofortification complements fortification and supplementation programmes, which work best in centralized urban areas and then reach into rural areas only in areas with good infrastructure. Initial investments in agricultural research at a central location can generate high recurrent benefits at low-cost as adapted biofortified varieties become available in country after country across time at low recurrent costs.

In broad terms, three things must happen for biofortification to be successful. First, the breeding must be successful – high nutrient density must be combined with high yields and high profitability. Second, efficacy must be demonstrated – the micronutrient status of human subjects must be shown to improve when consuming the biofortified varieties as normally consumed. Thus, sufficient nutrients must be retained in processing and cooking and these nutrients must be sufficiently bio-available. Third, the biofortified crops must be adopted by farmers and consumed by those suffering from micronutrient malnutrition.

First greeted with scepticism by plant breeders who worried that adding micronutrients would reduce yield, it has now been demonstrated conclusively that these high mineral and vitamin traits

can be combined with high yields and high profits. More than 15 million people in 30 developing countries are already growing and eating biofortified foods, and the number continues to grow rapidly. *Ex ante* and *ex post* cost-effectiveness analyses have been conducted for several micronutrient-crop-country-crop combinations. Cost-effectiveness of biofortification interventions has also been compared with other micronutrient interventions within several countries. All of these analyses indicate that biofortification is highly cost-effective and has the potential to engender significant reduction in micronutrient deficiencies.

Peer reviewed published data demonstrate that these nutritious foods improve nutritional status and reduce disease incidence and duration. For example, a study in Mozambican children (Jones and de Brauw, 2015) who ate biofortified vitamin A-rich sweet potatoes showed an impressive 42 percent reduction in the incidence of diarrhoea in children under five, and a 52 percent reduction in children under three. The same study showed a reduction in the duration of diarrhoea among children who fell ill – 10 percent in under-fives and 25 percent in under-threes. These were comparisons between children in intervention villages four years after orange sweet potato was first introduced and two years after all extension activities were discontinued, as compared with children in control villages where white sweet potato was continued to be grown.

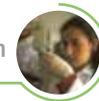
To date, all released biofortified crops have been developed using conventional plant breeding techniques. However, transgenic techniques are very powerful tools for adding vitamins and minerals to food staples. Transgenic biofortified crops could be of great benefit in reducing mineral and vitamin deficiencies if political barriers to their development and release could be overcome.

The example of golden rice is well-known. Milled rice contains no provitamin A. Potrykus and Beyer have demonstrated that transgenic techniques can result in high levels of provitamin A in milled rice (Ye *et al.*, 2000).

Likewise, recently Trijatmiko *et al.* (2016) demonstrated that high levels of both iron and zinc can be added to milled rice using transgenic techniques. Substituting this biofortified transgenic rice one-for-one for non-biofortified rice on any given day would result in an additional 30 percent of the estimated average requirement (EAR) of iron in the diet and, at the same time, an additional 60 percent of the EAR of zinc.

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4.4.5 Fish matters: Role of biotechnology in improving nutrition

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Aquaculture has been the world's most rapidly growing food sector for over a quarter of a century, with total global production (including all farmed aquatic plants and animals) increasing over nine-fold from 10.2 million tonnes in 1984 to a new record high of 97.2 million tonnes in 2013. Valued at over US\$157 billion, global aquaculture production has been growing at an average annual rate of 8.1 percent per year since 1984, compared with 0.66 percent per year for total capture fisheries landings, and 2.6 percent for terrestrial meat production over the same period. Moreover, with over 95.2 percent of total global aquaculture production being produced within developing countries, aquaculture is viewed as an important weapon in the global fight against hunger and malnutrition as a much-needed provider of high-quality food and essential dietary nutrients.

According to FAO, agricultural biotechnology includes “Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use”. For the purposes of this paper, agricultural biotechnology is used here to include those activities related to improving nutrition, including the improved nutrition of the aquaculture feeds used for the production of farmed aquatic species, the reduction of potential environmental impacts of aquaculture feeds, and the improvement of the nutritional content of aquaculture produce for direct human consumption.

The paper presents examples of microbially-produced feed additives commonly used within commercially-formulated aquaculture feeds (total global production currently estimated at about 42 million tonnes), including microbially-produced dietary essential amino acids (lysine, threonine, tryptophan), dietary enzymes (proteases, phytases, complex carbohydrate digesting enzymes), vitamins (vitamins B₁₂, riboflavin), trace minerals (selenium yeast, zinc yeast, chromium yeast, iodine), carotenoid pigments (algae-produced astaxanthin), nucleotides and immune enhancers (derived from bacteria and/or yeast), organic acids and probiotics.

Particular emphasis is given to the use of microbially-produced phytases to increase the utilization of indigestible plant-based phytates, and by so doing reducing phosphorus excretion and pollution to the aquatic environment. Similarly, the important role played by the microbially-produced essential amino acids lysine and threonine (these two amino acids usually being the second and third limiting amino acids in most aquaculture feeds) within compound aquafeeds has helped the aquaculture feed industry move away from its reliance on fishmeal with alternative more sustainable feed ingredients.

In addition to feed additives, agricultural biotechnologies have recently placed particular effort to the mass production of microbial biomass for use as dietary fishmeal replacers (including yeast and bacterial single cell proteins) and/or as a source of long-chain polyunsaturated fatty acids (algal docosahexaenoic acid [DHA]). The paper also discusses the traditional and current use of fermentation technologies for the conservation of small lower-value fish (from a marketing viewpoint) within most Asian countries, including the common production of fish sauces for food seasoning, and the more recent trend toward the fortification of farmed fish produce with supplemental nutrients for the benefit of consumers prior to harvesting, including long-chain omega-3 polyunsaturated fatty acids and essential trace minerals.

Finally, particular emphasis is given to the fact that aquatic food products represent one of the world's most nutritious and healthy food sources. Thus, according to the FAO/WHO Joint Expert Consultation on the Risks and Benefits of Fish Consumption (FAO, 2010), there is convincing evidence that: 1) fish consumption reduces the risk of death from coronary heart disease and that fish consumption by women reduces the risk of suboptimal neuro-development in their offspring; 2) fish consumption may reduce the risk of multiple other adverse health outcomes, including ischaemic stroke, non-fatal coronary heart disease events, congestive heart failure, atrial fibrillation, cognitive decline, depression, anxiety and inflammatory diseases; and 3) fish consumption may provide a greater nutritional impact than the sum of the health benefits of the individual nutrients consumed separately.

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Chapter 5

Parallel sessions: People,
policies, institutions
and communities



5.1 Report of outcomes from the three parallel sessions dedicated to the theme of people, policies, institutions and communities

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As part of this theme, three parallel sessions were organized. The first parallel session was entitled “Social and economic impacts of agricultural biotechnologies for smallholders: Taking stock of the evidence and prioritizing future assessments.”

The session looked at the impact of biotechnologies on agricultural productivity, environmental sustainability and socio-economic well-being. It also considered the role of evidence in policy-making. Nineteen case studies were discussed in consideration of applying non-GMO biotechnologies for smallholders, which could eventually assist policy-makers when deciding on potential interventions involving biotechnologies for smallholders in developing countries. Specific case studies and experiences from China and India were also discussed, with reference to both GMOs and non-GMO biotechnologies.

Through those case studies, five key lessons were learned:

- 1) Political commitment by national/local/state governments is critical for improving the productivity of smallholder enterprises and the livelihoods of smallholder farmers.
- 2) Financial support from donors and international agencies is indispensable for supplementing efforts.
- 3) Partnerships are vital for achieving results, particularly for translating research outputs into field outcomes and impacts.
- 4) Long-term national investments in both human capital and infrastructure for science and technology are critical.
- 5) Biotechnologies do not work in a vacuum, but are introduced into the fields of both researchers and farmers through integration of traditional knowledge and science-based considerations of applying innovative methodologies.

Despite the complexities of smallholder farmer production and farming systems, agricultural biotechnologies can represent powerful tools to benefit smallholder farmers given the appropriate conditions and enabling environment.

Continued investment in assessing the impact of biotechnologies on smallholders is needed to gauge their productivity, sustainability and welfare outcomes.

Participants recognized the importance of learning from the past and looking to the future through well-structured *ex ante* and *ex post* socio-economic assessments, and evidence-based analyses, long-term studies and credible counterfactuals that assess the cost of non-adoption of agricultural biotechnologies.

Participants also recognized the importance of taking an integrated and interdisciplinary approach to impact assessment, linking traditional knowledge to the process of impact assessment, and careful consideration of different perspectives towards biotechnologies and their applications.

Impact assessment will also be aided by active and global sharing of the scientific data and long-term financial support by donors and international organizations.

Finally, participants recognized that technology alone cannot solve the problems that small-scale farmers are facing, and that there is a strong need for strengthening rural education so that small-scale farmers can make informed choices.

The session concluded with the statement that the contribution of agricultural biotechnologies to effective and sustainable food systems and nutrition will require continued accumulation of evidence on their sustainability, productivity and welfare impacts based on well-designed social, economic and environmental assessments.

The second parallel session was entitled “Public policies, strategies and regulations on agricultural biotechnologies”.

The session looked into public policies, strategies and regulations around agricultural biotechnologies, including GMOs. The five speakers discussed institutional structure, governance issues, health and food safety, environmental risks and issues around intellectual property rights (IPR) from the perspectives of the private sector, public sector, civil society and research institutes.

The session also considered the challenges faced by developing countries in developing national policies and strategies for biotechnologies and the importance of ensuring that the needs and capacities of smallholders are taken into account.

In many instances, it is not IPR *per se* that impede diffusion of agricultural biotechnologies in developing countries but rather lack of appropriate institutional frameworks. IPR are legal tools to arrange a licensing agreement; there are legal tools available to handle conflicts raised within IPR (for example, competition law and policies) which should be activated whenever needed.

The participants acknowledged that most developing countries needed to strengthen their institutional, regulatory and legal frameworks on the use of biotechnologies. At the same time, it was realized that many elements around such frameworks are actually common for conventional agriculture and breeding. Regulating the process and use of biotechnology is a challenge when compared with setting up end product based regulation schemes.



Furthermore, the following key points emerged from the presentations and the discussion on the presentations:

- 1) There is a clear need for a common understanding on vocabulary and definitions of the terminology used for agriculture biotechnologies (e.g. what is meant by GMO?) for an informed discussion. Presenters devoted time to discussing this need, highlighting that the term “agricultural biotechnologies” is broader than GMOs. Non-GMO biotechnologies have been used successfully in many developing countries.
- 2) GMO-related policies, however, seem to ignore the historic evolution of genetic engineering, whereas problems in the legal national definition of GMOs are on what is intended, what is unintended, what are the regulatory uncertainties and how to cope with potential risks.
- 3) The enabling environment for biotechnology is very much related to handling knowledge and so is very closely related to research and development (R&D). It should be acknowledged that the developing environment for agricultural biotechnologies is not the same as the one for conventional agriculture because technology is developing at a quicker pace for the former.
- 4) Elements of the enabling environment for agricultural biotechnologies should be the convergence of biological with other sciences, the higher investment requirements, more attention to IPR and biosafety issues and the changed role of the private sector in developing and using technologies.
- 5) Although it is not simple, agricultural research and technological policy should become integral parts of a country’s overall R&D agenda. Furthermore, policies should be decomposed to instruments addressing issues on access to knowledge and technologies and on instruments dealing with the use of technologies in specific production systems. Stakeholder participation in decision-making and in designing the enabling environment was thought to be of crucial importance.

Attention needs to be given to the dissemination of this knowledge and to the delivery systems in place. This issue was highlighted both in the presentations and in the discussion.

Consensus emerged on the lack of dissemination mechanisms so that scientific work reaches the final recipients, who are the farmers. The output of any research should become recognizable, affordable, locally available and readily understood and usable by smallholders, with short- and long-term individual and societal benefits and risks weighted and distributed fairly and transparently.

The third parallel session was entitled “Investing in biotechnology solutions through capacity development and partnerships”.

Partnerships have helped in adoption of new technologies. The establishment of regional bioscience facilities and technology platforms with the partnership of the International Livestock Research Institute and the New Partnership for Africa’s Development, leading to Biosciences eastern and central Africa (BeCA) is clear evidence of this in the African region.

Strategies for dynamic policy choices like public–private partnerships (PPPs) are very important. Vigilance of the public sector would be very important along with partnerships between farmers and other stakeholders.

- Bt brinjal in Bangladesh and Embrapa’s partnership with BASF for herbicide tolerant soybean are examples.

- Water efficient maize for Africa (WEMA) is going to be another example for the African region.
- New technological choices with open-source tools combined with gene editing methods like clustered, regularly interspaced, short palindromic repeats (CRISPR), zinc finger nucleases (ZFNs) etc. provide new opportunities. This may be good news for smallholder farmers. It may help in opening new doors at much reduced cost. However, issues related to the precision of these technological choices are yet to be fully addressed.
- Mega-mergers in the agricultural biotechnology sector are a growing trend. With the entry of China's public sector, this trend is further energized.
- The time is ripe for a new generation of innovative PPPs and new agricultural biotechnology paradigms aimed specifically at the needs of small and marginal farmers, meeting food security and nutrition needs of poor and vulnerable groups.
- South–South cooperation is an important opportunity for wider adoption of biotechnology with concerns and modalities being discussed among the leading economies from the South. New dimensions of cooperation between North and South may also be explored. This can be North–South–North or North–North–South. Trilateral cooperation should be explored where it is relevant.



5.2.1 *Report of the parallel session*

Social and economic impacts of agricultural biotechnologies for smallholders: Taking stock of the evidence and prioritizing future assessments¹²

A wide range of biotechnologies have been developed and approved for commercial use in many developing countries. The session confirmed the importance of impact assessment to be the basis of consideration of applying agricultural biotechnologies for smallholders. Assessing the cost of non-adoption of agricultural biotechnologies was also emphasized as a strong need. The session was chaired by Sachin Chaturvedi (India) and co-chaired by Eduardo Trigo (Argentina).

New tools in biotechnology have the potential to increase the availability of, and access to quality foods in developing countries and play an important role in accelerating progress in the agricultural and life sciences. Gathering continuous evidence about biotechnology tools and products is essential for more sound policy design in the global food and agriculture system. It is essential to further explore the costs, benefits and trade-offs of these applications under real-world conditions. Three types of evaluations on the social, environmental, and economic impacts of biotechnologies are needed to concretize the evidence-based policy development: 1) lessons-learned approach of the looking-back evaluation; 2) forward-looking evaluation, with the construction of scenarios that explore the societal, economic and environmental gains and losses associated with particular biotechnologies; and 3) looking deep: gaining insights into the choices that farmers, firms, consumers and governments make with respect to biotechnologies. The science should look not only on the output frontier, but should also provide evidence on sustainability, productivity and welfare. Ultimately, this combination of real-world impact analyses translates into the basic foundation to consider biotechnology applications at the national, regional and global levels and provides key consideration factors for policy-makers to make informed decisions.

Nineteen case studies were discussed in consideration of applying non-GMO biotechnologies for smallholders, which could eventually assist policy-makers when deciding on potential interventions involving biotechnologies for smallholders in developing countries. Through those case studies, five key lessons were learned: 1) political commitment by national/local/state governments is critical for improving the productivity of smallholder enterprises and the livelihoods of smallholder farmers; 2) financial support from donors and international agencies is indispensable for supplementing national efforts; 3) partnerships are vital for achieving results, particularly for translating research outputs into field outcomes and impacts; 4) long-term national investments in both human capital and infrastructure for science and technology are critical; and 5) biotechnologies do not work in a vacuum, but are introduced into the fields of both researchers and farmers through integration

¹² This report was prepared by Masami Takeuchi, Karin Nichterlein and Aikaterini Kavallari, the FAO rapporteurs for the theme of people, policies, institutions and communities.

of traditional knowledge and science-based consideration of applying innovative methodologies. Despite the complexities of smallholder farmer production systems and farming, the study results revealed that agricultural biotechnologies can represent powerful tools to benefit smallholder farmers given the appropriate conditions and enabling environment.

China has been maintaining more than 100 percent food self-sufficiency for many years. However, the current trend is that imports are exceeding exports and the rate of self-sufficiency has fallen slightly in the last few years. Domestic demand growth is exceeding the production growth and imports of many agricultural commodities continue to rise. Thus biotechnology is one of the major tools for China to meet the demands and to increase agricultural productivity and competitiveness, while reducing chemical uses, and improving farmers' welfare. In China, investment in agricultural biotechnology research has doubled every four years since the mid-2000s. The results have been impressive and China gained significantly from transgenic *Bacillus thuringiensis* (Bt) cotton and it is expected to gain much more from other crops, including maize and rice, derived from biotechnology. In China, biotechnologies will play ever-more important roles to feed the population. At the same time, there is a trend that more Chinese consumers are mindful of the topic of food safety; therefore the Government of China is actively conducting safety assessment of foods derived from biotechnology. Recent policy to facilitate commercialization of genetically modified (GM) maize in China has been a big step forward and will also have important implications for global biotechnology development.

In India, application of biotechnology in agriculture gained prominence with the cultivation of Bt cotton in 2002. Subsequently, 11 GM crops have been approved for ongoing trials. However, in spite of phenomenal progress in GMO production, the general public has been hesitant in introducing other GM crops, mainly due to failure to exhibit resistance against all pests, low crop yield, high cost of seeds, heavy dependence on seed companies, lack of a governmental mechanism to monitor safety measures and assess potential risks, inadequate biosafety studies, monopoly of a few multinationals and lack of transparency. Resolving such issues is important in India to achieve food security. Tissue culture is another important technology that is popular and commercially viable in India. Use of biofertilizers and biopesticides has also become popular during the last two decades. Biotechnologies have been used in genomic studies of Indian cattle and buffaloes to obtain better economic traits and in clonal propagation. Studies of microbes are active as these may help in recycling bio-waste and production of efficient vaccines. The agricultural biotechnology sector has gained significance in India through the change in policy to grow GM crops. Biotechnology is expected to have a major role in food security and rural prosperity.

Summary of the open discussion

Participants recognized the importance of learning from the past and looking into the future through well-structured *ex ante* and *ex post* socio-economic assessments, evidence-based analyses and long-term studies. To analyse the impact of biotechnologies on smallholders, social benefits for sustainability and welfare and opportunity costs with productivity and profits are the main elements for constructing the baseline of the assessment framework. Effective modalities for assessing the impact and assisting policy-making include: 1) foresight analysis; 2) linking traditional knowledge to evidence-based data through a global approach; 3) an integrated and interdisciplinary approach to impact assessment, linking traditional knowledge to the process of impact assessment; and 4) careful



consideration of different perspectives towards biotechnologies and their applications. Furthermore, there is a strong need to strengthen rural education with the assessment results so that small-scale farmers can make informed choices.

Technology alone cannot solve the problems that small-scale farmers are facing. Long-term data analyses of the impact of biotechnologies in society as a whole, together with active and global sharing of the scientific data and financial support by donors and international organizations through strong partnerships are critical for developing countries to consider applying various agricultural biotechnologies.

The session concluded with the statement that establishing evidence for sustainability, productivity and welfare from assessments of social, economic and environmental impacts in smallholder farming systems is key in considering the role of agricultural biotechnologies in effective and sustainable food systems and nutrition. Credible counterfactuals that assess the cost of non-adoption of agricultural biotechnologies are also needed in such evidence-based studies.

5.2.2 Evidence-based policy-making: The role of impact assessment studies and their implications for agricultural biotechnologies

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Recent decades have seen an exciting increase in new tools and products that could accelerate the application of biotechnology to agriculture in developing countries. From genetic diagnostics, tissue culture, genetic modification and genome editing, to reproductive and vaccine technologies, nanotechnology, and synthetic biology – all of these technologies have the potential to increase the availability of, and access to, quality foods in developing countries and to improve the livelihoods of the rural and urban poor. In fact, scientists, businesses, governments and civil society organizations are already exploring technologies that increase crop and livestock yields, decrease production costs, reduce susceptibility to environmental stresses and improve the nutritional content of food crops.

The agricultural and economic impacts of several technologies in this broad category of biotechnology – for example, GM insect-resistant Bt cotton and maize – have already been the subject of extensive scrutiny at the farm, household and market levels. A large number of rigorous studies of these technologies find significant cost savings, yield improvements and reductions in pesticide exposure for farmers, including many who operate small and poorly-resourced farms.

There is also a range of innovative technologies – for example, tools that improve the efficacy and efficiency of plant breeding, livestock vaccine development or the propagation of planting materials – that have yet to receive much scrutiny. This is partly because these technologies are upstream process innovations that address scientific discovery and product development, rather than downstream product innovations that more immediately affect smallholders' farming practices and rural livelihoods. Nonetheless, we know these technologies play an equally important role in accelerating progress in the agricultural and life sciences.

Looking to the future, it will be important to continuously gather evidence about the full range of biotechnology tools and products in order to better inform policy design by developing-country governments and other actors in the global food and agriculture system. Well-informed, evidence-based policy design relies on rational, systematic decision-making to shape social, economic and scientific choices made by the state. Of course, evidence-based policy design does not occur in a vacuum. Careful attention must be given to the nature of evidence used in policy-making, how it is integrated into the policy-making process and the role of other influences on decision-making.



There is, however, general recognition that the use of rigorous evidence is essential to sound policy-making, particularly when the issues at stake concern agricultural growth, economic development and poverty reduction in developing countries.

Traditionally, published papers from the biophysical sciences have set the standard for credible and rigorous evidence. They evaluate new applications of biotechnology under carefully controlled conditions of a laboratory experiment or field trial. Yet this body of evidence is far from complete, which is why economists and social scientists are also asked to explore the costs, benefits and trade-offs of these applications under real-world conditions – where weather and price risk play a critical role, where individual and household characteristics are essential considerations, and where individual preferences, expectations and beliefs can further shape social and economic impacts. While their findings often support results from the biophysical sciences, they can also add nuance to the picture, or even call into question the best of good laboratory science.

Two types of evidence on the social, environmental and economic impacts of biotechnologies are increasingly needed to strengthen the evidence base around which public policies – laws and legislation, rules and regulations, public investments and expenditures, taxes and subsidies, and trade and investment regimes – are designed. The first is forward-looking evaluation, or the construction of *ex ante* scenarios that explore the societal, economic and environmental gains and losses associated with a particular biotechnology application or policy design relative to appropriate counterfactual scenarios. For example, a forward-looking analysis can be used to identify the varied impacts of a new labour-saving crop technology for large farmers, smallholders and landless labourers. It can also be used to understand the productivity losses associated with regulatory delays and uncertainty that impede the release of new biotechnology research tools to scientists or new biotechnology products to farmers. Rigorous foresight analysis of the impacts of both technologies and policies allows policy-makers to consider their policy options from a more informed position, particularly at high levels of aggregation – global, national or landscape.

The second type of evidence relies on insights into the choices that farmers, firms, consumers and governments make with respect to biotechnology. Here, the science of individual and household decision-making has advanced considerably in recent decades. Economists and social scientists have access to more rigorous experimental designs and long-term panel data that allow them to identify complex causal – not just correlated – relationships between technology or policy interventions on the one hand, and productivity, sustainability and welfare outcomes on the other. Moreover, a growing convergence among disciplines that study the behavioural dimensions of decision-making is increasing our understanding of how individuals make choices about new technologies, how they value competing choices and how they learn about these technologies and choices over time.

These same scholars are applying increasingly sophisticated tools of analysis to the study of how the interactions between firms in the market for innovation in agriculture can influence the availability and price of new biotechnologies for farmers and consumers, and how government interventions in those markets can help or hinder innovation processes around biotechnology.

More rigorous evidence on these micro-level dimensions not only improves the accuracy of our forward-looking analyses, but also helps us to better identify what works under real-world conditions.

Ultimately, this combination of real-world evidence and forward-looking analysis translates into insights about biotechnology applications at the landscape, national or global scale, taking into account both patterns of technological change and social, environmental and economic impacts. When combined with historical perspectives and qualitative insights from stakeholders, these analyses and insights can provide the critical evidence needed for developing countries to improve the policy, regulatory and investment choices that influence the development and introduction of biotechnology applications. Greater commitment to the use of science-based evidence in policy-making can, in turn, help overcome ideology and advance the technological opportunities available to the world's 500 million farmers and seven billion consumers.



5.2.3 Lessons learned from case studies of applying biotechnologies for smallholders

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FAO promoted the study of 19 cases in which biotechnologies were applied to serve the needs of smallholders in developing countries. The case studies, selected after an open call for proposals, were prepared by scientists directly involved in the initiatives who were asked to describe the background, achievements, obstacles/challenges encountered, factors for success (or failure), impacts and lessons learned from their case study. The cases covered different world regions, production systems, species and underlying socio-economic conditions in the crop (seven case studies), livestock (seven) and aquaculture/fisheries (five) sectors. Apart from one on West Africa, the studies focused on a specific initiative within a single country. More details on the different case studies are provided in Ruane et al. (2013).

A wide range of biotechnologies was used in the case studies, including some of the traditional methods such as fermentation and artificial insemination (AI), as well as several advanced techniques involving sophisticated DNA and genetic analyses. GMO applications were not included because of the highly polarized debate they normally engender. By dominating the debate, this has prevented serious consideration to be given to the potential contributions that the many non-GMO biotechnologies can make to sustainable development and food security (Ruane and Sonnino, 2011). Most of the case studies involved application of a single biotechnology in a single crop, livestock or fish species, with the objective of overcoming biological and technological constraints to increase productivity, improve people's livelihoods, tackle diseases and pests, expand market opportunities through diversification and value addition, and to conserve genetic resources.

The case studies yielded many varied and valuable outputs, in terms of the scientific and technical knowledge, capacities and products. While not all cases provided evidence of widespread adoption by farmers, some biotechnologies were adopted on a large scale. For example a new high-yielding and downy mildew resistant hybrid of pearl millet, developed in partnership by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Indian agricultural universities and UK research institutes, was released in 2005. By 2011, cultivation of this variety had spread to almost 900 000 ha in northern India, bringing greater food security to about two million people. In rice,



the International Rice Research Institute (IRRI) and Indian research institutes released in 2009 the Swarna-Sub1 variety, highly tolerant to submergence and lodging. In flood-affected areas, it was able to produce 1–3 tonnes per hectare more than other previously grown varieties. During the 2012 wet season, Swarna-Sub1 was cultivated by over three million farmers, covering over one million ha.

In aquaculture, the Jian carp, developed in China by within-family genetic selection and gynogenesis (a reproductive technology resulting in all-female carp offspring which have received genetic material only from their mothers), is now grown on about 160 000 farms and is responsible for over 50 percent of the total common carp production in the country.

The rate of adoption indicated in other case studies was less wide but nonetheless meaningful to the farming communities concerned. For example, a community-based foundation provides production-related veterinary services, including AI, to around 3 000 smallholder dairy cattle farmers in Bangladesh. The initiative increased milk production and farmers' income and generated employment.

From all the case studies, ten general and interrelated lessons have been drawn which can be used to inform and assist policy-makers when deciding on potential interventions involving biotechnologies for smallholders in developing countries. These are:

1. Commitment by national and/or state governments was critical for improving the productivity of smallholder enterprises and the livelihoods of smallholder farmers.
2. Financial support from bilateral and multilateral donors and international agencies was indispensable for supplementing national efforts.
3. International and national partnerships were vital for achieving results, particularly for translating



- research outputs into field outcomes and impacts. The case studies provided numerous examples of successful partnerships within the public sector, between public and private sector entities, and involving non-governmental organizations (NGOs) and community-based approaches.
4. Long-term national investments in both human capital and infrastructure for science and technology were critical components of the recipe. The case studies involved continuous agricultural research efforts that extended over 15–40 years.
 5. Biotechnology approaches did not work in a vacuum, but were introduced into both the research mix and farmers' fields through appropriate integration with other sources of science-based and traditional knowledge.
 6. The diffusion of genetic resources, techniques and know-how across national and continental boundaries was an essential ingredient of most case studies.
 7. Intellectual property issues did not constrain research or the production or use of biotechnology innovations in the case studies examined here.
 8. Products generated through the biotechnologies described did not need to conform to new biosafety or food safety regulations or standards. Without entering into the merits of such regulatory issues, this clearly represents an advantage for the development and use of products from the biotechnologies described in these case studies over those developed using genetic modification.
 9. Some case studies demonstrated clearly that development projects involving smallholder farm production systems can be dynamic and risk-prone. Stakeholders need to be aware, and anticipate, that the system may evolve quickly because of issues like changes in plant or animal disease dynamics or changes in farmer and consumer preferences.
 10. Planning, monitoring and evaluation of biotechnology applications were weak and should be strengthened. Most of the studies provided no information concerning the costs or benefits (in terms of production, productivity or financial returns) or changes in livelihoods. To improve both the planning and management of future projects, these aspects should be given much higher priority.

These case studies demonstrate that despite the complexities of smallholder farmer production systems, agricultural biotechnologies can indeed represent powerful tools to benefit smallholder farmers given the appropriate conditions and enabling environment.

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5.2.4 Impacts of agricultural biotechnology and policies: China's experience

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Facing enormous constraints in natural resources, China's ability to feed its growing population with rising income is impressive. Per capita water availability is only one-fourth of the world average and arable land accounts for only 8 percent of world total, but China supported over 20 percent of the world's population and had been a net food exporter before the mid-2000s. However, total food demand growth has surpassed production growth thereafter, which resulted in a fall of overall food self-sufficiency to 96 percent in 2014. Most imports have been soybeans and feed grains (e.g. maize and other coarse grain) for livestock production.

China's food imports are expected to rise as demand growth is expected to exceed production growth for many agricultural commodities in the future. In the past, increased food production has been at the expense of sustainable development. Recent rising costs of production due to rising wages have resulted in less competitiveness of China's agriculture in the global market. Under these backgrounds, China has been looking at all potential measures to increase its agricultural production in more sustainable ways.

Among many efforts, biotechnology is considered as one of the major tools by the national leaders to boost China's agricultural productivity and ensure national food security. After China initiated its agricultural biotechnology programme in the mid-1980s, public investment was doubled every four years between the late 1990s and the mid-2000s. Since 2008, Chinese R&D on GM crops and animals has been further spurred by US\$3.8 billion of new funding from the National GM Variety Development Special Programme (GMSP) for the period 2008–2020. By 2010, there were more than 13 000 researchers working on agricultural biotechnology, including GM plants, animals and micro-organisms. By 2015, a number of GM crops have been issued with production safety certificates, though major GM crops have not been approved for commercialization.

Bt cotton is one of the most successful cases of GM technologies in China. After its commercialization in 1997, about 7.1 million small farmers adopted it by 2009, and now Bt cotton accounts for more than 85 percent of the total cotton area in China. Our empirical studies show that the impacts of Bt cotton have been impressive. On average, Bt cotton increased cotton yields by 9.6 percent, reduced pesticide use by 34 kg/ha, reduced labour input by 41 days/ha and, despite higher seed costs, net profit increased by 1 857 yuan (or about US\$25) per ha. Our surveys of randomly-selected farm households in the experimental villages show that the households which cultivated Bt rice, when compared with



households cultivating non-GM rice, small and poor farm households, also benefitted significantly from GM rice adoption through both higher crop yields and reduced use of pesticides. Moreover, both Bt cotton and Bt rice also contributed to improved health of farmers by reducing the probability of farmers suffering pesticide-related morbidity during the crop growing season.

The model simulations further show that the economic-wide impacts of GM crops are substantial. Annual gains from Bt cotton and Bt rice reached respectively US\$1.1 billion and US\$4.2 billion, which already exceeds the costs of total investment in agricultural GM R&D in China. Moreover, the commercialization of GM crops will significantly increase China's maize and other food production and therefore raise food and feed self-sufficiency levels in the future.

However, the rising debate on the safety of GM food has largely changed the consumers' attitudes toward GM food in China. Our surveys show that the percentage of urban consumers who perceived such food as unsafe for consumption increased by more than 30 percent in the period 2002–2012. Major shifts have occurred after 2010, one year after China issued the biosafety certificate of production for Bt rice and phytase maize. The public concerns on GM food have obviously affected China's policy on the commercialization of GM technology after the late 2000s. However, given the significant socio-economic impacts of GM technologies, China has re-emphasized the roles of biotechnology in ensuring the nation's food security in recent years. The national leaders have decided to take the three-step development strategy: moving from non-food (e.g. fibre) to indirect food (e.g. feed), and finally to direct food (e.g. rice and wheat). Under this new strategy, China is expected to commercialize its GM maize in the very near future.

The presentation ended with four remarks: 1) China has invested significantly in GM technology, and the progress has been impressive; 2) China has also gained significantly from Bt cotton commercialization, and will gain much more from the commercialization of other major GM crops such as maize and rice; 3) GM technologies will play more important roles in improving agricultural productivity, ensuring food security and improving farmers' welfare; and 4) recent policy to facilitate commercialization of GM maize is encouraging and will also have important implications for global biotechnology development and global trade in the future.

5.2.5 Socio-economic impact of agricultural biotechnologies for smallholders in India

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Biotechnology for improving agricultural production

Application of biotechnology in Indian agriculture gained prominence with the cultivation of transgenic Bt cotton crops in 2002. Since then, India has taken the lead in exploring the potential of biotechnology on various fronts. The biotechnology programme in agriculture includes molecular mapping of genes of important plants, marker genes for selection of quality traits, development of transgenic crops, tissue culture for plant propagation, biofertilizers, biopesticides, vermicomposting, biodegradation of wastes and toxic substances, and mushroom production. With regard to transgenic crops, the objectives of breeding new GM crops were: to increase crop yields, improve product quality, increase nutritional values, reduce biotic stress, improve tolerance to abiotic stress such as drought, frost, heat, salinity, herbicides, and produce plant-based pharmaceuticals.

Genetically modified crops

When the genetically modified Bt hybrid cotton was introduced in 2002, 55 000 farmers cultivated it on 30 000 ha. There was an initial setback because of certain concerns such as low yield, non-resistance to sucking pests and high cost of inputs. With the rectification of these problems, Bt cotton was widely accepted across the country. In 2014, 7.5 million farmers were engaged in cultivation of Bt cotton on 11.6 million ha, covering 96 percent of the total area under cotton production, using 1 100 varieties; more than 50 percent of the farmers were small landholders. Indian cotton production increased from 13 million bales in 2002 to 40 million bales in 2014 enhancing the income of farmers from 300 percent to 400 percent. Since the cultivation of Bt cotton, Bt cotton seed oil and Bt cotton seed cakes have entered the food chain in India. In 2007, the Government of India allowed the import of glyphosate tolerant GM soybean oil and canola oil to meet the growing demand for edible oils. Presently, India ranks fourth among GM crop-producing countries in the world.

However, India has been very hesitant in introducing other GM crops, mainly due to failure to exhibit resistance to all pests, low crop yield, high cost of seeds, heavy dependence on seed companies, lack of a mechanism to monitor safety measures and assess risk, inadequate biosafety studies, monopoly of a few multinational corporations and lack of transparency. However, with the change in the government in 2014, 11 new crops have been approved for field trials. These include corn, rice, mustard, wheat, sugarcane, groundnut, brinjal, okra, cabbage, cauliflower and tomato. A large number of public and private research institutions have taken up studies on identification of marker-assisted genes and the development of new transgenic crops and varieties.



Tissue culture

Presently, India is producing over 1 900 million plantlets every year particularly for cultivating horticultural, aromatic, medicinal and forestry crops. Tissue cultured plants are very well accepted by small farmers due to assured quality and timely guidance to adopt good production practices.

Biofertilizers and biopesticides

During 2012–13, over 0.5 million tonnes of biofertilizers were produced while the potential is 2.5 million tonnes/year. Presently, the biofertilizers under commercial production are *Rhizobium*, *Azotobacter*, *Azospirillum*, *Herbospirillum*, *Azolla* and blue green algae species, *Pseudomonas* and *Bacillus* species, *Frateuria* species and vesicular arbuscular mycorrhizae (VAM).

Commercial production of biopesticides such as biofungicides, bactericides, bioinsecticides and bionematicides has also been undertaken by the private sector for crop protection. These products have been very well accepted by farmers due to their low cost, easy availability, safety and effective control.

Biotechnology for animal husbandry

Use of frozen semen for breeding cattle and buffaloes since mid-1970s has already created a white revolution in India. Indeed, BAIF was the leader in taking this technology to small farmers across the country. India has been successful in clonal propagation of buffaloes. However, the major research focus is on genomic studies of Indian cattle and buffaloes to identify genes for economic traits and marker-assisted selection for productivity enhancement. Use of embryos for bull production, karyotyping for screening of cattle against genetic disorders, and use of sexed semen for producing female milk animals are the other initiatives which are likely to make significant impacts on the earnings of small farmers. Selection of thermostable microbial strains for production of efficient diagnostics and vaccines is another area of priority. Technologies have been developed for efficient recycling of dung and biowaste through vermicomposting and biogas production using efficient microbes, which benefit small farmers who represent 87 percent of landholders in India.

Studies on identification and introduction of bacteria which can suppress methane production in the rumen to improve feed efficiency while reducing the emission of greenhouse gases, need greater attention.

Conclusion

The biotechnology sector in India is generating an annual income of US\$4 billion with agricultural biotechnology having a share of 14 percent. With the change in the policy to grow GM crops, agricultural biotechnology is bound to have a major role in food security and rural prosperity in India. Development of critical infrastructure to facilitate backward and forward linkages, and building the capacity of farmers to access appropriate technology and market information systems are critical factors for success.

5.3.1 **Report of the parallel session**

Public policies, strategies and regulations on agricultural biotechnologies¹³

The session, chaired by Vimlendra Sharan (Embassy of India, Italy), looked into public policies, strategies and regulations around agricultural biotechnologies including GMOs. The five speakers discussed institutional structure, governance issues, health and food safety, environmental risks and issues around intellectual property rights (IPR) from the perspective of the private sector, public sector, civil society and research institutes. The session also considered the challenges faced by developing countries in developing national policies and strategies for biotechnologies and the importance of ensuring that the needs and capacities of smallholders are taken into account.

IPR were defined as the right to control the commercial exploitation of the projected subject matter for a specific period. Different forms of IPR exist, such as copyrights or patents, each having different requirements. It was noted that minimum standards for protecting IPR are set by the WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) for signatory countries. The use of IPR in agricultural biotechnology has been controversial, especially in developing countries, and have been criticized for a variety of reasons including conflicts with farmers' traditional practices to reuse seed; excessively broad patent claims; patentability of genetic material and plant varieties; uncertainty regarding the scope of research use; high transaction costs; pricing of improved varieties (high because it has to cover costs of licensing of IPR); and appropriation of traditional knowledge and sovereign genetic resources. In many instances, it is not IPR *per se* that impede diffusion of agricultural biotechnologies in developing countries but other confounding issues are involved. IPR are legal tools to arrange a licensing agreement; there are other legal tools available to handle conflicts raised within IPR (e.g. consumer protection legislation), which should be activated whenever needed.

The participants acknowledged that most developing countries needed to strengthen their institutional, regulatory and legal frameworks on the use of biotechnologies. At the same time, it was realized that many elements around such frameworks are actually common for conventional agriculture and breeding. Regulating the process and use of biotechnology is a challenge when compared with setting up end product based regulation schemes.

Some key points which emerged from the presentations and discussion on the presentations were as follows:

There is a clear need for a common understanding on vocabulary and definitions of the terminology used for agriculture biotechnologies (e.g. what is meant by genetic modification, genetic engineering or a GMO?) for an informed discussion. Presenters devoted time to discussing this need, highlighting that the term “agricultural biotechnologies” is broader than GMOs.

¹³ This report was prepared with input from Masami Takeuchi, Karin Nichterlein and Aikaterini Kavallari, the FAO rapporteurs for the theme of people, policies, institutions and communities.



The regulatory approaches should take into account the historic evolution of genetic engineering but should also keep in pace with the more recent changes in technologies.

The enabling environment for biotechnology is very much related to handling knowledge and so is very closely related to R&D. We are living through a “knowledge revolution” and it should be acknowledged that the latest globalized environment for agricultural biotechnologies is different from the previous one for conventional agricultural research due to the pace of the development.

Elements of the enabling environment for agricultural biotechnologies should be the convergence of biological with other sciences, the higher investment requirements, the higher profile of IPR and biosafety issues and the changed role of the private sector in developing and using technologies.

Although not simple, agricultural research and technological policies should become integral parts of a country’s overall science and technology policy. As a result, such policies will be the effective foundation in developing practical instruments to facilitate access to knowledge and technologies. An effective consultation process to allow stakeholder participation in decision-making and in designing the enabling environment was thought to be of crucial importance.

Regarding GMOs, some stakeholders expressed concerns about their possible adverse effects on human health and the environment; their economic impacts for smallholder farmers; and the implications of IPR and the role of multinational biotechnology companies. Biotechnology policies need to encompass aspects related not only to the safety of biotechnology products but also to their ownership.

To ensure adequate and effective policies are developed and communicated, the stakeholders who are likely to be affected (positively or negatively) by the relevant biotechnologies should be consulted. Key questions should be addressed during this process, such as whether the biotechnologies will be used directly by the farmer or by a specialist acting on his/her behalf; what practices are needed for the introduction of the new technologies?; what do people know and what inputs can they access?; what skills are required and how can they gain them?; if a redistribution of power, income etc. is involved, who will benefit and how can the losers be compensated?

Special attention needs to be given to the dissemination of technologies and knowledge and to the development of efficient delivery mechanisms and seed systems. There was consensus regarding the importance of having a functional delivery system for biotechnology so that the outputs of scientific work do not remain on the shelf but actually reach the final recipients, i.e. the farmers. It was noted that the importance of delivery systems was often underestimated. The central role that the private sector can play in delivery systems was underlined, including through stewardship to ensure that a GM product contains the relevant trait in successive generations. The outputs of any research should become recognizable, affordable, locally available and readily understood and usable by farmers including smallholders, with short- and long-term individual and societal benefits and risks weighted and distributed fairly and transparently.

International standards and agreements relevant to policy-making and regulation of biotechnology are important. For example, a representative of the Secretariat of the International Plant Protection

Convention (IPPC) informed participants that international standards are developed, negotiated and agreed by 182 countries under the IPPC framework, and that one of the standards specifically provides guidance for assessing the potential risks of living modified organisms that could affect plants and their ecosystems.

The session closed with the Chair noting that: “Biotechnology, like any other technology, gives us the power. But it does not and cannot tell us how to use that power”. Designing appropriate policies can be facilitated, but at the end it is the responsibility of the governments themselves to put them in place and to ensure they work for the benefit of its citizens.



5.3.2 The role of intellectual property rights in enabling or impeding the application of agricultural biotechnologies in a developing country context

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International legal framework for intellectual property rights (IPR)

IPR bestow on the owner the right to control commercial exploitation of the projected subject matter for a specified period of time. Different forms of IPR exist such as copyright, patents, trademarks and plant variety protection (PVPs), with each having different requirements. The exclusionary rights conferred by IPR are typically justified in economic and policy terms as being essential to reward innovation which would otherwise not occur in the absence of such rights.

The WTO Agreement on Trade-Related Aspect of Intellectual Property Rights (TRIPS) sets down minimum standards for protecting IPR which signatory countries are required to implement through national legislation. With 162 signatories, TRIPS-driven harmonization facilitates global trade across industries in which IPR operate as the common bedrock across industries, driving innovation and diffusion of technologies in developed and developing countries alike. Patents and PVPs in particular are considered to be key drivers of innovations in agricultural biotechnology as they allow recoument of the substantial investment in research required to develop novel inventions and plant varieties.

IPR impeding the diffusion of agricultural biotechnologies

The use of IPR in an agricultural biotechnology context is not without controversy, particularly in a developing country context. Critics claim that far from facilitating access and diffusion, the increasing fragmentation of IP ownership from upstream agricultural research inputs and production technologies to downstream improved plant varieties and agricultural inputs for use in cropping systems collectively raise barriers to access and impede dissemination. This proliferation of IPR also increases the threat of infringement such that in a developing country context IPRs are often accused of favouring the market-expansion interests of corporations at the expense of farmers and consumers. Criticisms concerning IPR-related issues are also broad and include, for example, conflicts with farmers' traditional practices of reusing seed, excessively broad patent claims, patentability of genetic materials and plant varieties, uncertainty regarding the scope of research use, high transaction costs, pricing of improved varieties as a result of licensing of IPR, and appropriation of traditional knowledge and sovereign genetic resources.

IPR in agricultural biotechnology create a complex landscape to navigate and while there is certainly substance in many of the critiques raised, in many instances it is not IPR *per se* that impede diffusion of agricultural biotechnologies in developing countries. Often confounding issues are involved such as institutional familiarity with IPR, increased transactions costs, and regulatory/stewardship challenges. The presentation will draw examples from the CGIAR to contrast the role of IPR with these confounding factors as an impediment to diffusion.

IPR enabling the diffusion of agricultural biotechnologies

Global harmonization and strengthening of IP protection in recent decades has been credited with attracting an increase in private sector investment in agriculture-related research and development, and a surge in innovation leading to improved plant varieties, agricultural chemicals and production technologies. Agricultural biotechnologies have transformative potential in a developing country context and an effective IPR framework not only encourages home-grown innovation, it also provides a framework for catalysing technology transfer. Permissive licensing of IPR plays an important role in the local adaptation and diffusion of agricultural biotechnologies and the presentation will draw examples from the CGIAR to highlight IPRs as an enabler for diffusion.

Developments concerning IPR-related issues and diffusion of agricultural biotechnologies

Future developments concerning a number of IPR-related issues and trends have the potential to effect the diffusion of agricultural biotechnologies. These include the following and will be covered in the presentation if time permits:

- Humanitarian licensing and the rise of “open-access” frameworks;
- Increased patent activity and the potential for patent thickets/pools;
- The expiration of patents for GM traits and the potential for a generics market;
- Prior Informed Consent and Mutually Agreed Terms associated with access and use of genetic resources under the Nagoya Protocol (potential for reach through for commercialization);
- Differentiated regulatory approach for transgenic and cisgenic technologies;
- Increasing concentration of the agricultural biotechnology market.



5.3.3 Biotech policy: The need for historical perspective and context

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Introduction: A bit of essential history

Modern biotechnology is a collection of technologies, or tools, that are based on the use of cells and biological molecules. All are rooted in and derived from earlier biology-based tools that allowed humans to use and modify living organisms, both multicellular and single-celled, for centuries. At first, our manipulations of organisms were hit-and-miss ventures. However, as scientific knowledge of living organisms grew, our use and modification of them became more directed and precise because we better understood the biological bases of the processes we wanted to control and the changes we hoped to make. As the reductionist approach to biology led to an understanding of biochemical mechanisms, the evolution of our science-based use of organisms reached a point where we understood our manipulations at the molecular and cellular levels. This has allowed us to capitalize on unique properties of life at the molecular and cellular levels: its extraordinary specificity and its “oneness.”

The evolutionary transition from poorly-informed use of whole organisms to directed and predictable manipulation is seen most easily in the evolution of crop plants. Until approximately 8500 BC, all of the plant material people used came from wild, gathered plants. Around that time, they began to save seeds and intentionally plant them rather than relying on the plant’s mechanisms of random seed dispersal. Thus the first technological revolution – agriculture – was born. Once they recognized plant offspring resemble their parents, they began to save seeds from certain plants with traits they valued. As soon as humans started planting certain seeds and not others, they unknowingly began to alter the genetic make-up of the wild plants they had been gathering. Our ancestors genetically transformed wild gathered plants to domesticated crops by trial and error, relying only on the minimal understanding they had amassed through experience. Humans were stuck in the “artisan seed selection” stage for thousands of years because they understood nothing about the biological processes they were relying on: seed production and trait inheritance. They were limited to selecting the best seeds from whatever nature provided. Reaching the next level of crop improvement meant exerting control over the type of seeds produced. Scientists learned how plants reproduce in the 1600s, and soon thereafter, farmers began incorporating desirable traits into crops by intentionally cross-pollinating certain plants by hand. Hand-pollination, which limited seed production to the best plants, along with selection of certain offspring for next year’s planting greatly accelerated crop genetic improvement. Yields increased as farmers developed crop varieties specifically adapted to

local conditions. Taking control of plant reproduction also allowed them to create crops that would never have occurred in nature, because they began overriding some of nature's restrictions on cross-pollination.

The next stage in science-based plant breeding was made possible by Mendel's elucidation of the laws of trait inheritance. Armed with a fundamental understanding of genetic mechanisms provided by Mendel's work, farmers and plant breeders now knew they could cross well-adapted cultivars to another plant with a desirable trait, no matter how inferior or poorly adapted, without fear of losing the genes in the superior, well-adapted line and replacing them with the inferior's gene. After creating a hybrid plant whose genetic make-up consisted of half superior and half inferior genes, they could cross the hybrid to the superior line for a number of generations. Plant breeders began to look for desirable traits in cultivars from all over the world and in the ancestral, wild plant of the crop in question and its relatives. They developed a number of laboratory techniques that allowed them to hybridize crops and plants that would never have been able to interbreed in nature. Many of these "wide crosses" involved plants belonging to different species. In some cases the amount of genetic difference between the crop and other plant was even greater, because breeders began crossing plants in different genera. For example, bread wheat contains genes from at least ten different species in six different genera.

Plant breeding and regulatory policy

The long history of genetic modification of plants has not received the attention it deserves in policy discussions surrounding "GMOs" an ill-defined term that means different things to different people.

By neglecting the long history of genetic modification through interspecific and intergeneric breeding, as well as mutagenesis, many definitions of "GMOs" drafted by governmental bodies inadvertently capture thousands of varieties of crops that were in the food supply many decades before the development of genetic engineering in the 1980s. Others capture processes that occur regularly in nature. The governments opt to either ignore the crops genetically modified by other means, even though they are captured by the definitional scope of the regulation, or they are forced to add on a list of exemptions. It goes without saying that neither approach is based on risk, leading to regulatory systems all over the globe in which the risk of the product is uncoupled from the degree of regulation.

Plant breeding and intellectual property (IP) protection

The history of plant breeding has not been ignored in the development of IP protection. In the United States of America, laws passed in 1930 and 1970 grant IPR to various categories of plants developed by plant breeders. And later a judicial decision granted even broader protection to new plant varieties. Although many people associate IPR issues with "GMOs", in many countries IPR for plants preceded the development of recombinant DNA techniques. In addition, although people assume that only the private sector in the United States of America protects IPR in its background germplasm and biotechnology traits, public sector institutions also seek patents or plant variety protection certificates for new varieties that they develop. In addition, public institutions in the United States of America also seek compensation through the courts if their IPR are not respected.



The *act* of patenting is not unethical. It is what the patent holder does with the patent that raises concerns about ethics and values. A public institution can pursue a patent or plant variety protection for a new crop cultivar and then provide access, free of charge, to any entity it chooses.

Summary

The issues most people consider to be problems of “GMOs” are not unique to agricultural biotechnology but, instead, are inseparable from all forms of agricultural production. Whether the issues are socio-economic, legal or biological, if modern biotechnology and “GMOs” disappeared from the agricultural landscape today, the issues and problems would remain. This presentation focused on one of those persistent issues: intellectual property protection for plants in the United States of America.

A unique issue associated with agricultural biotechnology is the pre-market regulatory approval of genetically engineered crops. In the United States of America this form of regulation is added to the post-market regulatory oversight that covers all new plant varieties. A pre-market regulatory approval process has significant impacts on the types of crops that are developed and limits the entities that develop the crops to only those with sufficient resources. The opportunity costs associated with NOT developing certain crops will vary from one country to the next.

5.3.4 **FAO must support peasants' selection and condemn the seizure of cropped biodiversity by patented genes**

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To deal with biotechnologies, it is legitimate for FAO to call upon those using them in research and industry. It is, however, not legitimate at all that FAO almost exclusively relies on those protagonists when it comes to discussions on public policies and food policies, considering that a great number of farmers and civil society organisations opposed to the uncontrolled use of those technologies are not invited to make presentations, or marginally through the invitation I received. I suggest you do take into consideration the public position those organizations have released.

Transgenic plants have not met expectations. Most of them have been modified to tolerate herbicides. It has led to resistant weeds emerging, an exponential use of herbicides being more and more toxic with sanitary and environmental impacts of which farmers, their families and rural people are the first victims. Other transgenic plants produce insecticide molecules which also lead to resistant insects emerging and an already known agronomic failure. First victims are once again farmers having lost their harvests, often despite an additional use of chemical toxic insecticides. Genetic technologies used to produce those plants have generated many unintentional and unintended effects the industry is desperately trying to hide. The most obvious ones have been loss of crops or of product quality. The cotton sector in Burkina Faso has lost its rank in the market after having conquered it with much effort thanks to the quality of its fibre, a quality which has suddenly disappeared after GMO adoption: what's the point to increase yields if harvests can't be sold? Once again, small farmers are the first victims when the industries, even though they are accountable for such disasters, simply claim they cannot explain what occurred.

Transgenic seeds will keep on being of no interest for food security. Their cost, as the one of the required inputs, makes them suitable for the sole market of industrial crops for rich countries' need of feed and fuel, and for the emerging economy of biomass which confiscates the agricultural lands for non-food uses. Industry shows no interest in subsistence crops which provide three-quarters of food available on earth. Small farmers producing this food do not have the funds to buy GMOs and the required inputs for cropping them. GMOs only aim at taking over their lands to replace them by industrial monocultures for export.

Every time they are authorized, transgenic plants replace the huge cropped biodiversity coming from centuries of farmers' selection by a few patented varieties. Patented genes are moving from one field to another because of the wind, insects and agricultural tools which carry pollen and grains. They



contaminate peasants' seeds which then become counterfeit of industries' patents. In less than 20 years, 89 percent of maize and 94 percent of soybeans in the United States of America have become patented GMOs. This violation of farmers' rights forbidding them to use seeds coming from their harvests also prevents them from adapting their crops to climate changes. Those changes are not linear. At the time of seedling, no one knows what the weather will be like. It is useless to have a gene for drought resistance during tornados or exceptional flooding years. And vice versa. Resilience of crops facing worsening violence of climate shocks depends in the first place on their genetic diversity and local adaptation, not on one new gene or another patented in a laboratory. Only the peasants' selection in the fields working with seeds coming from local harvests, contribute to this adaptation. No solution can exist without them. Patents present in all GMOs are an inappropriate solution because they forbid peasants' selection.

Facing consumers' rejection of GMOs, industry has come up with new techniques of genetic modification and is now willing to have them escape GMO regulations. Those genetic engineering techniques aim at modifying *in vitro* the genes of cropped plants' cells. They undoubtedly produce living modified organisms as defined by the Cartagena Protocol on Biosafety. Under the pretext that some of those techniques leave no trace of the genetic material introduced in the cells to modify their genome, the industry is willing to have those plants not qualified as GMOs in order to escape the international rules of the Cartagena Protocol and the mandatory labelling, risk assessment and follow-up as imposed by many national regulations. It therefore tries to modify the GMO definition in order to reduce it to the insertion of recombinant DNA found in the final product. It is totally unacceptable that FAO endorses in its own publications this obvious violation of the only accepted international definition of GMOs given by the Cartagena Protocol.

This new move from industry is all the more perverse by allowing it to patent genes without distinguishing them from naturally occurring genes in peasants' seeds and in seeds stored in gene banks. The entire cropped biodiversity available is this way being brought under the control of a few multinationals owning the biggest patent portfolios. Peasants and small breeders cannot know if seeds they are using contain patented genes or not in order to protect themselves from those. This legal uncertainty speeds up, on the one hand, the extreme concentration of seed industry allowing three multinational companies to control more than half of the international seeds trade and, on the other hand, the disappearance of the huge diversity of peasants' seeds preserved and renewed each year by peasants in their fields. By making free the access to the information of genetic sequences of the entire phylogenetic resources of the Multilateral System of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), the DivSeek programme violates the mandatory requirement for prior consent and sharing of benefits, supporting this new bio-piracy. ITPGRFA's complicity by collaborating with this programme is an unacceptable betrayal of the millions of peasants' trust who provided their seeds.

Via Campesina and civil society organisations supporting it expect FAO to immediately put an end to this new bio-piracy and to any kind of support of genetic modification technologies which only aim at allowing a few multinationals to patent and take over existing cropped biodiversity. On the contrary, FAO must support peasant organizations and researchers which are involved in collaborative peasants' selection programmes for food sovereignty and peasants' agroecology.

5.3.5 **The challenges of developing national policies and regulations for agricultural biotechnologies: Reflections from cumulative experiences**

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Biotecnology is transforming the processes and the products of agricultural research, as well as the institutional and economic environment of agricultural technology development and innovation systems. Advances in the biological sciences are producing quantum leaps in our knowledge about the way plants and animals grow and synthesize useful products, as well as the scientists' ability to transform them. In response to this, many developing countries have moved to design and implement promotional policies aimed at promoting the use of the new concepts both as research tools and at the level of specific production situations. Countries as diverse as Brazil, Colombia, the Dominican Republic, Jamaica, Mexico, Nicaragua and Paraguay in Latin America and the Caribbean; Namibia, South Africa and Zambia in Africa; and India, Malaysia and Sri Lanka in Asia, among others, have defined strategies and component policies to promote biotechnology-based activities and moved to create specific regulatory mechanisms, particularly concerning biosafety. Biotechnology has also been the base of many international cooperation initiatives linking developed and developing countries, as well as involving different kinds of South–South cooperation approaches.

Looking in retrospect, these efforts do not seem to have been very successful. Even though it is true that developing countries make up most of the list of the top ten performers in terms of the adoption of GM crops – the best known of the products of biotechnology – the fact is that biotechnology is not a widely-used tool within the toolkit of agricultural research. Consequently, great opportunities are being lost in terms of capturing the potential benefits of the new technologies for sustainable development, improving nutrition, and addressing the challenges of climate change among other issues. Explaining poor performance is not an easy task. In part, the issue is wider than biotechnology, and many of the same aspects can be pointed out in reference to conventional agricultural research as well as science & technology policies in general. However, it is important to highlight that biotechnology approaches evolve in an institutional environment that is very different than that of conventional agricultural research, and many of the shortcomings identified could be linked to a poor recognition of what this environment looks like, and the consequent failure to effectively reflect in the policies designed.



The increased convergence between biological and other sciences, higher investment requirements, the higher profile of intellectual property and biosafety issues, the changed role of the private sector both in the development of the technologies and the technology delivery systems, are all aspects that should be clearly present in an effective policy development process. Clearly, there are no recipes to follow for effective policy-making but given the characteristics of the present processes and their limitations, developing countries have to address a few comments that can contribute to more effective policy development in the future. A first issue is the need to make agricultural research and technological policy an integral part of the country's general science & technology policy, and discuss biotechnology-related issues within that framework. A second aspect – more related to a better recognition of biotechnology-based research, technology and innovation (RTI) processes – would be moving to decomposing the policy space in policies and instruments addressing issues dealing with access to knowledge and technologies, and instruments dealing with the utilization of the technologies in specific production systems could be a good way to improve existing approaches.

5.3.6 Ensuring that policies, strategies and regulations on agricultural biotechnologies benefit smallholders

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Why consider the impacts of biotechnology on small-scale farmers? Isn't small-scale farming a relic of the past? Some policy-makers and academics argue that small-scale farmers need either to take a "step up" in their farming operations – intensify, enlarge, commercialize and become more productive – or "step out" of farming altogether. According to this view, the major policy challenge in relation to smallholder farming is to find pathways out of agriculture for most of its practitioners, and pathways to large-scale agriculture for the few.

This is a debatable point. What is certain is that, today, many millions of rural people still depend heavily on agriculture for their livelihoods and food security. Agriculture can be a motor of economic growth and development in the wider economy. Moreover, times have changed since the days when industry was absorbing millions of unskilled workers. In the future there will be concerns not only about food security but about employment.

Meanwhile, many families with roots in rural areas exhibit a strong desire to keep hold of their land as a buffer against economic insecurity and a source of resilience. And farm-based rural livelihoods are diversifying to include off-farm and non-farm sources of income and livelihoods. So small-scale and family farm operations are unlikely to disappear overnight, if at all. So focusing policy on the needs and interests of small-scale farmers remains vital.

There is no structural reason for thinking that small farms cannot absorb or benefit from modern agricultural biotechnologies. Key questions for development policy and strategy include: What types of biotechnologies will be suitable and appropriate for small-scale farms? And how can the benefits for this sector be maximized and the risks minimized?

The first observation is that both the design of the technology and the context of deployment matter. The best policy, strategy or regulation to support the interests of small-scale farmers will be different for different types of technologies and for different communities or circumstances. There should not be a standard prescription for every situation. However, taking this into account I can offer some general suggestions. Most of these would apply equally to all kinds of farming technologies, not just biotechnologies, or transgenic crops and livestock.



A good start is to think about an effective *process* for developing policies, strategies and regulations. In particular, it is advisable to consult groups likely to be affected (beneficially or adversely) by the technologies in question. This is one reason why Article 23 of the Cartagena Protocol on Biosafety stipulates that signatories should take steps to inform and involve the public in decision-making; but it is particularly important to involve those stakeholders who are directly implicated in technological change, such as small-scale farmers.

It is well to ask some key questions, such as:

- Who is expected to deploy or practise this technology? For example, will it be used by an individual farmer him/herself, or by a specialist acting on his/her behalf (such as an extensionist, consultant or field technician)? Or will adoption of this technology require cooperation across a community of farmers? Answers to these questions can help decision-makers to develop impact strategies and design extension programmes.
- What behaviours or practices are envisaged if this technology is introduced, and which might be eliminated or changed? Who might be affected, positively or negatively, by such changes? Answers to these questions will help to identify key intervention points and the stakeholders who need to be involved in decision-making.
- What material inputs, equipment or tools may be needed in order to take full advantage of the technology? For example, does the new biotechnology depend on additional supplies of fertilizer or water? If so, are these resources readily available? Small-scale producers often farm in unfavourable environments where desirable inputs are unavailable or inaccessible.
- What information, knowledge or skills are required to make the most of the new technology? Who will supply the necessary information and how will farmers be supported to acquire new knowledge and skills they may need to benefit from the technology or avoid possible negative impacts?
- In many cases the deployment of new technology implies a redistribution of power, income, employment or other assets. Who are likely to be the winners and losers from this new technology? How might the potential losses be mitigated or how might losers be compensated? Or can policy ensure that the benefits are more evenly distributed?

Policy- and decision-makers can take several concrete steps to support the uptake of beneficial modern biotechnologies by small-scale farmers. Some key priorities should be:

- Ensuring that the extension and marketing of biotechnologies is done in ways that are effective, clear, transparent, accountable and well-targeted towards small-scale producers.
- Ensuring that modern biotechnologies are accessible to small-scale farmers – i.e. affordable (low or moderate prices), locally available (effective distribution and delivery), and readily understood and usable by small-scale farmers (accompanied by clear and useful information).
- Ensuring that short-term and long-term, individual and societal benefits and risks are weighed and distributed fairly and transparently.

Policy-makers can learn from mistakes that have been made in the past. For example, we know now that it is helpful if new technologies are *recognizable* and *trialable*, that is:

- Technologies can be distinguished from other technologies, inputs etc., both on the farm and in the market. This might be due to the technology's effects or because it is properly labelled. It is important to eliminate fraudulent misrepresentation so that farmers can be confident they are using the technology they need.

- Technologies are introduced at a moderate pace, which allows farmers the time necessary to familiarize themselves with the technology, try it out, observe how it works and understand how to get the best from it.
- Technologies are accompanied by clear and usable information, training and other support.

Learning from mistakes does not happen automatically, however. Decision-makers need systems for gathering lessons that can serve to inform improved policies into the future, from implementing agencies, extension services and field technicians and farmers.

These guidelines are especially important in the case of seed technologies (e.g. transgenic seeds or treated seeds) which might not be easily identifiable in the field or in the market.

A more challenging proposition is that genetic material, including transgenics, for example, should be made available to small-scale farmers in forms that are unencumbered by intellectual property restrictions, so that they can be decomposed and reconstructed to suit the farmers' own local requirements. Small-scale farmers have managed genetic material in their seed portfolios for many generations; allowing them to do so in future could be an effective way to ensure that useful traits are incorporated into locally adapted germplasm quickly and effectively.

This might be a controversial proposal because it confronts the interests of intellectual property owners, who wish to control who may use new genetic material, and also because it might create special difficulties for the stewardship and monitoring of genetically modified organisms in the environment. Assessing biosafety risks in advance would be vitally important (including short- and long-term effects on human, animal and plant health, crop and natural biodiversity, impacts on non-target organisms, and so on).



5.4.1 *Report of the parallel session*

Investing in biotechnology solutions through capacity development and partnerships¹⁴

The session, chaired by Kongming Wu (China), focused on capacity development as well as on the role of partnerships, including public–private partnerships (PPPs) and South–South cooperation (SSC), for agricultural biotechnologies. A key element of the enabling environment for agricultural biotechnologies is that the individuals and institutions involved have the capacities to generate, adapt and apply biotechnologies in crops, forestry, livestock and fisheries.

Biosciences eastern and central Africa – International Livestock Research Institute (Beca–ILRI) is one regional network of the African Union (AU) and the New Partnership for Africa’s Development (NEPAD) Africa Bioscience Initiative, established in 2002 to support and mentor African scientists from national and international public sector and private sector in the application of biosciences in food security and agricultural development. Capacity development at the Beca–ILRI Hub includes: 1) the Africa Biosciences Challenge Fund (ABCF) research fellowships (> 100 since 2010) for capacitating individual scientists and national agricultural research systems (NARS) institutions; 2) training workshops; 3) institutional capacity strengthening (laboratory maintenance and management etc.); and 4) mobilizing capacities for joint action for multicountry/multidisciplinary research. It was emphasized that mentorship is a key cross-cutting mechanism in the capacity building process, and that fund-raising from NARS is a challenge. The Hub will expand capacity development of African scientists, and strengthen the technology platforms that are addressing African agricultural issues, as well as fund work on fund raising to maintain the Hub activities.

In the second presentation, three case studies of PPPs related to smallholders were described: Bt brinjal/eggplant in Bangladesh commercialized in 2014; GM crop development by Embrapa in Brazil; and crops in Africa, such as water efficient maize for Africa (WEMA). Major lessons from recent PPP experiences are that success depends on a full commitment by host countries, appropriate regulatory systems (still emerging), and the sustained participation of all partners, especially smallholders, over a long duration. Such lessons are especially important given the recent development of gene editing methods (CRISPR) that will make current GMO methods (and their regulation) obsolete. Gene editing technologies can considerably widen the range of traits, especially smallholder-relevant traits, that can be improved much more rapidly and cheaply than before, which provides a golden opportunity for the emergence of new PPPs aimed specifically at improving smallholder agriculture. FAO should make sure that these new technologies will be available for improving smallholder agriculture.

The third presentation was about the Cornell Alliance for Science, founded in 2014 with a grant from the Bill and Melinda Gates Foundation. It aims to facilitate access to biotechnologies by building an international network of concerned scientists, farmers and humanitarian organizations to facilitate

¹⁴ This report was prepared by Masami Takeuchi, Karin Nichterlein and Aikaterini Kavallari, the FAO rapporteurs for the theme of people, policies, institutions and communities.



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access by farmers to modern biotechnologies to help them provide safe, stable and environmentally sustainable food supplies. The Global Alliance (> 6 000 members) aims to strengthen the global network through: 1) The 3-month Global Leadership Fellows Program, designed to equip and empower emerging leaders to foster a more enabling environment for the adoption of biotechnology globally; and 2) Short courses held regionally to strengthen the networks of global leadership fellows in strategic communications planning and grassroots organizing; fellows are already making impact on biotechnology dialogues in their countries.

The presentation on North–South/West–East cooperation in agricultural biotechnologies illustrated an applied biotechnology solution related to partnerships between Italy and China and capacity development in the sector of buffalo production to improve milk production in swamp buffalo. The presentation showed that it was essential to find a common language, common interest and complementary goals for the partnership. The sector is of mutual interest to both countries and it is a good example of the use of a set of different complementary biotechnologies, using the joint Sino-Italy buffalo research centre and private partners in China. The five-year project involves using artificial insemination; using genotyping technology to improve milk and meat production traits and to reduce methane emissions from buffalo populations; and establishing nucleus herds of Mediterranean buffalo with a higher production level and optimized management.

SSC is an important mechanism in technology development, transfer and diffusion. Benefitting from the support of the respective governments and due to substantial investments in R&D, many developing nations have developed home-grown technologies in agricultural biotechnology. However, the level of biotechnology development is uneven among countries with many where biotechnology is at an initial stage. The speakers highlighted that it is essential for countries to have functional



agricultural innovation systems to enable the effective utilization of agricultural biotechnology and that SSC is important in this context using three cases to illustrate this point. They demonstrated that SSC in agricultural biotechnology should be based on an integrated approach that includes product development along with capacity building, and that countries such as Brazil, Russia, India, China and South Africa (BRICS) can engage in SSC as a group, complementing each other's strengths providing complementary GMO and non-GMO biotechnologies.

Summary of the open discussion

Through the active discussions, moderated by Courtney Paisley from Young Professionals for Agricultural Development (YPARD) in Rome, the participants recognized:

- That capacity development for biotechnologies includes not only technical (hard) skills but also skills that allow scientists and other actors of the agricultural innovation system to communicate efficiently with farmers, government, private sector and the general public to negotiate, engage in political dialogue and raise funds etc.
- That capacity development needs to go beyond training individuals in biotechnologies, because if they go back to their institutions and do not find possibilities in their organization to continue research or if their countries do not provide an enabling environment to make modern technologies accessible to farmers, their training will have no impact and they do not have incentives to continue.
- That South–South and North–South partnerships, as well as partnerships between the public and private sector, based on common understanding and mutual interests, political will of the host government, and smallholder farmer inclusion, are the preconditions for successful partnerships that benefit the farming sector.
- The potential of lower-cost biotechnologies such as gene editing for bringing benefits to smallholders, and potential of creating open-source technologies affordable for developing and emerging countries.
- Potential roles of international organizations like FAO to support capacity development for regulatory systems in countries lacking them, for technical skills, for business incubation, as well as providing a platform for public and private sector institutions to facilitate open-source repositories for the new generation of biotechnologies and guidance on how to develop efficient partnerships.

5.4.2 Biosciences capacity building in Africa: Lessons learned from the Biosciences eastern and central Africa – International Livestock Research Institute (BecA–ILRI) Hub

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Background

The need to harness biosciences-based innovations to capitalize on agriculture's potential underpinned the vision of the African Union/New Partnership for Africa's Development (AU/NEPAD) Africa Biosciences Initiative (ABI). The ABI aimed to create four regional biosciences "centres for excellence" across the continent:

- NABNet (North African Biosciences Network) for northern African countries;
- WABNet (West African Biosciences Network) for Economic Community of West African States (ECOWAS) countries;
- SANBio (Southern African Network for Biosciences) for southern African countries;
- BecA–ILRI Hub for countries in eastern and central Africa – Burundi, Cameroon, Central African Republic, Congo, the Democratic Republic of the Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Kenya, Madagascar, Rwanda, Sao Tome and Principe, Somalia, South Sudan, Sudan, Uganda and United Republic of Tanzania. The BecA–ILRI Hub was established in 2002 when ILRI agreed with NEPAD to host the Hub at its headquarters in Nairobi, Kenya due to its interest in supporting agricultural research in the region through facilitation of access to modern research infrastructure by scientists in Africa.

The need for the BecA–ILRI Hub

- Biosciences are one of the major engines of global growth not just in agriculture but also in human health, environmental conservation and industrial processes.
- Africa lags behind in biosciences due to low human capacity and limited facilities.
- The main driver of the BecA–ILRI Hub is to support and mentor African scientists in the application of biosciences in food security and agricultural development. The platform hosts and supports the work of scientists from African national agricultural research systems (NARS), ILRI, other CGIAR centres and CGIAR Research Programs, international institutions and the private sector.



Key programme pillars

- Biosciences research;
- Regional bioscience platforms (genetics, genomics, bioinformatics, biorepository, nutrition);
- Support to NARS and CGIAR to address capacity gaps and partnerships.

The BecA–ILRI Hub’s state-of-the-art suite of shared biosciences platforms avail the best technologies to the African (and international) scientific community to address national, regional and continental priorities. The outputs of research, technologies and capacity building combine to achieve (developmental) impacts at the beneficiary level, e.g. increased productivity or improved food safety. The BecA–ILRI Hub’s vision is that by contributing to stronger NARS, the livelihoods of millions of resource-poor people in Africa will be improved through advances in agricultural bioscience.

Capacity building at the BecA–ILRI Hub

- Africa Biosciences Challenge Fund (ABCF) research fellowships, an essential driver of the BecA–ILRI Hub, which seeks to strengthen the capacity of individual scientists and NARS institutions to deliver on their national research mandates:
 - Research projects of 3–12 months;
 - African NARS-affiliated scientists;
 - Fit with BecA–ILRI Hub priority research themes:
 - Crop improvement;
 - Food safety and nutrition;
 - Livestock productivity;
 - Climate change mitigation;
 - Underutilized crop/animal species.
- Training workshops:
 - Introductory molecular biology and bioinformatics;
 - Introductory laboratory management and equipment operations;
 - Advanced genomics and bioinformatics;
 - Scientific research paper writing;
 - Animal quantitative genetics and genomics.
- Institutional capacity strengthening:
 - Technical assistance with laboratory design/management, equipment installation and procurement, training of engineers and laboratory technicians;
 - Support with resource mobilization;
 - Connections to networks, e.g. suppliers of reagents and laboratory equipment;
 - Customized training workshops at NARS institutions;
 - Brokering partnerships for research, training and resource mobilization.
- Mobilizing capacities for joint action:
 - Joint NARS actions for multicountry/multidisciplinary research.

Capacity building achievements

- Increased awareness of BecA–ILRI Hub;
- Regional impact of the ABCF on the NARS;
- > 15 research papers published and > 40 in preparation;
- Informing private sector, policy and local government;
- ABCF contribution to downstream impact;
- Strong endorsement of the ABCF fellowship scheme by stakeholders. Evaluation in 2014 found that 96 percent of stakeholders believe that the BecA–ILRI Hub builds the capacity of individuals and institutions to harness the latest bioscience technologies to improve agriculture in Africa;
- Four Communities of Practice at nascent stages – chicken genetics (four countries); fish genetics (three countries); striga resistance (four countries); taro improvement (four countries).

Challenges

- High demand for fellowships and training courses;
- Diversity of African research and capacity building landscape – some NARS are well resourced and others are less so. This has led to a decision to focus up to 2018 on engaging NARS in what the BecA–ILRI Hub calls “Stage Two” countries (where we have made substantial investments, matched by investments from NARS): Burkina Faso, Cameroon, Ethiopia, Ghana, Kenya, Rwanda, Senegal, Uganda and United Republic of Tanzania;
- Few applications from some countries;
- Few applications from women scientists;
- Limited investment by African governments.

Lessons learned

- Mentorship is a key cross-cutting mechanism in the capacity building process;
- A strictly competitive process for ABCF fellowships may not achieve strategic objectives;
- Need to engage National Councils of Science and Technology to provide return-to-home institution grants;
- Need to encourage NARS to provide increased co-funding of laboratory users and ABCF Fellows;
- Collaboration with other capacity building programmes helps to magnify impacts, e.g. African Women in Agricultural Research and Development (AWARD) and the International Foundation for Science (IFS).

Way forward

The development of an African-led R&D agenda that responds to market drivers and supports the transformation of agriculture as a driver of economic growth is being articulated by the African Union and its partners, including AU/NEPAD, the Forum for Agricultural Research in Africa (FARA) and other Pan African, regional and national bodies. Being aware of and responding to new priorities and new opportunities will keep the BecA–ILRI Hub relevant as well as responsive to the emergence of agriculture as a profitable enterprise in growing African economies.



The BecA–ILRI Hub faculty will be expanded to include as adjunct appointees more senior bioscientists working with African NARS as well as those with advanced and international research institutes. This expanded faculty will enable a broader and deeper range of capacity strengthening programmes to be conducted at the BecA–ILRI Hub and a larger number of young African scientists to be mentored in their research by more experienced African and international scientists.

Ensuring the availability of “state of the art” technology platforms across a wide range of modern biotechnologies is an important part of the BecA–ILRI Hub’s role as a shared research platform that is a “centre for excellence” for biosciences in Africa. These technology platforms serve multiple partners and research consortia that are addressing African agricultural issues. As bioscience is a rapidly evolving field, these technology platforms will need to be continually updated to stay relevant.

The BecA–ILRI Hub is accessible, but not always affordable, for scientists working in national research institutes and universities across Africa. Restricted core support from international investors will be needed to underwrite some of the fixed and capital costs. Mobilizing additional financial resources will also be required to fund more ABCF fellowships for African scientists. Affordability can also be increased by forming new partnerships with African governments and regional bodies, such as the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), the West and Central African Council for Agricultural Research and Development (CORAF/WECARD) and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) to support tailored capacity strengthening programs for particular countries/regions.

5.4.3 Case studies of public–private partnerships in agricultural biotechnologies: Lessons learned

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Introduction

Public–private partnerships (PPPs) have played vital roles in much of the progress of modern agriculture, from the creation and dissemination of hybrid maize in the early twentieth century to the green revolution of the 1960s and beyond. However, during most of the twentieth century, much of the leadership in organization and innovation in agricultural systems in industrialized countries was provided by powerful public bodies, such as the USDA and land-grant universities in the United States of America. This public sector dominance was much reduced after the 1980s as many state entities were privatized and/or suffered funding reductions. The process coincided with the growth of a dynamic, increasingly globalized agricultural biotechnology sector, originally based on agrochemical companies that diversified into bio-based areas including crop breeding and livestock management. As we move through the twenty-first century, future innovations and their implementation will require ever-closer partnerships (i.e. PPPs) between public entities (including state organizations, research institutes, universities, extension bodies etc.) and an increasingly diverse private sector that includes multinationals, small and medium-sized enterprises, NGOs, citizen groups, retailers, small farmers etc.

Such PPPs are especially important in enabling smallholders to contribute to the nature and implementation of modern biotechnology-derived crops, most of which have hitherto addressed the needs of larger commercial farmers and agribusiness interests. These PPPs tend to be highly dynamic as the nature of the various partners constantly changes, the technologies advance, and fresh challenges arise, such as climatic change and (possibly related) newly-emerging threats including pests and diseases. Because PPPs involve so many players and can occur at all scales from single farmers to globe-spanning international partnerships, it is difficult to describe them fully in such a brief presentation. Instead, three selected PPP examples relating to smallholders will be described in some detail in order to derive some lessons for future policy-making.

Case studies

a) Brinjal in Bangladesh: Breaking the impasse on GM crop acceptance?

While there have been several examples of widespread smallholder adoption of GM cash crops, most notably Bt cotton, several promising subsistence GM crop candidates have faced lengthy delays.



However, in 2013 Bangladesh approved Bt brinjal/eggplant for planting after a rapid approval process. In 2014, commercialization was initiated via a PPP when a total of 120 farmers planted 12 hectares. This followed strong political support from the government, with leadership from the Ministry of Agriculture, and close collaboration with farmer groups and private sector breeders. This approval by Bangladesh is important in that it has broken the impasse experienced in trying to gain approval for commercialization of Bt brinjal that blocked its introduction in India and the Philippines. It also serves as a possible model for other small poor countries.

Two other developing countries in Asia, Vietnam and Indonesia, also approved cultivation of GM crops in 2014 for commercialization in 2015. Vietnam approved Bt maize and Indonesia approved a drought tolerant sugarcane for food, whilst approval for feed is pending; 50 hectares of sugarcane were planted in 2014 for planned commercialization in 2015. In 2014, it is estimated that approximately 18 million farmers grew GM crops, about 90 percent, or 16.5 million, were small farmers in developing countries. In addition to economic gains, farmers benefited enormously from at least a 50 percent reduction in the number of insecticide applications, thereby reducing farmer exposure to insecticides, and importantly contributed to a more sustainable environment and better quality of life. All of these GM crops were introduced via PPPs.

b) Embrapa in Brazil: PPP-led GM crop development

Embrapa is the major public agricultural R&D organization in Brazil with an annual budget of US\$1 billion and has been especially active in fostering PPPs in agricultural biotechnology. It is one of the few public bodies to have developed and commercialized GM crops that are grown by farmers ranging from smallholders to large international combines. In 2014, Brazil planted GM soybeans with insect resistance and herbicide tolerance commercially on 5.2 million ha, up substantially from 2.2 million ha in 2013. In 2015, Embrapa gained approval to commercialize its GM virus-resistant bean, planned for 2016, plus a novel herbicide tolerant soybean, which it developed via a PPP with BASF (this variety is currently awaiting EU-import approval prior to planned commercialization in 2016). Embrapa is also developing GM folate-fortified lettuce and drought resistant sugarcane. Embrapa is an example of a large state enterprise that has taken the lead in innovative biotechnology crop development with PPP engagement, which has been primarily commercially focused but with increasing trickle-down to smallholders.

c) Emergence of agricultural biotech PPPs in Africa

Over the past decade there has been a range of PPP ventures in Africa that have focused on both GM- and non-GM crops aimed at smallholders. For example, Cameroon, Egypt, Ghana, Kenya, Malawi, Nigeria and Uganda have conducted field trials on the following broad range of staple and orphan crops: rice, maize, wheat, sorghum, bananas, cassava and sweet potato. The water efficient maize for Africa (WEMA) is a major PPP that is expected to deliver its first GM drought tolerant maize with Bt insect resistance in South Africa as early as 2017, followed by Kenya and Uganda, and then by Mozambique and United Republic of Tanzania, subject to regulatory approval. Over the past two years there has been a distinct improvement in state engagement with biotechnology-related PPPs in much of Africa.

Future lessons

The major lessons from recent PPP experiences are that success is dependent on a full commitment by host countries, appropriate regulatory systems, and the sustained participation of all partners, especially smallholders, over the entire duration of what can be complex and long-term ventures. Such lessons are especially important given recent developments in agricultural biotechnology. During the last few years, and especially in 2015, there has been a veritable revolution in genetic technologies with the development of gene editing methods such as CRISPR and TALEN. In terms of crop breeding, this means that it will soon be possible to progress from the random insertion of single or small numbers of genes into a genome (as in traditional genetic modification) to the highly precise insertion into a defined location of large numbers of genes, chromosome segments or pseudo-segments encoding entire metabolic pathways into virtually any plant species.

These new technologies will make current genetic modification methods (and their regulation) obsolete and there are already calls that organisms altered by gene editing should not be characterized as GMOs. Gene editing can considerably widen the range of traits (especially smallholder relevant traits in hitherto orphan crops) to be altered much more rapidly and cheaply than was hitherto possible. This provides a golden opportunity for the emergence of a new generation of PPPs aimed specifically at improving smallholder agriculture as we face up to increasing food security challenges across the world.



5.4.4 Building partnerships, empowering champions: The case of the Cornell Alliance for Science

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We face a global challenge of ensuring access to safe, nutritious food for an unprecedented population, while simultaneously seeking to minimize agriculture's negative impacts on the environment. Innovations in the field, such as the tools of genetic engineering, should help us address this challenge.

Many promising products generated using the tools of genetic engineering are in the late stages of development and testing. Public sector institutions, including universities and national agricultural research programmes, have played an important role in the development of these products. In many cases, scientists in the developing world not only lead these projects, but their farmers are the intended beneficiaries. In order for these products to reach their intended beneficiaries and to have impact on increasing access to a safe, sustainably-produced food supply in the face of an increasingly erratic climate, the proper enabling environment must be established.

Private foundations have demonstrated their willingness to make higher-risk investments to ensure these technologies do not bypass the poor. The Bill and Melinda Gates Foundation has invested across diverse areas of the biotechnology ecosystem to ensure its impact, making significant investments in the research and the development of products that will address the biotic and abiotic constraints that some of the world's most vulnerable farmers face. In addition, they have invested in programmes to help foster an effective regulatory environment. The Gates Foundation invests in capacity building to address the dearth of voices in the community that can help lead the debates around agricultural biotechnology and help to bring a rational, evidence-based voice to the global conversation around it. The Cornell Alliance for Science is one such initiative.

Founded in 2014 with a grant from the Foundation, the "Alliance" is addressing this challenge by building an international network of concerned scientists, farmers and humanitarian organizations working to restore the place of science in food policy decisions. The organization works to ensure that scientists have access to the tools they need to innovate for the grand environmental and food security challenges we face today; the organization also works to give voice to farmers, regardless of where they live, who need access to the advances in science to help them provide the world with a safe, stable and environmentally sustainable food supply.

Hunger, poverty, malnutrition and sustainable agricultural growth problems impact less developed countries more than others. Solutions such as biotechnology are often inaccessible to those who need them most. In the global biotechnology discussion, opponent activists continue to spread misinformation, obstructing the voices of those who would benefit most. Stakeholders around the world now must face the ambitious task of fostering constructive public dialogue and policy that employs biotechnology as a tool to help solve global challenges.

Recognizing this, the Alliance has three primary objectives:

Our first goal is to build a globally coordinated alliance of individuals and organizations who share our mission of promoting access to scientific innovation as a means of enhancing food security, improving environmental sustainability and raising the quality of life globally.

We believe that as a coordinated community, this global alliance will have a much stronger voice for science that can favourably shift the global conversation around biotechnology. We want to serve as a platform where individuals and organizations can lend their voices to advocate for science-based decision-making and encourage global coordination of a proactive pro-science community. Just over a year into our initiative, we have engaged over 6 200 “science allies” in 109 countries.

It is our hope that we can engage not only “likely” allies who already co-habit our shared “echo chamber,” but also the “unlikely allies.” These are the people who share our core values around access to safe, sustainably-produced and nutritious food, but who maintain a healthy scepticism of the technology.

Our second goal (and the focus of the oral presentation) is to strengthen the global network we are building through innovative training programmes in forward leaning and strategic communications. The Alliance uses a people-focused, metrics-driven approach to train and support knowledgeable, empowered champions to build effective communications strategies in their own country contexts.

We host two types of training programmes: The Global Leadership Fellows Program, a 12-week, Cornell University certificate programme designed to equip and empower emerging leaders who will advance our shared mission for a more enabling environment for the adoption of biotechnology globally. This programme, held in August through November on the Cornell University campus in Ithaca, New York State, combines modules on strategic planning and grassroots organizing, training on digital and traditional communications tools, exposure to global thought leaders, weekly colloquia, and field trips. Through this programme, we host and build the capacity of 25 fellows from approximately seven to ten countries.

Additionally, in a series of week-long “short courses” held regionally around the world, we work with the global leadership fellows to strengthen their networks through courses in strategic communications planning and grassroots organizing.

Global leadership fellows come from diverse backgrounds; from communications specialists working at national agriculture research programmes, to organizers at NGOs, religious leaders, scientists and others. Upon completion of the programme, the fellows are members of a growing collaborative



international cohort of forward-leaning communicators uniquely equipped to promote evidence-based decision-making around global issues such as food security, environmental sustainability and agricultural growth and to ensure that the tools of science, tools like biotechnology, do not bypass the poor.

5.4.5 North–South/West–East cooperation in agricultural biotechnologies: Some lessons from Italy and China in buffalo

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A case of applied solutions through capacity development and partnerships is illustrated in the sector of buffalo production between Italy and China. The operative steps in the process of capacity development and the accomplishments in terms of partnership are illustrated. Operational steps are focused on existing difficulties and possible solutions in the buffalo breeding sector of mutual interest for both countries through complementary use of different biotechnologies. The set of operational steps could also be fitted to buffalo improvement programmes in different countries of the Southeast Asia region.

Buffalo in the world

The world buffalo population is estimated to amount to about 195 million animals, spread over more than 40 countries. Ninety-seven percent or 189.79 million buffaloes are in Asia (Perera, 2011). India has 112.9 million (approximately 57.8 percent of the total), followed by Pakistan (16.2 percent) and China (12 percent). Buffaloes provide more than 10 percent of the world’s milk supply; their milk has a higher fat, lactose and protein content than cow milk. In the domestic water buffalo (*Bubalus bubalis*), we find two subspecies which are interfertile: the river buffalo, which is the predominant type in India, West Asia, America and Europe, and the swamp buffalo which is found more frequently in Southeast Asia and China. The two subspecies differ in morphology, behaviour and chromosome number. In fact the river buffalo has $2n = 50$ chromosomes and the swamp buffalo has $2n = 48$ chromosomes.

River buffalo

The population of river buffalo is estimated to amount about 158 million animals. River buffalo breeds have become mainly dairy animals and among those, Mediterranean, Murrah and Nili-Ravi are the most productive breeds for milk yield. The Italian Mediterranean breed has a well-established recording system, supporting since the early 1990s an official breeding programme for the genetic improvement of dairy traits. The Italian Mediterranean buffalo breed is a small population compared with Asian buffalo populations, representing only 0.19 percent of the world buffalo population. However, it is the largest “active population” in the world. In fact about 54 000 Mediterranean buffaloes in more than 300 herds are currently milk-recorded in Italy. This recorded population



is used to run a national genetic improvement programme allowing progeny testing of at least five young bulls every year. Currently more than 20 proven bulls are producing frozen semen in Italy.

The Murrah buffalo is mainly found in the Indian sub-continent. Murrah has spread widely to other parts of Asia and in the world and it has been broadly used as an improver breed. The population size is over six million animals (Borghese, 2005). The Nili-Ravi buffalo is mainly farmed in Pakistan but it is also present in India. The population size is of about 6.5 million head (Borghese, 2005). The three dairy river buffalo breeds present differences in dairy performance. Currently the Italian Mediterranean breed shows the highest milk yield production per day as compared with Murrah and Nili-Ravi breeds. Additional important traits to be compared are body weight, age at first calving and calving interval. For all these traits the Mediterranean breed has the most suitable phenotypic values for a dairy buffalo type. In particular, it is important to underline the smaller body size of the Mediterranean breed, about 20 percent and 10 percent smaller than Murrah and Nili-Ravi, respectively. This means that Mediterranean buffaloes need less energy for body maintenance.

Swamp buffalo

The population of swamp buffalo is estimated to amount about 37.16 million, representing 19 percent of the total world population (Perera, 2011). The history of swamp buffaloes is rooted in the traditional agriculture based on smallholdings; in fact they play a major role in the practices and economic income of small farmers. These buffaloes are easy to raise, the costs involved in raising them are low, and they can make full use of low-quality local forage. They may be used for the cultivation of crops and for rice field preparation, and their dung is used as a soil fertilizer so reducing expenditure on chemical fertilizer and preserving the environment. Swamp buffaloes are smaller than water buffaloes and they are very poor in milk production, the average milk yield ranging from 1.0 to 1.5 kg/head/day over 270 to 305 days of lactation.

Buffalo breeding and greenhouse gas (GHG) mitigation

Methane emission from enteric fermentation is a major source of agricultural GHG emissions. Enteric fermentation from ruminants is the largest single source of methane total emissions. The world buffalo population contributes significantly to such methane emissions. It is well known that the following actions can mitigate the total GHG emissions from ruminants per unit of milk and/or meat produced: 1) increasing productive and improving reproductive traits in a given population; and 2) improving feeding strategies in a given herd. Both of these goals could be achieved by suitable buffalo breeding and buffalo herd management programmes. Increasing the efficiency of production can reduce the total number of animals needed to produce a fixed level of output. In the world buffalo population, room exists for such improvement and modern genetic improvement technologies should be more largely adopted.

Use of biotechnologies to improve buffalo milk production in China

In China, 23 million swamp buffalo are farmed and about one million of swamp buffalo have been mostly crossed with Murrah and Nili Ravi river buffalo to produce milk. Cross-breeding has improved milk production in the first generation but, in the long-term, crossing alone will not improve milk

yield in the Chinese buffalo population. CREA has proposed a five-year project based on three applied biotechnologies: 1) using artificial insemination to replace a subpopulation of swamp crosses with Mediterranean buffalo; 2) using genotyping technology to improve milk and meat production traits and to reduce methane emissions from buffalo population; and 3) establishing nucleus herds of Mediterranean buffalo with higher production levels and optimized management.

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5.4.6 South–South collaborations in agricultural biotechnology: Lessons learned

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South–South collaboration is an important mechanism in technology development, transfer and diffusion. Thanks to the support of the respective governments, with massive investments in R&D, many developing nations have developed home-grown technologies in agricultural biotechnology. They may range from tissue culture to development of GMOs and gene stacking.

A RIS study of biotechnology capacity in the Asia-Pacific region showed that while many countries remain at the low end of agricultural biotechnologies, some have moved rapidly to high-end technology. The picture in Africa and Latin America is no different. In Africa, agricultural biotechnology has taken roots in few countries such as South Africa while in many countries it is in the initial stages. Similarly in Latin America, while countries like Argentina, Brazil and Mexico have applied this technology rapidly despite controversies, in many countries it is in the initial stages. Another important concern in agricultural biotechnologies is that of biosafety and many developing nations have ratified the Cartagena Protocol on Biosafety. In fact, countries with very limited activities in agricultural biotechnologies have ratified the Protocol and hence are bound by it.

For effective utilization of agricultural biotechnology, it is essential that countries have a functional innovation system in the agricultural sector. This is important for technology adoption and further development of agricultural biotechnology.

This talk presents three case studies where South–South cooperation (SSC) has helped countries move upward on the trajectory. The areas captured are cooperation for capacity building in biosafety management; India-Bangladesh cooperation for Bt brinjal; and cooperation for primary biotechnology.

The presentation concludes that, in the long run, SSC in agricultural biotechnology should be based on an integrated approach that includes product development along with capacity building. The groupings like India, Brazil, South Africa (IBSA) and Brazil, Russia, India, China and South Africa (BRICS) can play important roles as they can engage in SSC as a group complementing each other's strengths. As the countries in these groups have the capacity to develop GM and non-GM boutiques of agricultural biotechnology, they can jointly promote SSC projects in this field.



Chapter 6

Student interactive session: Bringing fresh perspectives



6.1 Report of outcomes from the student session

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I would like to start by thanking Louise Fresco, Ren Wang and Marcela Villarreal for their tremendous support and encouragement to organize this session. It was a first for FAO and for the seven universities from the different regions of the world, who co-hosted it with us. These were the West Africa Centre for Crop Improvement from the University of Ghana; Universidad Nacional de Colombia; Bogor Agricultural University from Indonesia; La Sapienza from Italy; American University of Beirut, Lebanon; Wageningen University from the Netherlands; and Cornell University from the United States of America.

As you know, in preparation for this event, these universities hosted webinars of the opening plenary session which took place on the morning of 15 February. The student representatives who participated in the session yesterday collected inputs from their fellow students, colleagues and teachers and put together their comments which were presented yesterday. So, thanks to all the teachers, student representatives and the technical staff for making it happen. Thanks to Young Professionals for Agricultural Development (YPARD) for joining hands and organizing the session with us and to all who watched online and sent their tweets. I am pleased to report that it was the most visited session of the symposium with some 4 000 impressions.

The student session lasted one and a half hours and there were five panelists: Gebisa Ejeta (Purdue University), Louise Fresco (Wageningen University and Research Centre), Margaret Gill (CGIAR Independent Science and Partnership Council), Gunter Pauli (Zero Emissions Research and Initiatives Network) and Maria Helena Semedo (FAO Deputy Director-General). The session started with key messages from the five panelists. They were passionate in their messages. They urged the students to build a strong foundation of education, to bring their skills to transform agriculture, to understand the problems, to learn, to unlearn, to take risks and innovate and find new linkages and applications to address the current and future challenges of food security and nutrition. They did not mince words. They said that whatever you have learned you will probably need to unlearn and start learning again because things are changing really fast.

The students, in turn, presented their statements and posed a wide range of questions to the panelists. In fact, there were so many questions and so little time that probably we should repeat the initiative. These questions covered a lot of ground, starting from job opportunities, especially for agriculture students; engagement with FAO policy-makers – how to do it, who will take the lead, who will

support them?; integration of science so that the public have a better understanding; how to improve communication – the gap in communication between smallholders and researchers (a recurring theme which was heard in other sessions); access to new biotechnologies – how will small farmers benefit from these biotechnologies?; what are the issues linked to intellectual property rights; what are the issues about genetically modified organisms (GMOs) that bothered them?; and how to conserve local knowledge and local genetic resources?

Three main points came out of the session:

1. The student community wants to be part of the dialogue in the decision-making processes. They want to know about the opportunities, and the decisions being taken on their behalf. They emphasized that there is a need to improve communication between policy-makers, researchers and smallholders about biotechnologies in all its forms; its benefits, risks and opportunities. Panelists fully supported and welcomed this opportunity for dialogue. The proposal for Youth FAO energized the students and everyone was tweeting about it. The students would like to see such sessions repeated with FAO on different occasions and with different themes, particularly at the regional level.
2. Biotechnology has to be better integrated and linked with other topics and issues related to food and agriculture. Agricultural biotechnology should be considered a part of the whole production chain complemented by a programme to assure marketing of the product obtained in each one of the parts. Funding should be increased for research for local needs, extension and rural education programmes for smallholders and students, so that both can get involved with new technologies, and add dignity and improve life quality in rural areas.
3. Students emphasized that participation of farmers and inclusion of smallholders in policy processes is essential to be able to transfer biotechnologies for their needs. Universities and small and medium enterprises have to work together to develop the rural communities to take and adopt these technologies. They want to have better capacity, a better understanding of issues. Academia, research centres, industry and communities should create new opportunities that can help young people to access and go to rural areas. Students from the cities particularly feel isolated and that they are losing touch. They don't want it, but that's the way it is. What can we do to change the approach? Panelists, in turn, noted that this session has created an opportunity and it should be seized to move forward. In closing the session, Maria Helena Semedo and Louise Fresco thanked the students for their active participation and reiterated that there was a need for a comprehensive approach to biotechnology to build trust and reduce risks. Appropriate policies at a higher level, together with appropriate regulations, were essential for a better engagement with biotechnology.

To sum up, the interaction confirmed that the student community is both hopeful and concerned about the role of biotechnologies and the state of food and agriculture and its impact on small farmers. They are aware of the new technologies, the vast new potential and the rapid advances that are being made. But will it translate into a better future? Will it make the world better? These are the larger questions that merit our reflection. Thank you.



6.2 Inputs from American University of Beirut, Lebanon

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Today, food production in the Near East region is facing many challenges, the primary one being climate change which is shifting our region from semi-arid to arid. Further, it is estimated that by 2050 we will have almost 692 million mouths to feed in one of the driest areas in the world. We believe that biotechnology is one of the tools to face this problem but, unfortunately, in most countries of our region, research in biotechnology is very limited and faces many problems, as noted below:

- the absence of national/regional strategies to address biotechnology-related issues as reflected in the absence of legislation and policies regarding biotechnology research, biosafety, transgenic crops and new technologies such as precision genetics;
- lack of proper communication resulting in poor public knowledge of the issue and their fear of biotechnology, as people are asking “Is it safe for consumption? Does it harm the environment?” or making statements such as: What you are doing is unnatural;
- lack of sustainable research funds to conduct long-term research along with the absence of proper infrastructure such as adequately equipped high-tech laboratories (which we have only few), appropriate glasshouses and research facilities;
- lack of cooperation and coordination between NGOs, governmental organizations, farmers and research establishments along with the limited governmental support to the agricultural sector;
- failure to attract and retain local expertise or skilled and experienced personnel by failing to provide them with the tools to achieve their ambitions;
- limited baseline data on the inventory and characterization of some or most local genetic resources.

American University of Beirut students support the advancement of biotechnology especially in terms of plant and animal tolerance to abiotic factors such as heat, drought and salinity, improving productivity and nutritive value of crops, resistance/immunity to plant and animal diseases. We believe that research in these areas can aid in overcoming the problems previously described as long as the ethics are conserved along with the safety of consumers and the environment.

We believe that intellectual property rights (IPR) should be reconsidered. Multinationals make use of the genetic resources found in developing countries, selecting genes of interest and using them for

their benefit in producing transgenic crops. It is reasonable to be rewarded because they are spending money, time and effort in studying biodiversity and discovering beneficial genes. However, these companies should be prevented from monopolizing this technology. We demand a way to allow firms and developing countries to mutually benefit from advancements in science and technology. This can be accomplished through:

- reconsidering IPR and breeders' rights to meet the needs of smallholders;
- supporting developing countries to upgrade their infrastructure, training of administrators, researchers and policy-makers, issuing proper legislation concerning biotechnology research and biosafety, and to take the right decision based on their own risk assessment. Developing countries should have the right to ban the entry, or ask for appropriate labelling, of any product containing or derived from GMOs;
- encouraging developing countries to engage in dialogue with smallholders and, based on the local need assessment, invest in biotechnology by making use of existing indigenous knowledge and resources;
- establishing deterrent penalties on firms/persons who hide information about the biosafety of a newly introduced product;
- developing capacities for management of genetically engineered crops.

Additional important points include:

- establishing a regional platform for sharing expertise and harmonizing laboratory procedures;
- encouraging innovative farming practices through merging biotechnology, conventional breeding and organic agriculture for sustainable development in reference to Professor Gunter Pauli on enhancing resource productivity;

With globalization, sustainable development in developing countries becomes the world's responsibility; problems in one country may result in problems in other distant countries as evidenced by immigration waves to developed countries.

Questions:

1. The major concern in Lebanon is biosafety and hiding information about labelling. How can this be addressed?
2. How can compromise be found on IPR to make technology more accessible to resolve problems in developing countries?



6.3 Inputs from Bogor Agricultural University, Indonesia

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Good evening, Ladies and gentlemen, my name is Irvan. I am the student representative from Indonesia. It is an honour to be invited to organize and participate in the agri-biotech webinar event of FAO. We conducted a discussion with eight universities across Indonesia and have concluded that biotechnology is a factor to achieving success for a sustainable food system and nutrition in Southeast Asia, especially in Indonesia.

In the modern world perspective, biotechnology in Asian countries, especially in Southeast Asia, is far behind the Western world. For instance, many biotech seeds (GMO) are monopolized by giant multinational companies. They protect their seeds with IPR, which causes dependency of developing countries and smallholder farmers on multinational companies. However, the costs for developing countries, like Indonesia, to develop their own seeds are expensive and it takes a long time to create a successful output. If food sustainability and nutrition are rights for every country, then we need to eradicate capitalism in biotechnology. In Indonesia, however, we don't rely on GMOs. Our farmers put a great effort to developing and making hybrid seeds themselves. Therefore, we urge the panelists to prioritize support to local biotechnology development.

In order to protect the rights of good food and nutrition to all people, FAO and related institutions must focus on how to educate and strengthen the local farmers to be independent and developed. This might be done by giving capital support which include human, financial or even constructed capital. Developed countries should help developing countries in term of biotechnologies education and help them to be independent, not to be dependent. Biotechnology should be the property of government, NGOs and local communities and not the responsibility of private sector for profits.

Traditionally, Asia is a rich continent with thousands of heritage cultures and high biodiversity. This legacy has proven to be the crucial resource for sustainability. Asia is already aware of simple biotechnology for centuries. For instance, fermentation processes. Biotechnology is part of our culture. We have tempe in Indonesia, kimchi in Korea, appam in India, gundruk in Nepal etc. We have hundreds of fermented foods. Many of our fermented foods are healthy nutrition sources, a cultural treasure and source of income to communities.

On biodiversity, the focus on high productivity in developing countries often contradicts the preservation of biodiversity. Illegal deforestation is happening every year. As a developing country, we believe that high productivity should be hand-in-hand with protecting nature. We propose:

- Policy-makers, scientists and international bodies to consider the local wisdom in the making of policy. Deeper research should be done before making any policies.
- Policy-makers need to consider the biodiversity. Illegal activity that could harm preservation should be punished, without exception.

Lastly, in Asia's case, especially Indonesia, we have obstacles in agricultural branding, especially with youth interest in agriculture. Young generations tend to choose popular topics such as medicine, law, engineering, etc. Agriculture is considered far inferior to those topics. Agriculture is related to dirt, crops and low salary jobs. Following these issues, we propose to FAO and policy-makers to support student associations and youth activities that relate to agriculture. We believe that more participation from youth equals higher success rates in our agriculture. This will automatically affect the sustainability of agriculture, especially biotechnology. This is why I joined the International Association of students in Agricultural and related Sciences (IAAS), the largest agricultural student association in the world. IAAS Indonesia has an activity called Youth Agriculture which aims to make agriculture sexier than ever before.

Questions:

1. For Gunter Pauli: Earlier in this statement, we proposed to focus on giving capital support to local farmers. How can the Blue Economy support this proposal, what is the relation between them, and how can Blue Economy support the 2020 Goals related to the proposal?
2. For Maria Helena Semedo: In Asia, the image of agriculture is less popular than other subjects such as economics, law and medicine. How will the effects of Zero Hunger programmes raise the image of agriculture to youth as a career?
3. For Gebisa Ejeta: Imagine that sorghum projects are being implemented in Asian countries where farmers already have other crops growing on their land. What is the argument supporting urgency to plant sorghum in Asian countries?
4. For Louise Fresco: You have vast experience in running boards across several continents and see agricultural development in many parts of the world. Which country is more likely to succeed in reaching independence to ensure the sustainability of food and nutrition – the country using GMOs, or the country against GMOs?



6.4 Inputs from Cornell University, the United States of America

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We are impressed with the scope of this FAO symposium to address the role of agricultural biotechnology in our global food system. The students at Cornell University noted an overall recognition of the importance of communication in the implementation of new technologies. We certainly do not disagree.

However, we suggest focusing on the following four points:

1. Existing communication gaps between policy-makers, researchers, farmers and consumers inhibit actions in implementing solutions to food security that require input from each stakeholder.
2. Agricultural extension systems provide a “way in” for policy-makers and researchers to work with smallholder farmers, who often lack a voice in decision-making. More fully supporting those working in extension is necessary to strengthen these systems.
3. We must embrace innovative solutions to foster specific and successful networks. Too long have we relied on imprecise methods of capacity building instead of using data-driven methods.
 - Network analysis and visualization tools offer tangible solutions that can be implemented TODAY to help address capacity building in smallholder communities. Additional data-driven solutions should be regularly employed to help farmers make smart decisions about what to grow, and when.
4. As we know, scientific methods include successful and failed experiments and we learn from both. It is important for policy-makers to become comfortable with the fact that science is cumulative, and failure is a necessary part of the process. Funding science does not always mean funding success – at least the first time around.

That being said, I would like to challenge you to facilitate a more in-depth discussion that takes full advantage of the people and stakeholders you currently have available.

Few people disagree with the fact that local knowledge is valuable and community wants and needs should be incorporated into development work. Rather, we need to address the communication gap by utilizing existing extension networks to facilitate a system that transports ideas, wants and needs in both directions. Many see the current system of implementing biotechnology as a top-down approach, where researchers and policy-makers develop solutions independently from beneficiaries.

The scientific community has the responsibility to communicate the benefits and limitations of research. This is especially true in agricultural biotechnology, where the objections move beyond those which science can answer. Policy-makers must reconcile with competing economic and development interests, while still amplifying the voices of their constituents.

I would like to thank each of you for including students in this symposium. We are excited and enthusiastic about participating, and agree that incorporating a diverse number of stakeholders in your approach to agricultural biotechnology policy is an important step in creating an effective strategy. Thank you.

Question:

What are some policy incentives that would encourage public–private partnerships in the biotechnology sector while creating opportunities for small businesses and researchers to capture some of the potential profit?



6.5 Inputs from Universidad Nacional de Colombia, Colombia

Nathalie Tatiana Acosta and Juan Carlos Rojas

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Colombia is a unique country with a privileged geographic position, giving it a wide variety of ecosystems, weather and biodiversity, including its own genetic material of livestock, fishes, forest, crops and micro-organisms. Our country traditionally has been an agricultural producer.

Eighty years ago, 70 percent of Colombia's population lived in rural areas. Today, rural areas are inhabited by only 25 percent of the population (approximately 11 300 000 people). This is largely due to migration of the rural population to cities, resulting from internal conflict (paramilitaries, guerrilla and drug trafficking) and poor living conditions of the rural areas. Notably, 70 percent of the total food consumed in Colombia is produced in its rural areas by smallholders, an incredible number taking into account that less than 55 percent of the smallholders do not receive technical assistance.

Today, Colombia is negotiating a peace treaty between the government and the guerrilla, which should change the rural environment in our country.

Suggestions, opportunities and challenges: “A rich country with poor people”

Income generation through development of new biotechnologies can be one tool for combating narcotic trafficking, especially for smallholders living and working in areas of conflict. Development of biotechnologies should be considered as a part of the production value chain, and with a complementary marketing programme can ensure income stimulation. Investment in research funding to address local needs such as extension and rural education programmes and engaging smallholders in new technologies can add dignity and improve the quality of life to people living in the rural areas.

It is important to choose and prioritize the research applied to local needs, including traditional knowledge of the communities. This research can create a link between academia, research centres, smallholders and the market to develop new value-added products (i.e. certificate of origin, products coming from conflict areas now in peace and gastronomic new trends).

Considering that Colombia is a biodiverse country, it is necessary to conduct research on the identification, depuration, evaluation, conservation and uses of native species and varieties produced in local communities to preserve genetic heritage resources. This is especially relevant given the change in global climatic conditions. An example of such research is a project undertaken at the Institute of Biotechnology at the Universidad Nacional de Colombia, with the cooperation of the Netherlands, to conduct research on genetic identification, depuration and increased pest resistance of varieties of yams and the use of biopesticides and biofertilizers in small communities.

Colombia's national policy of science, technology and innovation is focused on the biotechnology, but it is only designed for funding of big biotechnology enterprises (industrial producers). While some biotechnologies may not be relevant to smallholders, there may be opportunities to bridge and adopt this knowledge for the smallholders' benefit. We suggest support and inclusion of smallholders in policy dialogue and policy development for increasing strong governmental extension programmes and addressing smallholders' biotechnology needs and concerns. This could be possible through promotion of smallholders associations and organizations with political will.

As Colombian students, we would like to ask FAO to support the involvement of smallholder organizations in the development of biotechnology policies and applied research programmes. Also, financial support is required to develop local projects and build capacities of smallholder associations and cooperatives, leading to increased incomes which will raise the welfare and dignity of the rural population.

Finally, we would like to emphasize the integration of academia, research centres, industries and communities to jointly develop new opportunities which will encourage the return of young people to the rural areas.



6.6 Inputs from Universidade Federal do Rio Grande do Sul, Brazil¹⁵

Felipe Vargas

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Brazil

Before addressing the panel and to all the students that are watching and listening to right now, I would like to thank FAO for giving me the opportunity to be here.

As a social scientist, I would like to address many subjects. However, I recognize the need to be short and sharp in my contribution in this particular session. For the record, I emphasize an interesting feature of these debates: that some ideas and concepts such as “small farmer” do not mean the same in all corners of the world; that the word “biotechnologies” encompasses many old and new technologies and techniques; and even the heterogeneity of the stratum of students present in this session, including graduates and postgraduates, engineers, biologists, agronomists and sociologists.

At a parallel session yesterday, I attempted to formulate a question about the relation between biotechnological processes and the logical way to implement them on behalf of small farmers. For me, two main ideas seem to be often repeated in the symposium: 1) biotechnologies are not equal to GMOs; and 2) we need to integrate small farmers into biotechnological development. Useful ideas were presented in this axis. I will try, at least, to address them.

“Biotechnology” has multiple meanings, even if sometimes we use it indistinctly. It is a definition that is not easy to grasp. In this idea, with the gratitude that I feel about this open debate, there comes also worries or concerns. My worry about “biotechnologies are not equal to GMOs” is in the way that this “broader” definition de-emphasizes the particularities of each biotechnology. For instance, the recent history regarding what the implementation of some biotechnologies implies. In Brazil, as well in other countries such as Uruguay, Bolivia (Plurinational State of) and Mexico, for instance, there are plenty of examples of farmers who have lost access to seeds or the right to save them. This has resulted in diminished varieties, which have lost some features of the social, cultural and historical processes of farming because of the GM crops and some “biotechniques” such as *in vitro* fertilization or laboratory fermentation.

¹⁵ Felipe Vargas delivered his statement while attending the student session in Rome. Unlike those from other universities, the statement was not prepared following the hosting of a webinar to gather inputs from other students at his university.

I will address biotechnologies in the framework of the processing (part of) of farming materials outside the context of the small farmers' lands. Biotechnologies give power, but they do not allow one to define its use or the directions it should take. It is, of course, a technical insight but also a political one, and I'm going to define politics as the various possible ways we assemble persons, things or institutions all together.

In the implementation of GMOs, for example, we have a tricky assemblage. To be adapted and become productive, the GM crops must rely on the local varieties (the crossbreed that takes place after the laboratory modification and before the sowing) the same varieties that come to be reduced after a while in the name of production. This is a paradox.

And my second concern, about "the need of small farmers' integration", goes in the same direction. Taking forward what Dominic Glover said in a parallel session of this symposium, that these are the same varieties passed on by generations and they require and express the attachments of small farmers at "homemade knowledge". But taking these away for laboratory analyses and "improvement" can de-contextualize them. This is the case in Brazil and for some southern states such as Rio Grande do Sul, Santa Catarina and Paraná. Such varieties carry specific potential in facing food scarcity, nutrition and climate change within the assemblages they respond to. Another paradox. It is not that we must avoid change. But it is important to envisage change without taking "production" and "integration" for granted. I have seen many of the presentations during the symposium about fungus cultures, fermentation, livestock with artificial insemination and so on, and my worries apply to them in the sense that they might also activate this historical framework.

My questions then are very concrete: how to target the new biotechnologies to small farmers so that no one loses, especially them? Which policies or decision-making tools do we have to account for farmers' choices? I do not know if IPR can answer that, but it is imperative that small farmers are included in discussions at each step.

To me, this is a concrete question with a concrete line of action. I hope it will make us hesitate about the "certainties" of benefits. Certainties, I emphasize, in contrast with "supposed" risks that biotechnologies produce. Thank you all once again.



6.7 Inputs from Università degli Studi di Roma “La Sapienza”, Italy

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Sustainable food systems: A point of view of the Italian students

In 1944, the agricultural initiative known as the “green revolution” had an aim to save over a billion people from hunger and malnutrition. According to FAO data, at the end of the 1960s, 34 percent of people living in developing countries were malnourished. In the last 25 years, this has declined to 13 percent, with a slight increase from 2002 to 2007.

Through science and technologies, the aim of the current generation will be to improve food production while reducing soil erosion and minimizing use of fossil fuels and water resources. The key words are “productivity” and “sustainability”. To find medium- and long-term solutions, it will be essential to investigate basic biological and molecular biology research. For example, research will allow for: 1) greater understanding of plants and the biological inefficiencies to improve yields while starting from the same input resources; 2) understanding how a plant responds to environmental stresses in order to develop stress-resistant plants; and 3) sequencing of the most important agronomic species. Modern biotechnology techniques, such as genome editing, can enhance scientific knowledge and its applications.

Agricultural biotechnologies have a key role in sustainable food systems and nutrition, particularly in food safety. Notably, fungal pathogens generate severe safety and economic losses by killing plants or reducing their yield through contamination of mycotoxins; hazardous side effects caused by chemicals continue to emerge; environmental pollution is impacting human and animal health. To preserve safety and quality of crops, such as cereals, biotechnology research programmes can stimulate plant defence through biocontrol agents, using biopesticides to limit pathogen growth, inhibiting or degrading toxins with biodegraders.

A great percentage of worldwide energy comes from fossil fuel refineries. The use of biomass as a renewable energy resource has gained attention in the last decade due to its potential to reduce the carbon dioxide burden of the atmosphere. In most cases only parts of the incoming biomass are actually used for the generation of a particular food product, with potential biogenic residues occurring in large quantities during the food processing stage (“product specific residues”). The most prominent use of food processing residues includes biomaterial resources, animal feedstock, chemical feedstock and energy resources.

In the last few years, the development of mixed culture processes for polyhydroxyalkanoates (PHAs) production from agro-industrial waste effluents has gained considerable attention from researchers. PHAs are among the most promising candidates as substitutes for synthetic polymers. Indeed, PHAs are biologically synthesized polyesters completely biodegradable to water and carbon dioxide and can be produced from renewable resources. The main applications of PHAs include packaging, compost bags, agriculture/horticulture films and bags (e.g. mulch films), durable goods and consumer retail goods (cosmetic and hygiene materials).

Environmental pollution is one of the risk factors increasing incidence of non-communicable diseases, together with poor diet, physical inactivity and psychological stress. According to the World Health Organization, in 2008 approximately 37 million deaths were attributed to non-communicable diseases. Increasing consumption of fruits and vegetables containing nutraceuticals and bioactive substances can reduce the risk of death due to non-communicable diseases. Further research in health medicine and modern biotechnologies can provide assessments on disease predictive index throughout metabolic suitable parameters.

In sum, it is the duty of wealthy countries, companies and international organizations to realize a more equitable world through a redistribution of wealth, regulating processes and involving local communities in the development of their nations.

Questions:

1. In order to enhance productivity, sustainability and food safety of the most important agronomic species that are best adapted to each environment, it is key to develop solutions through modern biotechnologies. Do you think it will be possible in Europe?
2. People are concerned about the use of modern biotechnologies in nature. Today it is more important than ever that the dissemination of biotechnology information be shared with the public. Would it be helpful for citizens to encourage scientists to share this information?



6.8 Inputs from University of Ghana, Ghana

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The role of agricultural biotechnology in sustainable food systems and nutrition

Biotechnology can meet the growing demand for food due to rapid population growth and consequences of climate change on agricultural production. Biotechnology offers an opportunity to develop new plant varieties with beneficial genetic traits for high yield, pest and disease resistance, improved nutritional value, and tolerance to drought, salinity and herbicide to adequately meet the growing population and conserve our biodiversity.

Conventional breeding approaches have been used by scientists to improve plants and animal for human benefit for over decades. However, conventional breeding through crosses takes 7–10 years to breed a new variety.

With biotechnology, modern crop breeders can identify and move gene(s) conferring a specific trait into another plant with ease and precision, selecting for the most beneficial traits. These tools also allow plant breeders to overcome cross-ability barriers. Beneficial traits such as high yield, high beta-carotene and high iron can have great impact on sustainable food production and nutrition in our systems. The advent of biotechnology increases job opportunities for men, women and youths and reduces the labour involved from production to processing along the food value chain. Consumption of biofortified food developed through biotechnological means, can reduce nutritional deficiency in the vulnerable population in Africa.

Despite all the benefits of agricultural biotechnology, gaps exist in Africa regarding gender issues, capacity building, technology transfer and genetically modified products. We believe that providing solutions to concerns raised below will address challenges facing Africa in agricultural biotechnology.

1. Why is technology transfer from West to Africa slow?

There is weak collaboration between the western world and Africa in such a way that available technologies are not accessible to Africans. This increases the dependency of biotechnology application on the western world and retards the development of Africa in the area of biotechnology.

2. How do we deal with the poor adoption of GMOs in Africa?
The adoption of biotechnology is limited by low levels of education of stakeholders, lack of biotechnological facilities and commercialization of the GM products. The beneficiaries of the technology are not well informed of its benefits and risks. This gives rise to misconceptions which implant fear in beneficiaries leading to low adoption of the technology. Additionally, limited job opportunities in Africa render biotechnologists ineffective in knowledge transfer.
3. What are the policies governing the introduction and use of GM products in Africa?
There is fear that the introduction of GM varieties will result in loss of landraces which will eventually put our poor farmers at the mercy of multibillion companies with unaffordable cost on GM products. In this regard, there should be regulations to effectively conserve our landraces with the introduction of GM varieties and control the price of GM products.
4. What opportunities exist for youth in Africa as next generation policy-makers?
Youths in Africa have received little consideration regarding biotechnology. By exposing the youth to biotechnology activities as next generation policy-makers, the youth can institute measures that will improve and promote biotechnology in Africa. Additionally, the youth can also engage in training and public sensitization for people to appreciate the benefits of biotechnology to subsequently reduce the controversy on the use of GMOs in Africa.
5. How do farmers benefit from biotechnology?
The larger portion of the world's poorest and hungry population is the small-scale farmers, the majority of whom are in Africa. Major limiting factors to food production in Africa include: land issues, disease and pests, drought, poor soils and poor quality seed. Biotechnology can effectively contribute to mitigating some of the above issues in Africa, for example: increased productivity and reduction in production costs, improvement of farmers' health by enriching staple food with more nutrients such as essential vitamins, reduced effects on environment, reduced poverty and increased income.



6.9 Inputs from Wageningen University, the Netherlands

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First and foremost, thank you for including this student session as part of the agri-biotechnology symposium. We feel extremely privileged to share Wageningen University's students' perspectives on biotechnology.

The current and future problems in food insecurity and agriculture globally are complex, and have been extensively talked about during this symposium. We believe biotechnology can be one of the potential solutions to eradicating hunger through an integrated approach. To begin, we would like to start with input of Wageningen students in the form of three points of discussion.

First, we believe it is essential to employ public debates to raise awareness and insight on biotechnology. This has not been sufficiently addressed; people must be informed to develop proper opinions. These debates should be transparent and not based on assumptions.

Second, we have heard from many pro-GMO speakers that current regulations on GMO technology take too long. Multiple independent studies have shown that GMOs do not have adverse effects. However, as Professor Louise Fresco said: no evidence of risk is not proof that there is no risk. Thus, we strongly recommend that while shortening current regulations, the quality of the regulation and the quality of the decisions should be strictly maintained.

Finally, we suggest an integration of both agroecology and biotechnology and not to consider these as completely different fields of study. We sincerely hope, as Professor Gunter Pauli has shown, that multiple approaches are seen as feasible, and that a multidisciplinary approach is preferred. The world hunger problem is more than simple technical and financial issues, and we believe that investments in science in the broadest way possible are needed. These investments are not necessarily the same techniques in which the big companies are investing – where public demand has already been established. A narrow view could potentially lead to lost opportunities of finding solutions, as Professor Pauli has demonstrated to us in using the example of a whole-chain approach.

In sum, we recommend biotechnology as a systems approach – an integration of the best of both worlds. We would suggest to organize a symposium bringing both fields of study which could potentially lead to even better solutions than a symposium on biotechnology alone. We would appreciate the opportunity to participate as students and scientists in this potential event.

Questions:

1. Local knowledge, needs and social dialogue are said to be important in biotechnology innovations, but in which phase of the innovation process are they needed – at the moment of setting the agenda for research and development or at the point of implementation?
2. In your opinion, can the world hunger problem be solved by investing in agroecological approaches, and, if so, why do you believe we need to invest public budgets in biotechnology?
3. In solving world hunger with biotechnologies, are we not overlooking the fact that a huge share of the arable land is now used to produce feed for livestock animals, instead of feeding the hungry people?
4. How can a good knowledge infrastructure be established in poor countries in which investments will not be one-sided, but distributed over the diverse fields of knowledge?



Chapter 7

Side events: Reports



7.1 Delivering nutrition, productivity and climate resilience – The Africa Biofortified Sorghum project

This side event was moderated by Dr Margaret Zeigler, Executive Director of the Global Harvest Initiative, and other panelists included Mr Daniel Kamanga, Director for the Communication Program, Africa Harvest, and Dr Firoz Amijee, Head of Global Registration & Regulatory Affairs, DuPont Pioneer. The Africa Biofortified Sorghum (ABS) project partners are DuPont Pioneer, Africa Harvest, the Kenya Agriculture and Livestock Research Organization (KALRO) and the Institute of Agricultural Research (Nigeria). Additional partners throughout the life cycle of the project include the Nigeria National Biotechnology Development Agency (NABDA), the University of Pretoria, the University of California Berkeley, the Agricultural Research Council (ARC) South Africa, ICRISAT, INERA (Burkina Faso), the Bill and Melinda Gates Foundation and the Howard G. Buffett Foundation.

The panelists presented for approximately 40 minutes about the ABS project, which is a multistakeholder initiative to fight malnutrition in one of the most food-insecure regions of the world. The presenters discussed the increased nutritional stunting of children in Africa: zinc deficiency is prevalent in 50 percent of children and anaemia (in part due to lack of iron) is prevalent in between 40 to 60 percent of all children under five. Vitamin A deficiency is the leading cause of preventable blindness in children and the rate of prevalence across Africa is 32 percent. An estimated 57 million children in Africa are stunted from lack of micronutrients and sufficient nutrition.

Sorghum is a critical food grain for many of the world's most food-insecure people and is uniquely adapted to Africa's climate. The ABS project is focused on improving the nutritional profile of sorghum, while also building research capacity and strengthening seed systems. Biofortified sorghum has the potential to deliver 50 to 100 percent of vitamin A requirements for extended periods of time after sorghum harvest and up to 80 percent of iron and zinc needs through normal consumption of sorghum.

Through the project, vitamin A, iron, and zinc levels are either raised or made more available through the use of transgenic technology. In summary, the project has excellent stewardship, compliance and governance processes and oversight to see the biotech products through, from discovery to commercialization. On the national regulatory side, years of biotech regulatory science training and outreach in target African countries has been conducted and the project has solid relationships with biotech authorities. The Kenya National Biosafety Authority has recently granted a five-year approval for continued ABS project efforts.

The presenters took questions from the audience, and questions centred upon what next steps are needed. Panelist Daniel Kamanga mentioned that Kenya, Nigeria, and Burkina Faso have signalled a desire to work with the research partners on next steps for biofortified sorghum. Confined field trials (CFTs) for biofortified sorghum have been done in Nigeria and Kenya with Burkina Faso as a possible next country test site. Dr Amijee mentioned that while the project has reached many of its goals, what is needed now is additional donor support to finish the final stages of field and nutrition testing and eventual commercialization to market.

7.2 Helping farmers grow: Climate change, food security and the technology nexus

CropLife International organized a side event that explored the specific role for agricultural technologies in combatting climate change and achieving food security. Howard Minigh, president and Chief Executive Officer (CEO) of CropLife International, moderated the panel session which discussed the potential for plant biotechnology, especially in developing countries, in helping to mitigate and adapt to climate change conditions.

The event featured four panelists reviewing the potential plant biotechnology has for food security. Nicolas Cenacchi, Research Analyst, International Food Policy Research Institute (IFPRI), reviewed two studies that analysed the impact of various biotechnologies on crops both regionally and globally under climate change conditions. IFPRI's research looked at how the adoption of biotech-improved varieties shows the potential for reducing the effects of climate change on yields and how this may translate into positive food security outcomes due both to effects on production and global food prices.

Sir Gordon Conway, Professor at Imperial College and Director of Agriculture for Impact, reviewed the potential devastating impacts climate change could have on food production. His presentation covered current conditions in Africa and how population growth, soil degradation and climate change are leading to reduced or stagnating yields during a crucial time where increased production is needed. This is exacerbated by the huge impact pests and disease have on crops. He provided case studies showcasing the benefits of biotechnologies to combat these variables. While biotechnology will not solve the entirety of the problem, he stated, it will be a part of it. He concluded by reviewing the current legislative framework in Africa and highlighting how variable it was, but that African leaders are increasingly cognizant that biotechnology is part of the answer to defeating pests and disease in agriculture.

Julie Borlaug, from the Borlaug Institute for International Agriculture, Texas A&M University, focused on the importance of expanding the conversation about plant biotechnology and food systems beyond the agriculture industry and connecting with new industries and audiences in an effort to take a multi-party approach to solving these complex problems. She also reviewed the need to educate the public, not only on the current state of agriculture, but on the benefits of biotechnologies, as there is a great deal of misinformation and misunderstanding.

Catherine Swoboda, Director of Planning of the World Food Prize, reviewed past winners of the World Food Prize and highlighted the important benefits of their technologies, including plant biotechnology, in ensuring global food security. She showcased how often these winners would put these technologies, often biotechnologies, in the hands of those who needed it the most, the farmers.

The speakers concluded that FAO needs to continue to invest in events like the FAO Biotech Symposium, work with farmers on the ground to develop advanced technologies, and openly provide its support for biotechnologies to achieve global food security. Also, the speakers reached a consensus about the need for farmers to have a choice to utilize biotechnologies, in particular to achieve global food security.



7.3 The voice of farmers: Biotechnology in the field

The side event was organized by the Canadian Canola Growers Association and co-organized by the Brazilian Confederation of Agriculture and Livestock.

The purpose of the side event was to provide a “boots on the ground” perspective on the role of agricultural biotechnology and the challenges farmers face in accessing new technology. The panelists included: Pomasi Ismail (Cocoa Abrabopa Association, Ghana), Dale Leftwich (Canadian Canola Growers Association, Canada), Mugo Makanga (Integrated Community Organization for Sustainable Empowerment and Education for Development, Kenya), Edwin Paraluman (rice and corn farmer, Philippines) and Santiago del Solar (Asociación Argentina de Consorcios Regionales de Experimentación Agrícola, Argentina). The event was moderated by Thiago Masson from the Brazilian Confederation of Agriculture and Livestock.

The panel described the contributions of biotechnology to their farm and respective commodity. The panel reported that herbicide tolerant (HT) and *Bacillus thuringiensis* (Bt) crops have been effective tools to manage production loss. HT canola provides Canadian farmers with a tool to control weeds. Bt corn has provided farmers from Argentina, Brazil and the Philippines a defence against the destructive corn borer, and in the case of the Philippines has made the difference between planting a crop or abandoning production altogether. Today, the Philippines is a net corn exporter. Both these biotechnologies have allowed farmers to use less pesticides, to employ more environmentally friendly inputs, and to widely adopt zero or minimal till farming practices.

A case study of Bt cotton in Kenya was presented. Cotton production has declined because of inability to control insects, and correspondingly ginners are idle, negatively impacting local economies. The Government of Kenya currently maintains a ban on GM crops. Access to Bt cotton could reverse the downward trend and keep Kenyan farmers competitive. It could provide a pest management solution, as well as lower costs of insecticides, improve seed quality and increase yields (e.g. better farmer income).

A key theme was the importance of farmer awareness and grass-root extension activities. How do farmers get access to accurate information on new technology? A multifaceted approach is required to reach farmers. For any agriculture biotechnology to truly take hold, it is critical to manage farmers' perception of new biotechnology and ensure they receive factual information. Misinformation and misunderstanding has created a great deal of confusion on the ground and with the public-at-large.

Various sources were discussed, including the role of farm organizations. Farmer associations or cooperatives are well positioned to share information. They can play a central role in organizing training sessions and site visits, engaging local advisors and demonstrating the importance of better farm management practices and the application of new technology. They also provide a collective farmer voice with government, and can streamline access to credit for crop inputs. Public research

and institutions also play a significant role in ensuring biotechnology is regionally suited and delivered in an appropriate manner.

All the panelists agreed that biotechnology is an important component of sustainable farming in the long term, and a tool to meet the production challenges they face. The panelists stressed that farmers are rational decision-makers and make decisions on what is best for their land, farm and family. New biotechnology and better farm management practices will enhance their farms and ensure the younger generation remains farming. The question is not whether to adopt new biotechnologies, but how it can be done to ensure that farmers understand the benefits, how it builds on existing practices and how it can work locally.



7.4 New breeding technologies for smallholders' challenges

The side event was organized by the Ministry of Economic Affairs of the Government of the Netherlands. It was introduced and moderated by Gerda Verburg, Permanent Representative of The Netherlands to the UN Organizations in Rome.

During the side event the focus was on the different new plant breeding technologies that are available that could address the needs and challenges of smallholders. Smallholders worldwide face multiple challenges in striving to make a living in agriculture that exceeds just being able to feed their families. Plant breeding technologies are key to the creation of new useful plant varieties (e.g. biofortified orange sweet potato, golden rice). Added value, availability and access are key. They can help to bolster production, supply and market value, as well as nutritional content and value of crops (protein, amino acid, antioxidants, vitamins and micronutrient content). Plant breeding technologies can also increase resistance to major pests and diseases and increase the efficiency of “post-farm-gate” practices (processing, storage and shelf-life). And last, but not least, new plant varieties can also be developed to use more efficiently water, nutrients and sunlight. Any innovative breeding technology must prove its added value at grassroots level and thus be adapted to local circumstances. If so, the new variety will contribute to more sustainable crop management, improved yields and better farmers' income. Improved production in a sustainable way contributes also to Agenda 2030 (Sustainable Development Goal 2 and others).

René Smulders, Business Unit Manager, Wageningen UR Plant Breeding (the Netherlands), presented an overview of existing and new plant breeding technologies now available for improving and creating new plant varieties. One is the new gene-editing technique like CRISPR-Cas, which is very quick, precise and cheap. But the toolbox of precision breeding methods contains more than just genetic modification. It provides lots of innovative opportunities that could address changing needs of smallholder farmers. Niels Louwaars, Director of the Dutch association for the plant reproduction material sector (the Netherlands), showcased proven business strategies of seed companies in developing countries. He also stressed the need to counter possible constraints in the area of intellectual property rights and biosafety rules using these new breeding techniques before new varieties could become available for smallholders on scale.

Smallholder, Walter Quispe Huilcca, at the Potato Park in Cusco (Peru) recognized the challenges and stressed the urgency in the broader use of new techniques for smallholder farming. As in the centre of origin of the potato, Parque de la papa in Peru, due to climate change, plant diseases now endanger native varieties at altitudes where they never occurred. Walter was assisted by Alejandro Argumedo, Program Director, Asociación ANDES, Cusco (Peru).

7.5 **Practical approaches to regulation and oversight of agricultural biotechnology: Experiences from developed and developing countries**

The Governments of Canada and the United States of America co-hosted a panel discussion entitled “Practical approaches to regulation and oversight of agricultural biotechnology: experiences from developed and developing countries”.

Panelists from Canada, Uganda and the Inter-American Institute for Cooperation on Agriculture (IICA) shared experiences with regulation of genetically modified (GM) crops. An engaged audience of about 50 symposium participants attended.

Veronica McGuire of the Canadian Food Inspection Agency presented Canada’s three pillars of regulation for biotechnology (science-based decisions, transparency and engagement), highlighting that food, feed and environmental safety underpins the regulatory oversight of GM crops. Dr Barbara Mugwanye Zawedde of Uganda Biosciences Information Centre, under Uganda’s National Agriculture Research Organization, discussed Uganda’s interest in GM crops, including those developed by public sector scientists in Uganda, as a tool for smallholder farmers to enhance productivity, and described the current status of Uganda’s current biosafety bill. Dr Pedro Rocha of IICA talked about the varying positions on GM crops among Latin American countries and outlined IICA’s work in assisting countries to develop practical, science-based policies and oversight frameworks, including efforts to foster regional cooperation.

Recurring themes in the presentations and following discussions included:

- the importance of transparency and public engagement. While many countries acknowledge the potential value of agricultural biotechnology, public acceptance remains an issue;
- the need for capacity building and training for both the development and the implementation of regulations and confident decision-making;
- the need for other enabling factors such as effective seed systems and resolution of ownership and intellectual property issues; and,
- the value and practicality of regional cooperation to share resources, infrastructure and experiences, and to build confidence among regulators and decision-makers. Examples of such initiatives include the Regional Approach to Biotechnology and Biosafety Policy in Eastern and Southern Africa of the Common Market for Eastern and Southern Africa (RABESA/COMESA), and the Initiative for Central America on Biotechnology and Biosafety (ICABB).



In conclusion, while regulatory frameworks are recognized as an essential tool for enabling the safe adoption of agricultural biotechnology to achieve national goals including for the benefit of smallholder farmers, countries seeking to develop and implement such frameworks may need to consider issues such as public acceptance, capacity constraints and other policy and regulatory conditions. This event successfully provided a venue for symposium participants to share experiences and views on addressing these challenges.



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Chapter 8

Final plenary session



8.1 Some highlights of the symposium from a non-FAO perspective

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This has been a very exciting symposium in which I think we have broken some new ground and found a way to bring cohesion to several diverse ideas. I have great hope that this is not the end of a symposium but the beginning of a dialogue between member countries and between different parties; a dialogue in which FAO has to play an important role. I will not try to summarize all the different ideas. Instead I will highlight some unresolved issues or some issues that need attention as we move forward.

One such issue is the risk that we consider biotechnology either in a very wide sense or in a very narrow sense. At times there is a tendency to equate biotechnology to GMO, a narrow view that does not do justice to exciting new precision breeding techniques and which risks paralyzing the debate. The other risk is that we consider it too widely. While it is true biotechnology is a tool in a wider context of developing sustainable production systems and of helping farmers to increase their yields, biotechnology is not everything.

As stated very clearly in this symposium, the biotechnology toolbox needs to be linked to the agroecology toolbox and coordinated in a comprehensive and inclusive fashion. This new linkage will be a real challenge technically as it requires an interdisciplinary approach and it will be necessary for governments to engage many different sectors and not just the ministry of agriculture.

We also have a major set of issues related to intellectual property rights. On one hand, we have the desire for open access which is vitally important to allow farmers, small and medium enterprises, poorer countries and other groups to access the latest developments in science. This needs to be balanced with the justified need to encourage investment in a technology that is still very costly to develop. Here, new precision breeding techniques, such as CRISPR, allow us to speed up the process and to find more location-specific solutions that could be of interest for smaller markets. What is important here is that we move the discussion past the black and white view of patenting versus open access and make sure that small farmers, poor countries and poor consumers do not become the victims of this debate. There is a tremendous potential in these new technologies that combine the heritage of mankind with the newest scientific ideas.

There is also a need for innovative public–private partnerships. There are models in some countries where the private sector and civil society, including NGOs, the governments and science work together well. In the area of biotechnology we need to develop this. Maybe we can consider developing a code of conduct for responsible biotechnology. FAO in particular can help to highlight the best practices and specific cases where this can work.

This brings me to capacity building – another issue that I think is very important. It has been mentioned by many people in the symposium and is at the heart of FAO’s mandate. Capacity building is not just a matter of training new scientists. It’s also about building science infrastructure in countries, the creation of food safety and biosafety agencies and the involvement of both young and mid-career people, particularly women. It is an enormous area of work but one that we must address urgently if we want to bridge the divide between countries that have this kind of capacity and others that do not.

One issue that was only briefly mentioned during this symposium is that of open data or big data. As genetic data becomes available online we can combine it with climate data and soil data to form an enormously powerful tool to fine-tune research efforts as well as farmers’ activities to get the best out of the environments in which they work. However, that data is valuable and so it must be considered in terms of intellectual property rights. How should we deal with this massive data? This is an issue that we have barely begun to address.

What does all this mean for FAO? By hosting this symposium, FAO has positioned itself right in the heart of a new debate on biotechnology. This is very different from the old black versus white, pro versus contra GMO debate. It is a debate which goes beyond just talking about small farmers but instead addresses the entire food chain. It also goes beyond science and involves governments, civil society and the private sector.

I think the call for FAO to provide a platform, a neutral place where this debate can be played out is very important. But associated with the platform there is also a need for “friends” – a couple of countries, a couple of scientific institutions and a couple of private sector institutions that want to work in partnership with FAO to make it happen. I think that by having a group of friends it can succeed. Not because the friends will do all the work but because the friends can also help to mobilize resources. It’s very important to realize that if FAO and the member countries want to support capacity building or establish a programme to exchange best practices or develop other similar initiatives, it requires a long-term involvement including financial commitments. It will therefore be really important to gather together as a group of friends of the new biotechnology, the new future, the new genetics if you want, for small farmers and for poor consumers.

I think one of the most exciting things that we should retain is the enormous enthusiasm of young people. Given the long time lag between the first experiments in the laboratory and the use of new crop varieties or improved animals in the field, we need to involve the younger generations as they will be the ones who will actually work with farmers, industry and governments to move forward with biotechnology. We should involve young people not just at the level of capacity building but to get their ideas to shape the future of science and to decide the kind of technology and agricultural development we want. Continuing the engagement with the young people, begun here in the symposium, is a very exciting idea.



This is an urgent issue. Many things are going to happen very fast. Countries can be taken unaware, companies can feel unprepared and scientists can feel that they are lagging behind. The sense of urgency has been expressed extremely well by the FAO Director-General in saying we cannot leave any solution untouched or underutilized when it comes to fighting hunger and malnutrition. I think we need to promote a participatory approach to this kind of science and develop something which goes beyond the borders of individual countries and institutions. It is a sensitive issue and a difficult one but since when have we been afraid? We're here to do something!

8.2 Closing statement

José Graziano da Silva

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Excellencies; Members of the Podium; Distinguished guests; Ladies and gentlemen; After two and a half days of presentations and deliberations, this International Symposium is coming to an end.

We had the opportunity to hear from representatives of governments, civil society, the private sector, academia, research institutions, cooperatives and others.

For the first time in FAO, a special session with students from different regions was organized to identify and convey key messages from the young generation.

FAO is very proud to have fulfilled its role as a neutral forum for frank and open dialogue among all stakeholders.

This was our objective in 2014, when we organized the Agroecology Symposium. And this has also been our goal with the Biotechnology Symposium.

But by organizing these two events, we have opened ourselves to much criticism.

This is the price of entering the dialogue on issues on which no consensus has yet been reached.

Let me tell you that FAO will not shy away from any issue that is relevant to our mandate of ending hunger and improving nutrition, as well as promoting a shift towards sustainable agriculture development.

As a knowledge Organization, we have provided all interested stakeholders with the opportunity to express their views and concerns.

Knowledge and dialogue are essential to make informed decisions and to build consensus. And if it is not possible to reach an agreement, we should make it clear on what points we disagree.

We want to use knowledge and dialogue to determine whether to advance certain topics, how, and in which direction.



No one single tool, technology or approach will provide a complete solution for all the problems we have.

Responding to the urgent and diverse challenges of the twenty-first century will require a combination of responses.

And our responses will also evolve as our knowledge advances.

Ladies and gentlemen,

We have unlocked the door to discuss and analyse how agroecology and biotechnology can live together and, perhaps, be used as complementary options. This is an outstanding achievement of this symposium.

It opens a window of opportunity for the development of new technologies that could make agricultural sectors more sustainable in the years to come.

We have also agreed that tools and approaches must be useful and accessible for farmers, in particular family farmers.

By launching the Agenda 2030 and the Sustainable Development Goals (SDGs), we have agreed that no one is left behind. This is fundamental for reaching sustainability.

Inclusiveness. This is what the SDGs are all about.

This is why FAO's efforts must always focus on assisting the most vulnerable people, where poverty and hunger are concentrated.

Ladies and gentlemen,

Some presentations made in this symposium highlighted the possible contributions of new biotechnologies, both low-tech and high-tech, that could best serve the interests of farmers, in particular family farmers.

Several presentations also reiterated that agricultural biotechnologies are much broader than genetically modified organisms.

Now FAO has to move forward.

We intend to bring the debate to a regional perspective. We want to hear from governments, farmers and researchers of all regions about their needs and concerns regarding biotechnology.

This will help us to improve our knowledge in order to take the right decisions and move in the right direction.



It will also help us to continue building trust among ourselves in order to achieve some level of consensus in the future.

I am sure that, together, we have started to bridge the gap between biotechnology and agroecology.

I do not think we have solved all the issues. And this was never our intention when we started organizing this symposium.

What I can assure you is that FAO Member States have listened to you with great attention. Your statements have been registered. And they will be the base for new discussions.

I have also taken note of your concerns. For example: regarding intellectual property rights and patents, as well as preserving traditional knowledge. These are also key issues for FAO. Your concerns are legitimate.

Let me also stress that the open and frank dialogue that we began with the Agroecology Seminar, and which has continued with this Biotechnology Seminar, forms the basis of our strategic alliance to promote food security and nutrition for all, based on a more sustainable agricultural production.

I believe in this. And I hope you also do. We need to move together.

Ladies and gentlemen,

My last words are of gratitude.



Thank you once more for attending this event and sharing your knowledge and views.

My thanks go also to the researchers from the best academic circles, who have shared new and fresh ideas.

I would like to express my appreciation to the representatives of the private sector and civil society for having the courage to listen to each other with open minds and to promote a fruitful debate.

Thank you all for believing that dialogue will make us stronger and better able to face the challenges ahead.

I would like also to express my gratitude to all the people who helped make this symposium successful, such as my colleagues Maria Helena Semedo and Ren Wang, Ms Louise Fresco, members of the Advisory Panel, the FAO support team and the interpreters.

Thank you to the students that have interacted with us.

For those who have come from abroad, I wish you a safe journey home. I hope to see you all soon. FAO will count on you to continue this dialogue in different parts of the world.

I declare this FAO International Symposium on Agricultural Biotechnologies closed.

Thank you for your attention.

The FAO international symposium on “The role of agricultural biotechnologies in sustainable food systems and nutrition” took place from 15 to 17 February 2016 at FAO headquarters, Rome. Over 400 people attended, including 230 delegates from 75 member countries and the European Union, as well as representatives of intergovernmental organizations, private sector entities, civil society organizations, academia/research organizations and producer organizations/cooperatives.

The symposium encompassed the crop, livestock, forestry and fishery sectors and was organized around three main themes: i) climate change; ii) sustainable food systems and nutrition; and iii) people, policies, institutions and communities.

The proceedings provide the main highlights of the symposium which covered a broad range of biotechnologies, from low-tech approaches such as those involving use of microbial fermentation processes, biofertilizers, biopesticides and artificial insemination, to high-tech approaches such as those involving advanced DNA-based methodologies and genetically modified organisms.

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