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Proceedings of the Global Conference on Green Development of Seed Industries

4–5 November 2021

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Edited by John Ruane, Chikelu Mba and Jingyuan Xia

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FOREWORD

In 2015, the international community, through the United Nations Sustainable Development Goals (SDGs), pledged *inter alia* to end hunger, malnutrition and poverty by 2030. Yet, in 2020, in keeping with a trend of worsening food insecurity and malnutrition, nearly one in three people globally, or 2.37 billion, did not have access to adequate food. The COVID-19 pandemic has overlapped with strife, erratic and extreme weather events, and other drivers, to exacerbate food insecurity and malnutrition and lower the prospects for the universal achievement of the SDGs.

These statistics are worrisome considering that significantly more food, estimated at 50 percent over the 2013 figures, should be produced to meet the nutritional demands of approximately 10 billion persons by 2050. Daunting as the task ahead may seem, the attainment of the SDGs is still possible. However, a business-as-usual approach is not an option, as we cannot continue doing the same things we did in the past and expect different outcomes.

The FAO Strategic Framework 2022–31, with its aspirational four betters – better production, better nutrition, a better environment and a better life for all, leaving no one behind – aligns the Organization's work over the next eight years with the 2030 Agenda. Its aim is the transformation to MORE efficient, inclusive, resilient and sustainable agrifood systems to achieve the SDGs. One attribute of the envisaged agrifood systems is enhanced productivity, which is producing significantly more yields while using fewer external inputs.

With over 80 percent of our food being plant-based, it is evident that sustainable crop production systems are critically important for any meaningful transformation of agrifood systems. We are very mindful that seed systems are key for crop production. There are no good crops without good seeds because seeds are the vehicles for translating the genetic potentials in crop varieties into desired outputs from farmers' fields, such as improved productivities and enhanced nutritional quality attributes.

Due to this critical importance of seeds to agrifood systems, FAO convened the Global Conference on Green Development of Seed Industries to support implementation of the four betters, especially better production, by starting from better seeds. Through the conference, FAO provided a neutral forum for its Members, partners, industry leaders, opinion leaders and other stakeholders to discuss evidence-based solutions to the problems that constrain farmers' access to quality seeds and planting materials of preferred productive, nutritious and resilient crop varieties.

Over 2200 participants from 126 FAO Members attended the conference. The feedback received thus far on this global convening has been overwhelmingly favourable. The conference has also been recognized worldwide as being timely, informative, inclusive and inspiring, which creates a momentum to facilitate the development and delivery of the solutions for farmers to have access to quality seeds.

In my opening remarks at this milestone event, I underscored the critical importance of leveraging green innovations to strengthen seed systems to develop and deliver solutions that work for farmers. The keynote speakers at the conference echoed my sentiments, which were further reaffirmed during the high-level ministerial segment.

I strongly encourage all stakeholders along the extensive seed value chain, especially governments, researchers, extension agents and all development practitioners engaged with the task of transforming agrifood systems to be fit for achieving Agenda 2030, especially SDG1 and SDG2 on ending hunger and poverty, to read this important publication.

QU Dongyu
FAO Director-General

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PREFACE

FAO organized the Global Conference on Green Development of Seed Industries on 4 and 5 November 2021, in a virtual format due to the COVID-19 pandemic, 12 years after the previous World Seed Conference. The event served as a neutral forum for FAO Members and all relevant stakeholders along the seed value chain to discuss evidence-based means to enhance farmers' access to quality seeds and planting materials of preferred productive, nutritious and resilient crop varieties.

A Steering Committee, chaired by the FAO Deputy Director-General, Ms Beth Bechdol, provided strategic advice for the conference while a Scientific Advisory Panel, chaired by FAO's Chief Scientist, Ms Ismahane Elouafi, assisted in the development of the conference programme. The Director of FAO's Plant Production and Protection Division, Mr Jingyuan Xia, led the Conference Secretariat, which was responsible for the preparations for, and hosting of, the event.[1]

The event included an opening and keynote address plenary session, and a high-level ministerial segment and closing plenary session. There were eight parallel sessions, which consisted of two for each of the four conference themes: advanced technologies; conservation of plant genetic resources for food and agriculture; crop varietal development and adoption; and seed systems. A fifth theme, policy and governance, was crosscutting.

Over 2200 participants from 126 FAO Members took part in the two-day event. Of the 100 speakers, co-chairs, panellists or moderators in the sessions, 39 percent were from research or academic institutions, 23 percent from governments and intergovernmental organizations, 22 percent from the private sector, 10 percent from civil society organizations, farmers' organizations or cooperatives, and 6 percent from international non-governmental or extension organizations.

These proceedings, which are an important legacy for the conference, are composed of seven chapters:

- Chapter 1 contains the opening remarks from the FAO Director-General, Dr Qu Dongyu, and the keynote addresses of six high-level speakers.
- Chapters 2 to 5 include the summaries of the presentations given by global experts and representatives of stakeholders in the eight parallel sessions.
- Chapter 6 contains the statements delivered in the high-level ministerial segment by the representatives of six governments from different world regions and the closing remarks by the FAO Deputy Director-General, Ms Beth Bechdol.
- Chapter 7 contains the ten recommendations on Strategic Actions for the Green Development of Global Seed Industries identified by the Steering Committee of the conference.

The two parallel sessions of the theme of "Advanced technologies" were titled "Modern plant breeding technologies" and "Emerging biotechnologies and informatics technologies", respectively. For the first session, there were four presentations, five brief interventions and a moderated discussion during which the presenters responded to participants' questions. For the second session, there were four presentations, three brief interventions and another moderated discussion. During both parallel sessions, case studies were presented on the applications of novel technologies, especially molecular biology and related disciplines, to the conservation of, and research on, plant genetic resources for food and agriculture (PGRFA) and the development of progressively superior crop varieties. The techniques included genetic modification, genome editing, next generation sequencing, high-throughput phenotyping, genomics-assisted breeding technologies, synthetic biology, microbiome research, machine learning and artificial intelligence.

[1] The video recordings of all the conference sessions, as well as the detailed programme, are available on the conference website, at www.fao.org/events/detail/global-conference-on-green-development-of-seed-industries/en

For the theme of "Conservation of plant genetic resources for food and agriculture", the first of two parallel sessions was titled "The global conservation system". The first part of the session, dedicated to "The global conservation system – how it works", consisted of three presentations followed by a moderated discussion. The second part of the session, dedicated to "The global conservation system – what impact has it had?", included a conversation between the chair of the session and a representative of Indigenous Peoples; two presentations and a moderated discussion. The second parallel session was entitled "Access and benefit-sharing". Its first part consisted of five presentations while the second half consisted of a moderated discussion with five panellists, followed by a concluding presentation. The state of the art for, and experiences from, both the technical and normative domains of the safeguarding of PGRFA in nature (*in situ*); in genebanks (*ex situ*); and through the enhancement of on-farm diversity – in particular, by cultivating farmers' varieties/landraces – were presented and discussed in these two parallel sessions.

The first of the two parallel sessions dedicated to the theme of "Crop varietal development and adoption" was entitled "Accelerating genetic gains in crops". There were five presentations and a moderated discussion with five panellists. The second session, titled "Facilitated adoption of improved varieties by small-scale farmers", included five presentations and concluded with a discussion involving six panellists. The case studies presented in these parallel sessions dealt with the means for addressing the imperatives of the continuing development, dissemination and adoption of progressively improved crop varieties. Result-oriented plant breeding programmes typically adopted efficiency-enhancing scientific and technological methods to introduce desirable attributes into improved crop varieties. The adoption of new crop varieties was enhanced when farmers participated in the selection of such varieties or otherwise had their preferences reflected in the breeding objectives.

The two parallel sessions dedicated to the theme of "Seed systems" were titled "System innovations in the seed value chain" and "Seed enterprise development and international trade", respectively. In the first parallel session, there were seven presentations, followed by a moderated discussion. For the second session, there were also seven presentations and a discussion involving four panellists. The coexistence of the so-called formal and informal seed sectors was underscored through the case studies that were presented and discussed in these two parallel sessions. Depending on the context, both seed sectors are means for farmers to access affordable quality seeds and planting materials of preferred and well-adapted crop varieties in timely manners. The interventions also demonstrated the multiplicity of actors in seed delivery systems, including the public and private sectors, farmers' associations and cooperatives and community-based organizations. These actors thrived in settings where there were measures to ensure predictability, such as enforced laws, policies and regulations and the requisite institutional frameworks.

In addition, the presentations that were delivered in the different thematic sessions highlighted the importance of policy and governance, which was the crosscutting theme for the conference. These presentations and discussions demonstrated that the deployment of appropriate scientific and technological methods by suitably strengthened institutions and personnel, within the context of nurturing laws, policies, regulations, incentives and partnerships, resulted in effective seed value chains that delivered context-relevant solutions to farmers.

Annex 1 describes the roles and membership of the three conference organizational bodies – the Steering Committee, Scientific Advisory Panel and FAO Secretariat while Annex 2 contains the final conference programme.

Jingyuan Xia

Jingyuan Xia
Executive Secretary, Conference Secretariat and
Director, Plant Production and Protection Division, FAO

ACKNOWLEDGEMENTS

The organization of the Global Conference on Green Development of Seed Industries would not have been possible without the invaluable support and commitment of many people. Of particular note, the contributions of all the members of the three conference organizational bodies – the Steering Committee, Scientific Advisory Panel and Conference Secretariat – who are listed in Annex 1, were immeasurable.

The members of the Steering Committee, chaired by the FAO Deputy Director-General, Beth Bechdol, and with the vice-chairs Yemi Akinbamijo, Marco Ferroni and Hanzhong Wang, discharged with distinction their role of providing strategic advice on all aspects of the conference. Their wise counsel ensured that the conference exceeded the expectations of most of the stakeholders.

Similarly, the members of the Scientific Advisory Panel, which was chaired by the FAO Chief Scientist, Ismahane Elouafi, with Rachel Chikwamba and Niels Louwaars as vice-chairs, were stellar in deploying their significant expertise and breadth of experience to develop the programme for the conference. Deserving of special commendation are the co-leaders of the Panel's working groups who developed the draft programme for two parallel sessions dedicated to each of the four conference themes, namely advanced technologies (Rajeev Varshney and Vittorio Venturi); conservation of plant genetic resources for food and agriculture (Lamis Chalak and Charlotte Lusty); crop varietal development and adoption (Emmanuel Okogbenin); and seed systems (Keshavulu Kunusoth and Niels Louwaars). Immense thanks are also due to Rachel Chikwamba and Long Mao, who co-led the working group on the overarching theme of policy and governance, which was embedded in the thematic sessions.

The FAO Plant Production and Protection Division, led by the Director, Jingyuan Xia, provided the secretariat for the conference, which was responsible for the core technical and organizational activities for the event. In particular, the contributions of Wilson Hugo, Chikelu Mba, John Ruane and Chantal Wedge, who oversaw the day-to-day running of the secretariat, were invaluable. The secretariat was also responsible for the publication of these proceedings.

All of the 116 people who served as chairs, panellists, presenters, moderators and rapporteurs of the different sessions discharged their duties most creditably. They ensured that a wide diversity of views and updated knowledge about green development of the seed industries were shared worldwide through this conference. Barbara Wells, the former CGIAR Global Director for Genetic Innovations, gave the keynote presentation in the parallel session, "accelerating genetic gains in crops", and most eloquently conveyed the message that new and improved crop varieties were strategic assets for sustainable development. Regrettably, she died on 16 February 2022. She leaves a towering legacy as an inspiring leader who contributed immensely to getting the benefits of crop improvement to underserved small-scale farmers in remote parts of developing countries.

The COVID-19 pandemic made it necessary to organize this conference, with its concurrent parallel sessions, as a virtual event. This was a significant undertaking that demonstrated the resilience of FAO's information technology infrastructure and the expertise of those who supported the secretariat in using it. Also, the sterling resourcefulness, patience and flexibility of FAO's audio-visual, communications and multilingual interpretation teams were instrumental in creating the conducive atmosphere in which the conference was held. The work of all these behind-the-scenes professionals is gratefully acknowledged.

ABBREVIATIONS AND ACRONYMS

ABS	Access and benefit-sharing
Bt	*Bacillus thuringiensis*
CBD	Convention on Biological Diversity
CIMMYT	International Maize and Wheat Improvement Center
CRISPR	Clustered regularly interspaced short palindrome repeats
CRISPR/Cas	CRISPR/CRISPR-associated protein
CRISPR/Cas9	CRISPR/CRISPR-associated protein 9
DNA	Deoxyribonucleic acid
DSI	Digital sequence information
DUS	Distinctness, uniformity and stability
Embrapa	Brazilian Agricultural Research Corporation
EWS-KT	East-West Seed Knowledge Transfer Foundation
FAO	Food and Agriculture Organization of the United Nations
GM	Genetically modified
GMO	Genetically modified organism
IRRI	International Rice Research Institute
ISF	International Seed Federation
ISTA	International Seed Testing Association
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
KEPHIS	Kenya Plant Health Inspectorate Service
Nagoya Protocol	Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity
NGO	Non-governmental organization
OECD	Organisation for Economic Co-operation and Development
PCR	Polymerase chain reaction
PGRFA	Plant genetic resources for food and agriculture
PVP	Plant variety protection
QDS	Quality declared seed
R&D	Research and development
SADC	Southern African Development Community
SDG	Sustainable Development Goal
SNP	Single nucleotide polymorphism
UN	United Nations
UPOV	International Union for the Protection of New Varieties of Plants
USDA	United States Department of Agriculture
VCU	Value for cultivation and use

1. OPENING AND KEYNOTE ADDRESS PLENARY SESSION

Participants at the Opening and Keynote Addresses Plenary Session.
From left to right, top row: Qu Dongyu, Beth Bechdol, Ismahane Elouafi and Jingyuan Xia;
middle row: Fatma Ben Rejeb, Marco Ferroni, Mauricio Antonio Lopes and Michael Keller;
bottom row: Hanzhong Wang and Rachel Chikwamba.

1.1 Opening remarks

Qu Dongyu
FAO Director-General

Excellencies,
Ladies and gentlemen,

I start by saying congratulations for all your efforts to make this global seed conference happen, 12 years after the previous one.

Good harvest depends on good seeds. The world is facing a global population rise – that is expected to reach about 10 billion by 2050! We need to produce 50 percent more food to adequately feed everyone.

The only way to achieve this target is by increasing crop productivity, through science and innovation. Tom Vilsack, the Secretary of Agriculture of the United States of America, and Janusz Wojciechowski, the European Union Commissioner for Agriculture, made a statement yesterday saying that increased productivity is essential and that science and innovation will bring about a more sustainable agriculture. And that the solutions have to be good for farmers, for consumers and for the planet.

With innovative technologies and new business models we can do so in a sustainable manner, to protect our planet, our limited natural resources and biodiversity. And ensure profitability and social equality. We need to adapt our agrifood systems to mitigate the impacts of the climate crisis, and to reduce our environmental footprint.

Food insecurity has been increasing over the past six years. In 2020, almost 2 billion people did not have regular access to safe, nutritious and sufficient food. And up to 811 million people are currently facing hunger.

We need to speed up action, be efficient and effective, and coherent. We must produce more – more quantity and more food diversity with higher quality – with less – less inputs of resources and less impacts on the environment. All the SDGs can be achieved, including SDG1 no poverty and SDG2 zero hunger. But we need to do things differently. Business as usual is no longer an option.

FAO's new Strategic Framework for 2022–2031 supports the 2030 Agenda. Through the transformation to MORE efficient, inclusive, resilient and sustainable agrifood systems. For better production, better nutrition, a better environment and a better life, leaving no one behind. This Global Seed Conference will contribute to the four betters, especially better production, for which "better seeds" are fundamental.

There are no good crops without good seeds. Seeds are the foundation of agrifood systems. We rely on seeds to produce food, feed, fibre, fuel, and they contribute to a friendly environment. Seeds play a crucial role in promoting food security and healthy foods, including food quality and food safety. And in supporting farmers' livelihoods, economic growth and rural development. An improved and resilient crop variety can deliver a good and nutritious yield.

We need green innovation for sustainable agrifood systems – and to lay the path to green agriculture. Green agriculture is a fundamental approach for sustainable agrifood systems. It will ensure food security, improve human well-being, create opportunities for employment and decent work for all, and protect the planet, now and in the future.

Today's Global Conference focuses on the green development of the seed industry, with four major objectives:

- First, increase awareness of the contributions of the seed industry to green innovation for sustainable crop production.

- Second, promote cooperation among sectors, especially as a means to enhance public–private partnerships and international cooperation to enable greater access to resources, and sharing of knowledge and information.
- Third, commit to setting new priorities and targets for mobilizing scientific, technical and financial resources to strengthen seed systems.
- Fourth, encourage constructive debate on innovation and to share updated knowledge and evidence – research and development are key drivers for improved crop varieties.

Dear colleagues,

FAO is a technical organization that generates, facilitates and promotes professional knowledge. And provides a neutral global platform for scientific and evidence-based knowledge sharing, including on affordable quality seeds, and planting materials of well-adapted and nutritious crop varieties.

To support this work, we have identified five key themes to be covered over the next two days:

- One, advanced technologies, including modern biotechnologies, such as gene editing and genetic improvement, are important tools for generating superior crop varieties.
- Two, conservation of plant genetic resources for food and agriculture, both in nature and in genebanks, and relevant data must be made available for research and breeding programmes.
- Three, crop varietal development and adoption: Plant breeding should be encouraged as it generates progressively superior crop varieties adapted to different stress environments and requiring less external inputs.
- Four, seed systems: Fit-for-purpose seed systems for delivering context-specific cropping systems solutions to farmers should become the norm.
- Five, policy and governance: Effective policies, legislation and regulations must be in place to enable all relevant stakeholders to engage beneficially in the seed value chain.

Governments are the key drivers to eradicate hunger. They should launch national seed actions to strengthen the seed value chain, and FAO will continue to support governments to develop and implement national policies, regulations and laws to create predictability and foster confidence in seed systems.

Over the next couple of days, prominent speakers will present their insights on developing and delivering solutions to farmers, to set the scene for a robust exchange of ideas. Ministers from different regions will share their thoughts on initiatives and policies aimed at making quality seeds of priority productive, nutritious and resilient crop varieties available to farmers.

Participants will discuss progress on the various aspects of the seed industry value chain and make recommendations to guide global work to promote the green development of global seed industries, in support of the 2030 Agenda.

We only have nine harvests ahead of us before we reach our 2030 agenda. Let us sow the new seeds for a promising future now! FAO is committed to leverage the momentum generated by this conference to transform the evidence provided into action on the ground.

Thank you.

Keynote addresses: Developing solutions for farmers

1.2 Solutions for small-scale farmers

Fatma Ben Rejeb
Chief Executive Officer, Pan-African Farmers' Organization, Kigali, Rwanda

Farmers in Africa are the most highly-organized actors in the agricultural sector. From the local and national levels, till the five African regions and up to the continental level with the Pan-African Farmers' Organization (PAFO), which is representing dozens of millions of smallholder farmers from more than 45 African countries.

As we are all aware, agriculture in Africa is the primary sector for generating income and it employs the majority of the continent's population. The African agriculture sector is dominated by smallholders and family farmers who constitute over 80 percent of the total, according to FAO. Africa is the continent with the fastest growing population, and this puts more pressure on smallholder farmers to increase the production to feed the population with a non-expanding area of land. To do so, there is a need to increase the productivity per plot.

Several factors will play a major part in this. But most importantly, increasing the availability of good quality seeds which are resilient to climate stress, improve the use of natural resources, boost the food and nutrition security, is a great contribution to secure higher crop yields, leading to the economic development and improved incomes of farmers.

Smallholder farmers managed for centuries their own seeds. This ancestral knowledge makes them have a better understanding about how to select good seeds, and how these seeds can contribute to the increase of production. Their role in saving the seed diversity and the local seeds no longer needs to be proven. The smallholder farmers are the drivers for agriculture development and, if well supported, they can reach the needed self-sufficient agriculture sector.

Besides the smallholder farmers, different stakeholders are also playing a major role. For example, different governments established programmes and policies to support farmers accessing quality seeds distributed to them at a lower price. At the continental level, several initiatives are working on facilitating the research and accessibility of inputs to African farmers, like the African Seed and Biotechnology Partnership Platform (in which PAFO has a membership seat), the African Agricultural Technology Foundation and the African Union guidelines for harmonization of seed policies and legal frameworks. An impact is predictable whereby FAO and the Organisation for Economic Co-operation and Development (OECD) anticipate an increase of 21 percent in agricultural and fish production between 2020 and 2029 in sub-Saharan Africa.

However, some smallholder farmers in Africa still find it hard to access the quality seeds, and this is due to different reasons:

- malfunctioning seeds supply chains;
- insufficient seeds available for farmers;
- limited certified local seeds multipliers;
- the research on quality seeds is somewhat neglected (most traditional crops are being left behind by many researchers); and
- limited participation of farmers in seeds research processes due to the gap in collaboration between farmers and researchers.

Given the mentioned challenges, a lot still needs to be done to ensure that smallholder farmers have accessible and affordable quality seeds for all value chains. To achieve that:

- There is a need, first of all, to reconfirm the recognition for smallholders of their right to seeds. This is already recognized under the UN Declaration on the Rights of Peasants and Other People Working in Rural Areas adopted in 2018. It is needed to recognize the role of smallholders in saving the seed diversity, especially the much more resilient local seeds. This need is extended to protect their rights to ensure the selection, conservation and exchange of seeds, including the protected varieties or those under intellectual property which challenges the protection of this right to seeds.
- There is a need to safeguard the main source of seeds for smallholders, which are the local markets. The public–private partnerships should be strengthened to improve the infrastructures to better access these markets. The cross-border exchange should be improved while strengthening the linkages between the formal and informal seed sectors, the market and non-market channels.
- There is a need for improving the participation of farmers in the seed research process and multiplication, focusing on the demand-driven seed research and considering farmers as partners and not beneficiaries.
- There is a need for more financing in the seed sector, from the research, multiplication and distribution and also to support the capacities of farmers and their organizations in ensuring the use of improved seeds for higher production.

Through the structures of farmers, the development of the seeds sector in Africa is possible. Thus, it is important for all stakeholders to seize the existing opportunity in farmers' organizations to reach out to the large number of farmers, if we really need a productive agriculture in Africa.

1.3 Advanced technologies impacting the green development of seed industries

Mauricio Antonio Lopes
Brazilian Agricultural Research Corporation (Embrapa), Brasilia, Brazil

Abstract

The agriculture of the future will be impacted by concepts, methods and expectations far beyond conventional agricultural systems. The Sustainable Development Goals (SDGs) point strongly to the need of agriculture and related industries to embrace new practices and new criteria of performance, with more balanced attention to the three dimensions of sustainability – economic, social and environmental. The good news is that the technological standards of agriculture are being changed by the introduction of fast-paced advances in scientific knowledge. Scientific revolutions are happening in biology with genomics, in physics and chemistry with nanotechnology, in information technology and communication, with numerous innovations that increase our ability to respond to risks and challenges. Considering these advances and the gradual emergence of a cleaner, decarbonized, green economy, the expectation is that agriculture´s important domains, such as plant breeding, cultivar development and their related seed industry will be faced with a new set of standards and requirements, and increasing expectations for innovations to lower impact and drive food systems towards a sustainable future.

Introduction

A few years back, Klaus Schwab, founder of the World Economic Forum, analysing the accelerated scientific and technological development of our time, concluded that "we live in a time of great promise and great peril" (Schwab, 2016). According to him, this time of rapid changes and disruptions presses us to build a comprehensive and globally shared vision of how technology is affecting our lives and reshaping economic, social, cultural and human environments. The warning is prudent considering, for example, the emergence of mega-corporations accumulating enormous power, the radical changes in the world of work, the impact of technology on human relations, among other risks (WEF, 2022).

The warning becomes even more important now, with the world taking the first steps in the era of exponential technologies, which reveal capacity and reach many times multiplied, in increasingly shorter time frames and at ever-lower costs. Humans are incrementalists by nature, whereas technology increasingly is exponential. Thus, future changes, which are being led by new groundbreaking technologies, should be viewed as exponential and different from the incremental changes of yesterday (Harrington, 2018). A classic example of exponential technological advancement is the famous Moore's Law, based on a 1965 prediction that turned out to be true: that the processing power of computers would double every 18 months (Schaller, 1997). Since then, the rapid development of digital technologies has promoted enormous evolution of processes, competencies and business models, changes that will reach new levels with the emergence of artificial intelligence and quantum computing (Ayoade, Rivas and Orduz, 2022; Choi, Oh and Kim, 2020).

Digital transformation creates solutions that can operate in synergy or in "cross-fertilization", accelerating technological leaps that characterize the exponential progress we have already experienced with social media, e-commerce, the internet of things, artificial intelligence, robotics, etc. (Davidovski, 2018) – exponential innovations that will amplify their reach and impact with the inevitable explosion of connectivity (Langley *et al.*, 2021). As of January 2021, there were 4.66 billion active internet users worldwide – 59.5 percent of the global population. Of this total, 92.6 percent (4.32 billion) accessed the internet via mobile devices (Johnson, 2021).

This scenario of radical changes foreshadows numerous advances, but also many dangers, as Klaus Schwab warns (Schwab, 2016). As technology advances at exponential rates, institutions – particularly public ones – adapt at much slower rates (Hanna, 2018). How to reconcile capacity and action to respond to challenges at the frontier of knowledge, with capacity and action to broadly guarantee the most basic rights of populations, such as housing, education, health and security? It is probable that traditional governments, operating structures with limited coordination and synergy, will be incapable of understanding the emerging reality and, therefore, be less able to offer answers to the complex challenges ahead (Mazzucato, 2013).

Furthermore, in the face of the constant and faster evolution of science and technology, more innovations will emerge, and the gaps will tend to get wider and wider. Citizens with easy access to information and knowledge, disseminated massively through digital media, will become more enlightened, engaged and demanding. New business standards will emerge, incorporating concepts, tools and practices of management and governance, which makes the private world more demanding for governments, in their executive and structuring role, or in their role of formulating and improving appropriate public policies (Mazzucato, 2013; Stiglitz and Greenwold, 2014).

It is not enough to say that an era of exponential advances calls for governments capable of incorporating technologies and work models that are also exponential, with adjustments in skills, infrastructure and coordination (Hanna, 2018). A new workforce that is agile and adaptable to continuous change will need to be formed (Bongomin *et al.*, 2020). Working with citizens and engaging communities will be imperative to capture signals, cooperate and validate government actions. Infrastructure will suffer from high costs and rapid obsolescence. Therefore, eliminating redundancies, creating data standards and platforms, planning and shared projects will be mandatory changes (Hanna, 2018; Mazzucato, 2013).

This context of changes and challenges has many implications for food systems that are at the nexus that links food security, nutrition, human health, the viability of ecosystems, climate change and social justice (Caron *et al.*, 2018). To deal with food, environmental and social challenges in an age of fast technological changes and disruptions, countries will need to integrate data and information from public and private environments, carry out predictive and contextual analyses, guide policies, define performance goals and metrics – advances that can only be achieved with radical changes in structures, leadership and coordination.

Despite the huge success of agricultural research and innovation over the last century, current and emerging problems and crises will inevitably pressure the reinvention of agricultural systems, a challenge that will benefit from ever more abundant scientific advances. In an increasingly intensified, high-performance agriculture, a path to sustainability may be facilitated by the possibility to incorporate knowledge and technologies to manage more complex operations, involving rotation of different crops, wider choices of species and varieties, multiple methods of soil, water and fertility management, sophisticated risk management, among other challenges conducive to sustainable farming.

Progressive automation has immense potential to empower site-specific management methods and practices with gain in precision and efficiency in the use of inputs, in pest control and other operations. Under such circumstances, agronomic research in the future will have to deal with an increasing number of factors, requiring closer interaction with producers, whose areas will practically become fields of experimentation. With advances in information and communication technologies, agronomists will be able to access and process multiple combinations, in real time and in the real world of production, whether large, medium or small ventures, identifying combinations that are economically, environmentally and socially adequate for a given reality.

Another major challenge for agronomy and rural areas is the pressure for multifunctionality, in response to the 2030 Agenda and the SDGs (UN, 2015). Besides production of food and fibres, agriculture can also be a provider of renewable energy and biomass feedstocks to sustain cost-effective strategies to help decarbonize industries still dependent on non-renewable fossil sources, for production of energy, chemicals and materials. In addition, consumers are increasingly interested in new flavours and aromas, unique and memorable sensory experiences that shape culinary end products with enormous potential for social inclusion and wealth generation in rural areas.

In such a scenario, industries and businesses will have to evolve, integrating capacities and domains of knowledge to help empower agricultural systems and rural areas in the face of many forces and factors that will forge the agriculture and the food systems of the future (Schwoob *et al.*, 2018). The seed industry can be considered one of the most important, in this context, considering its enormous impact over the last century. Many modern agriculture successes are clearly associated to numerous biological innovations embodied in seeds. Unprecedented growth in crop yields began with the development of hybrid crops in the United States of America in the early part of the twentieth century, followed by the Green Revolution of the 1960s and early 1970s and, more recently, modern biotechnology, with game-changing innovations embarked in seeds.

This keynote address will analyse challenges for the seed industry, faced with a rapid development of new concepts, methods and advanced technologies and the emergence of a cleaner, decarbonized, circular, green economy, aligned to the SDGs. An industry faced with a new set of standards and requirements, and more expectations for solutions to help agriculture and food systems to move faster towards a sustainable future.

Technology increasing plant breeding capacity

Crop varieties are the foundations of civilization and, as such, have a sizeable impact on food security, economic and social stability around the globe. Plant breeding has provided a wealth of genetics-based solutions to help increase global food production, being a key driver for increased productivity in all agricultural sectors. It is consensus that the impressive growth in agricultural productivity and production over the last century was possible because farmers had a reliable source of good quality seeds of well-adapted varieties. Plant breeding, and the seed industry, made it possible for farmers to access a regular supply of seeds and planting materials with genetic potential to perform well, provided the availability of water, fertility, pest protection and adequate agronomic practices.

As such, plant breeding and the seed industry have provided extremely reliable technology solutions to meet increasing demands of an expanding global population. Take the advances in maize production in the United States of America over time, with initial progress made by the farmers themselves, who selected local open-pollinated cultivars adapted to diverse environments (Duvick, 2005a, 2005b). These initial gains soon, in the following cycles, became small and, sometimes, even null. After the discovery and introduction of hybrid maize, a significant jump in productivity became possible. Breeders rapidly learned the potential of inbred lines, that crossed, provided a burst of performance through heterosis. The advance led to substantial increases in crop productivity with double-cross and single-cross hybrids developed and disseminated over the decades, reaching yields considered impossible to achieve before hybrid vigour was discovered and managed (Crow, 1998).

Scientific plant breeding has also shown that plant genetic resources are the fuel for progress, allowing plant breeders to search for higher yield and adaptation to different environments and conditions through manipulation of genotypes and genes to meet the needs of farmers. The tropicalization of soybeans is one of the most successful examples of creative use of genetic variability with high impact in agriculture and food systems (Dall'Agnol, 2016). This species arrived in Brazil in 1882, remaining unknown for about seven decades. It gained some importance only in the 1960s, with production growing from

206 000 tonnes to 1 million tonnes in one decade, still restricted to the southern areas of the country, under environmental conditions more similar to the centre of origin of this species in Asia (Gazzoni and Dall'Agnol, 2018).

Until the mid-1970s, most of the soybean grown in Brazil came from the southern states. It was in the 1980s that the crop began to spread throughout central Brazil, a large tropical area of savannah known as Cerrado (Goodland, 1971). That was possible due to the development of cultivars well adapted to the low latitude of the region – varieties bred to be less sensitive to photoperiodic variations. Continuous investment in genetic resources characterization, breeding and cropping systems development allowed soybean to advance during the 1990s towards the centre-north of the country (around 10° south to 12° south) with further expansion occurring in the 2000s, further to the north (latitudes near 0° to 5° south or 5° north) (Cattelan and Dall'Agnol, 2018).

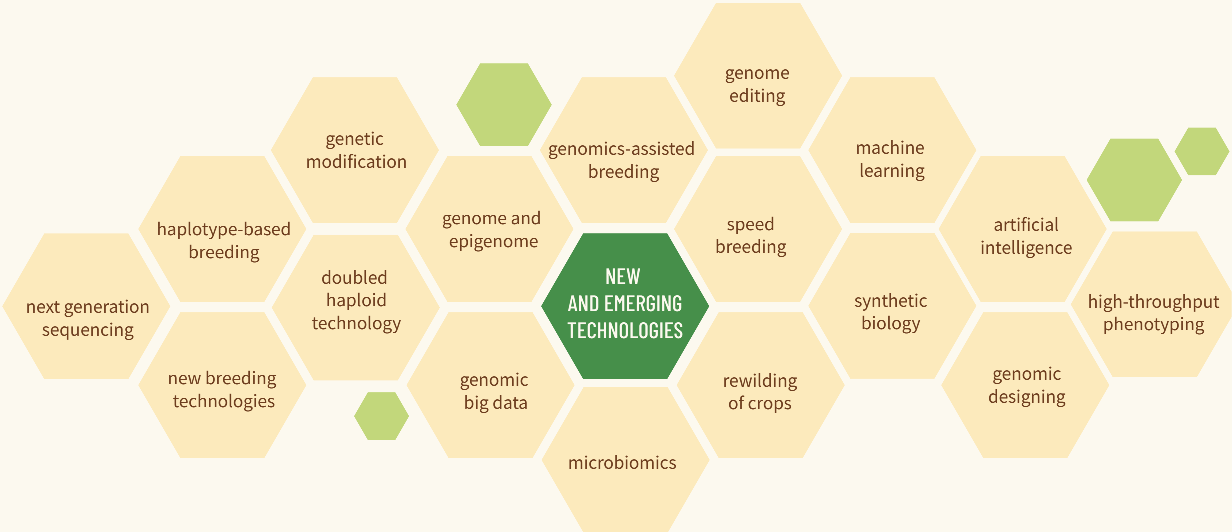
The expansion of soybean production in Brazil influenced expansion of other crops, especially maize, a preferred choice for rotation, with both crops accounting for more than 80 percent of the total area and 85 percent of the production of grains in the country. In the period 1990–2017, the total growth in production of these crops was significant – 313 percent against 76 percent increase in the farmed area (Embrapa, 2018) – an indication of substantial gains in agronomic performance, allowed by efficient access to genetic variability, to selection and breeding, together with improvement of agronomic practices. These advances strengthened food security, helping at the same time to transform Brazil into one of the major agricultural exporters in the world (Lopes and Martha Jr, 2014; Embrapa, 2014, 2018). The success of soybean and maize production in Brazil is an example of how investments in research and innovation were important to allow production in tropical areas considered marginal for centuries, like the Cerrado, with substantial impact in food security and economic progress (Martha Jr and Alves, 2018).

While conventional breeding approaches will no doubt remain a pillar of future crop improvement strategies, these will increasingly be augmented with the latest molecular innovations (Crisp *et al*., 2022). Technological progress has driven down the price of plant genotyping assays and sequencing, which has translated into diverse methodologies available to breeders to accelerate improvement. These range from marker-assisted selection to genomic selection, underpinned by an explosion in available reference pangenomes and paired with advances in high-throughput phenotyping technologies (Hickey *et al*., 2019; Varshney *et al*., 2020; Bohra *et al*., 2020; Steinwand and Ronald, 2020).

The tremendous impact of biotechnological developments we have seen in the past decades – such as transgenic technologies – were possible by building on knowledge and variability tailored by more than a century of traditional breeding and selection. Modern biotechnology associated with information technology and advanced instrumentation are giving us now a new wave of innovations capable of driving agricultural diversification, specialization and value aggregation, besides increased productivity, food safety and food quality well beyond any advances of the past (**Figure 1**).

Genome editing using clustered regularly interspaced short palindrome repeats (CRISPR)/ CRISPR-associated protein (CRISPR/Cas) technologies now offer efficient avenues to either create entirely novel alleles or to readily introduce rare or recalcitrant natural alleles into elite varieties. Initial applications have mostly focused on editing protein-coding regions within genes to knockout gene function. However, there is tremendous value in thinking beyond coding sequences, to tune the expression of genes and generate quantitative trait variation. We are gradually learning that factors beyond the coding sequence of genes contribute to trait variation in crops, and progress has been made in understanding the contributions of both epigenetic variation and cis-regulatory variation to plant traits. This non-genic variation has great potential in future breeding, synthetic biology and biotechnology applications (Crisp *et al*., 2022).

Figure 1. New and emerging technologies influencing the capacity of seed industries to deliver solutions to farmers.



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, with potential impact in cultivar development and the configuration of seed industries. 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 metre, also promises to revolutionize the development of multiple products, processes and instruments. Advanced sensors will enable the monitoring of production systems with great precision, new materials and processes will allow development of machines and equipment that are more efficient, accurate and durable.

Using these advances in agriculture to confront the challenges ahead is strategic for the world, considering the need to supply food for a growing world population, at the same time fulfilling expectations for diversity, adequate nutrition and sustainability (IIASA, 2018; Sachs *et al.*, 2019).

A wide array of technological advances is needed to facilitate preservation of natural resources such as soil, water, forests and biodiversity. In addition, we need more research 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 (Shukla *et al.*, eds, 2019). Plant breeding and seed systems are not detached from this reality. As challenges become more complex, the world will need greater diversity of genetic materials, readily available to farmers of different scales, in developed and developing countries.

Lastly, but not less important, it is crucial to be alert, informed and acquainted with current and emerging trends and changes in demands and expectations of modern society, especially in standards associated with the global development agenda (Rockström *et al.*, 2009; IIASA, 2018; Sachs *et al.*, 2019; Rockström *et al.*, 2020). The 2030 Agenda and the SDGs (UN, 2015) point strongly to the need of agriculture and related industries to embrace new practices and new criteria of performance, with more balanced attention to the three dimensions of sustainability – economic, social and environmental.

Plant breeding and seed systems in the emerging bioeconomy

Biodiversity and climate are central elements in the complex equation of civilization that has brought us to the present. Globalization, trade, the internet and the proliferation of air and sea routes cutting the globe in all directions (Khanna, 2016) allowed the world to use the planet's finite resources with increasing intensity, multiplying the human impact on the Earth´s natural resource base (Crutzen, 2002; Steffen, Crutzen and McNeill, 2007; Lewis and Maslin, 2015; Dodds, 2019; Subramanian, 2019). Together, climate change and loss of biodiversity could reduce ecosystem resilience and limit our ability to adapt to abrupt changes in natural systems, with threats to our food and agricultural systems, population health, trade and, ultimately, the world peace (IIASA, 2018; Sachs *et al.*, 2019).

These are among the reasons why sustainability has climbed to the very top of society's priority agenda (UN, 2015). The interest in sustainability grows stronger as society realizes the limits of the development model that relies on non-renewable resources (Rockström *et al.*, 2009; IIASA, 2018; Rockström *et al.*, 2020). As the population grows in number and consumption capacity, so does the perception that the economy must rely more on biologically based, recyclable, renewable – and hence more sustainable – resources. This is the foundation for the new bioeconomy, which has been ranking higher and higher on the agenda of governments and companies around the world (White House, 2012; El-Chichakli *et al.*, 2016; Bugge, Hansen and Klitkou, 2016).

This is the reason for the growing interest in low-carbon resource-saving technologies capable of promoting the sustainable intensification of land use and more sustainable agricultural production systems. There are challenges to be faced that demand technological sophistication for more resilient land use practices, with increasing provision of environmental and ecosystem services from agriculture, with waste reduction and recycling, restoration and conservation of water sources, reduction of greenhouse gas emissions, among others. Therefore, any consistent agenda for the future of plant breeding and seed systems must follow an integrative and systemic perspective, focusing on the nexus of different challenge areas, and in new ways to mobilize genetic variability to help drive sustainability in rural areas.

The emerging bioeconomy will become a source of many creative strategies to mobilize genetic diversity to help agriculture face the challenges ahead. More attention to research in genetic resources and crop breeding is paramount, to expand the variability base and to mobilize through improved seeds new biological functions capable to help agriculture fulfil its part in the pursuit of a sustainable future. Here are some challenges the agricultural research community will have to face, to assure that genetic diversity will be available, with the help of the seed industry, in pursuit of a much-needed food security for the world in the future:

Strengthening crop breeding capacity
The production of new, more-adapted, and productive crop varieties, a result of genetic improvement, is one of the main contributions of agricultural research to humanity. Plant breeders have been able to adapt plants to a wide range of agricultural areas around the world, to cropland with marked differences in soil and climate, intense biotic and abiotic stresses and diversified technology usage patterns. Thus, capacity to develop genetic innovations in the form of improved crop cultivars will continue to be fundamental to all countries, especially in the face of increasing challenges posed by climate change and stress intensification (Shukla *et al.*, eds, 2019). *Strengthening crop breeding capacity through efficient research in plant genetics and biotechnology will ensure that agriculture maintains the ability to respond to problems that may jeopardize food and nutritional security in the future.*

Sustainable use of water
Despite being the sector that already consumes most water, irrigated agriculture tends to grow in the future, due to climate change and more extreme weather events, especially droughts. In addition, the need to increase agricultural productivity to meet the demands of a growing population will increase concerns and conflicts

related to competitive uses of water. Therefore, a major challenge for the future will be the optimization of water use by agriculture in order to reduce the pressure on this finite resource and release water for other purposes. Innovations to rationalize the use of water and to avoid or reduce its waste will be critical to meet the growing demand for food, with minimal environmental impacts. *Access to genetic variability and to biotechnological tools and processes to empower crop breeding will be essential to make crops increasingly more efficient in the use of water.*

More effective protection of agriculture
One of the critical challenges for food production is the movement of exotic organisms or invasive species from one region to another, depending on trade, transport and tourism. Globalization of pests leads to displacement of organisms from one region to another, intentionally or not, with significant potential for economic, environmental and social impacts. Strong emphasis on technological innovation is critical to meet the diverse demands of importing countries and respond to rigid compliance standards that are consolidated internationally. Countries will have to develop production systems sustained in sanitary practices consistent with internationally accepted patterns of quality and safety assurance for their agricultural products. *Availability of genetic resources and breeding research on plant resistance to pests will play an increasingly prominent role in the defense of agriculture around the world.*

Safety and efficiency of agricultural inputs
There is no doubt that farmers will be pressed to seek alternatives or substitutes for inputs of high environmental impact, especially those derived from non-renewable sources. Many conventional inputs, like pesticides and fertilizers, contribute to rising costs in food production, and may have deleterious impacts on the environment. It is, therefore, necessary to develop alternative and safer sources of nutrients, such as nitrogen fixation by bacteria or biorelease of phosphorus and potassium from non-conventional mineral sources. In addition, the research in genetic resources can contribute to identify variability to efficiency of nutrient use by plants, particularly those nutrients that are scarce or have large potential impact on the environment. *Crop breeding and biotechnology have the capacity to mobilize variability to increase plant resistance to pests and nutrient use efficiency, with high potential of impact in the sustainability of agriculture.*

Linking food, nutrition and health
The concerted integration of food, nutrition and health strategies appears to be inevitable, due to demographic changes (increase in the average age of the population) and the exhaustion of health and social security systems, even in developed countries. The gradual change to a disease prevention paradigm will require food more suited to the needs of consumers (biofortified with vitamins, minerals and high-quality protein), adapted to demographic changes (increasingly elderly population) and capable of boosting performance in various capacities (physical, intellectual, etc.). *Genetic improvement will have to focus on the development of food with high nutritional and functional density, high quality, producing minimal waste and enabling manufacture at low cost with high productivity.*

Sustainable intensification of land use
Technologies capable of allowing increased and more sustainable use of the natural resource base will receive more attention in the future. In many parts to the world, agricultural land has been degraded and abandoned. If recovered, these are the ideal areas for expansion of agriculture, livestock and planted forest, without the need for further deforestation. It makes more sense to recover degraded areas than to open forested areas to farming. Integrating production systems, like crop–livestock, and crop–livestock–forest are viable possibilities for land recovery in many countries, especially in the tropical belt of the world (Lopes, 2019). Such technological innovations may allow configurations of low-carbon agriculture and dissemination of sustainable and more resilient farming practices. *The research on genetic resources and breeding will contribute to development of plants and animal breeds better adapted to low-carbon agricultural systems based on crop–livestock and crop–livestock–forest integration.*

Precision agriculture

The implementation of site-specific management practices on farms has the potential to provoke a revolution in agriculture, for reasons that include: a) virtually all agricultural areas have significant spatial variability in factors that affect crop yields, such as fertility, humidity, pest dispersion etc.; b) today we have knowledge and tools to identify and measure multiple sources of variability; and c) with this knowledge, we can use information and communication technology tools, associated with advanced automation, to modify management practices in order to increase efficiency and reduce impacts. With recent advances in drone technologies, artificial intelligence, sophisticated algorithms, sensors and actuators, significant gains in precision, accuracy and sustainability will become possible, *possibly requiring modulations in plant structure, functions and performance, which must be provided by breeding, through improved seeds.*

Conclusions

The agriculture of the future will be impacted by concepts, methods and expectations far beyond conventional agricultural systems. The SDGs point strongly to the need of agriculture and related industries to embrace new practices and new criteria of performance, with more balanced attention to the three dimensions of sustainability – economic, social and environmental.

Humans have built a successful journey on the planet by observing natural systems and making interventions to adapt plants, animals and ecosystems to their needs. But, at various points in this trajectory, such interventions began to ignore critical balances, refined by millions of years of trial and error that ensured nature's resilience and durability. The disruption of such balances to create benefits of exclusively human interest, in ever-shorter terms, puts the health of the planet at risk and, in the limit, may compromise the very viability of society.

Therefore, agriculture and food systems are under pressure to align with principles that were perfected millions of years ago and encoded in living things and natural systems, long before human evolution and the creation of agriculture, industries, commerce or any other modern artifact. It is urgent that we seek to mimic nature in its ability to integrate complex systems, using resources efficiently, incorporating waste into useful processes and products, conserving soil and water, fixing more than emitting carbon, maximizing energy efficiency, among many other functions.

Fortunately, scientific revolutions are happening in biology, physics, chemistry, information technology and communication, advanced automation and precision processes with numerous innovations that increase our ability to respond to risks and challenges. Considering these advances and the emergence of a cleaner, decarbonized, circular green economy, the expectation is that key agricultural innovation domains, like plant breeding, cultivar development and related industries will be gradually reinvented.

They will be reinvented to facilitate our journey towards the much-desired sustainability, which is nothing more than the reconciliation between human systems and nature. For agriculture, and the seed industry, such reconciliation will depend on a review of the concept of performance, traditionally associated with the amount of food or raw materials produced in a given space and translated into economic gain. The world that calls for sustainability already demands more sophisticated measures of performance from agriculture, focused not only on physical production and profitability, but also on eco-efficiency, social benefits and ethically acceptable management practices, all embedded in its operations, processes and products.

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1.4 Crop improvement, better seed – From conservation of crop biodiversity to impactful use

Marco Ferroni
Chair, CGIAR System Board

Distinguished participants,

Allow me to start by congratulating FAO on its bold vision and foresight in organizing this conference and thanking the leadership for their invitation to address you today.

Seeds – along with soil, water, the weather and hard-working farmers – are the foundation of agriculture. Their importance to food security, farmer and consumer welfare, and agricultural development and growth cannot be overstated. The concept of *seed systems* is useful to keep in mind. They are the set of formal and informal arrangements through which farmers gain access to seed. In recent decades, seed systems and varietal choice have improved substantially for selected crops in the global South, particularly in Africa and Asia. But many regions face significant shortages in the supply of seed for a broad range of crops and planting materials of recent varieties.

Modern plant breeding tends to benefit high-potential areas where farmers can profitably use inputs to control their environments. The impacts are less visible in areas where resource-poor farmers struggle to make ends meet because of the challenges inherent in the design, development and delivery of the products they seek. Seed systems often disappoint on the supply and demand side. They fail both to deliver and empower farmers to adopt market- and farmer-preferred genetic material that performs well under local conditions. Large tracts of farmland miss out on good seed, causing production and income losses in subsequent years. The seedsman Simon Groot knew what he was talking about when in his 2019 World Food Prize acceptance speech he said: "The farmer's main enemy is lousy seed".

Resource-poor small farmers, many of whom are women, are particularly underserved when it comes to accessing high-quality seed. Field studies have demonstrated that these farmers have to contend with low varietal purity and germination rates and high concentrations of pathogens and seed-borne diseases. This affects yields, farm incomes, livelihoods, nutrition, gender-equity and the nation's food supply. Compromised food security and avoidable food import dependency are among the consequences.

Sustainable Development Goal 2 (SDG2) – to end hunger by 2030 – cannot be achieved unless better seed can be accessed and planted by millions of low-income farmers in the global South. Seed is not everything in the drive to end hunger, but it plays a key role in nutrition, farm resilience and productivity, and the incomes of small-scale producers, particularly those of women and family farmers.

I hope to help bring this to life in my remarks today, focusing on the conservation of germplasm and its use in crop breeding and seed production.

My vision is for every acre farmed to be planted to appropriate high-quality seed. I know this is ambitious. But it is an essential part of achieving SDG2, and not infeasible with the right plans, funding, partnerships and implementation over time. If we are to scale up farmers' access to varieties with relevant traits, then strategies for accelerated development, delivery and uptake of improved seed need to focus on safeguarding genetic diversity and investing in breeding, seed production and the marketing and distribution of quality seed through formal and informal channels.

This would seem straightforward. But coherent policies and programmes to deliver on each of these aspects must be designed, funded and implemented to high standards. This is where technical and institutional difficulties, and those related to collective action, arise. Effective leadership and partnerships built on foundations of trust are essential ingredients of success, though sometimes found in short supply. Our task as conference participants – the community called upon to transform seed systems – is to rise to this challenge. We are called to bring the best of our commitment, ability and resources to bear – to display leadership.

Germplasm conservation

Agrobiodiversity is being lost at an unprecedented rate in our era because of deforestation and other land use changes, and the homogenization of landscapes and farming systems that characterize modern agriculture. As explained in the CGIAR's 2030 Research Prospectus (www.cgiar.org/research), this is extremely serious. Diminishing biodiversity can undermine the resilience of farming systems and nutritional security. Equally worrying, biodiversity loss can undermine the very foundation upon which crop improvement research is based, given its reliance on crop genetic resources, along with breeding methods and tools, to incorporate desired traits into cultivars.

Genetic diversity is the raw material that plant breeders use to develop high-yielding crops with desired agronomic and market characteristics, such as tolerance to biotic and abiotic stress, and advantageous health, nutritional, cooking and processing traits.

Climate change is putting the world's farming systems at risk because of potentially extreme (but locally hard to predict) abiotic stress factors, such as drought, and rapidly evolving weed, pest and disease pressure. To counter this threat and meet food demand driven by rising affluence and population growth, crop improvement research is challenged like never before. With the help of wild and improved agricultural biodiversity and modern plant breeding investments, it is called upon to go beyond the breakthroughs of the past, such as the Green Revolution of the 1960s and 1970s. Conserving biodiversity for use in plant breeding is vitally important *ex situ* (in so-called genebanks) and *in situ* in farmers' fields and in the wild.

"Aguapan" in Peru is an example of germplasm conservation in farmers' fields. It is a network of over 100 rural communities in the Andes that conserve more than 1000 potato landraces *in situ*. The initiative rests on partnerships between local communities and the genebank of the International Potato Center that "repatriates" landraces to their geographic area of origin for commercial cultivation by farmers (with female farm managers distinguishing themselves relative to males on punctiliousness and motivation in this experience). Farm income (an incentive to participate) is supported by marketing campaigns that involve restaurants and their chefs in cities such as Lima where culinary traditions based on local foods are being revived.

As for *ex situ* conservation, the global community has an elaborate system for it. However, it needs adequate funding to be able to live up to the full extent of its mission, adherence to shared protocols, standards and rules, and international agreements regarding the governance and use of genetic resources and genomic information. The key players in the global system are:

- The Global Crop Diversity Trust, which safeguards *ex situ* collections of unique and valuable plant genetic materials, acts as a funding intermediary through its Endowment Fund and project funds, and promotes a sustainable global system, with the Svalbard Global Seed Vault serving as a resource of last resort where duplicates of accessions are safety-duplicated from other sites;
- FAO, which hosts the Secretariat of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and plays valuable convening roles for negotiations on genetic resource conservation and use;
- CGIAR, which runs 11 genebanks managing a total collection of about 750 000 crop, forage and tree accessions, including about 26 000 *in vitro* accessions and 33 000 accessions held as trees or plants in the screenhouse or field; and
- About 1700 national genebanks and many private collections that hold an estimated 7.4 million accessions of different crops – ten

times more than the CGIAR which, however, accounts for more than 90 percent of the germplasm distributed internationally according to the guidelines of the ITPGRFA.

According to the CGIAR Genebank Platform's 2020 Annual Report, CGIAR genebanks have distributed approximately 115 000 germplasm samples a year globally since 2010, about 40 percent of which went to universities and research institutions, while the rest was shared in broadly equal quantities with national agricultural research systems and the commercial seed sector, non-governmental organizations (NGOs) and farmers or their organizations.

Though not easy to quantify, the value of properly managed and documented genebanks is huge – justifying commensurate investment in them.

The Crop Trust distinguishes between a) the production value of genebanks linked to the (high) economic returns to plant genetic resource use in impactful breeding; b) the value of positive externalities, such as the impacts of improved genetics in decreased water and pesticide use, reduced toxic run-off, and enhanced soil health through suitable multicropping; and c) the option value arising from valuable but unknown genes in collections that may generate production value in the future. The story of maize lethal necrosis, a devastating viral disease first spotted in East Africa in 2011, illustrates the massive production value represented by genebanks. The disease was substantially brought under control in about six years by introgressing lethal-necrosis-resistant genes from the International Maize and Wheat Improvement Center (CIMMYT) into susceptible lines.

CGIAR's Conservation and Use of Genetic Resources Initiative – the "Genebank Initiative", one of six Research Initiatives under our Genetic Innovation Action Area – aims to support the global system for the conservation and use of plant genetic resources for food and agriculture. This includes a) managing CGIAR's collections to increasingly ambitious standards and performance targets to guarantee the availability of germplasm in perpetuity; b) investing in research tools to characterize the content of the collections to improve searches for accessions that match users' needs, thereby increasing the collections' relevance and value; and c) strengthening the global system through capacity building and coordinated engagement in international policy negotiations, such as the post-2020 Global Biodiversity Framework of the Convention on Biological Diversity.

The principles governing international access and benefit-sharing of genetic resources are contested in intergovernmental fora, as most of us know. Allow me to point out that restrictive policies could undermine the exchange of germplasm and digital sequence information for impactful use. This could potentially threaten the availability of biodiversity to address climate adaptation, farming system diversification, and (for example) the development of crops with advantageous nutritional profiles, traits of interest to women farmers, and storage and processing properties that could lead to job creation, new value chains, and economic growth. Clearly, the stakes in germplasm sharing and conservation *ex situ* are high.

Yet, arguably, they are dwarfed by the challenges on the *in situ* front. Local, national and international actors – governments, the private sector, civil society, international stakeholders, among others – are called upon to inspire the transformation of landscapes and agricultural practices to protect and regenerate agrobiodiversity and the habitats and natural resources upon which it depends. The monumental Dasgupta Review of the Economics of Biodiversity (published in February 2021) reminds us of a basic truth that we would ignore at our peril. Humans are part of Nature, not separate from it. Our demands on Nature exceed what Nature can supply (leading for example to biodiversity loss). We need to correct the widespread institutional failure that leads to the undervaluation and overuse (beyond their regenerative capacity) of natural assets, such as biodiversity.

Impactful use

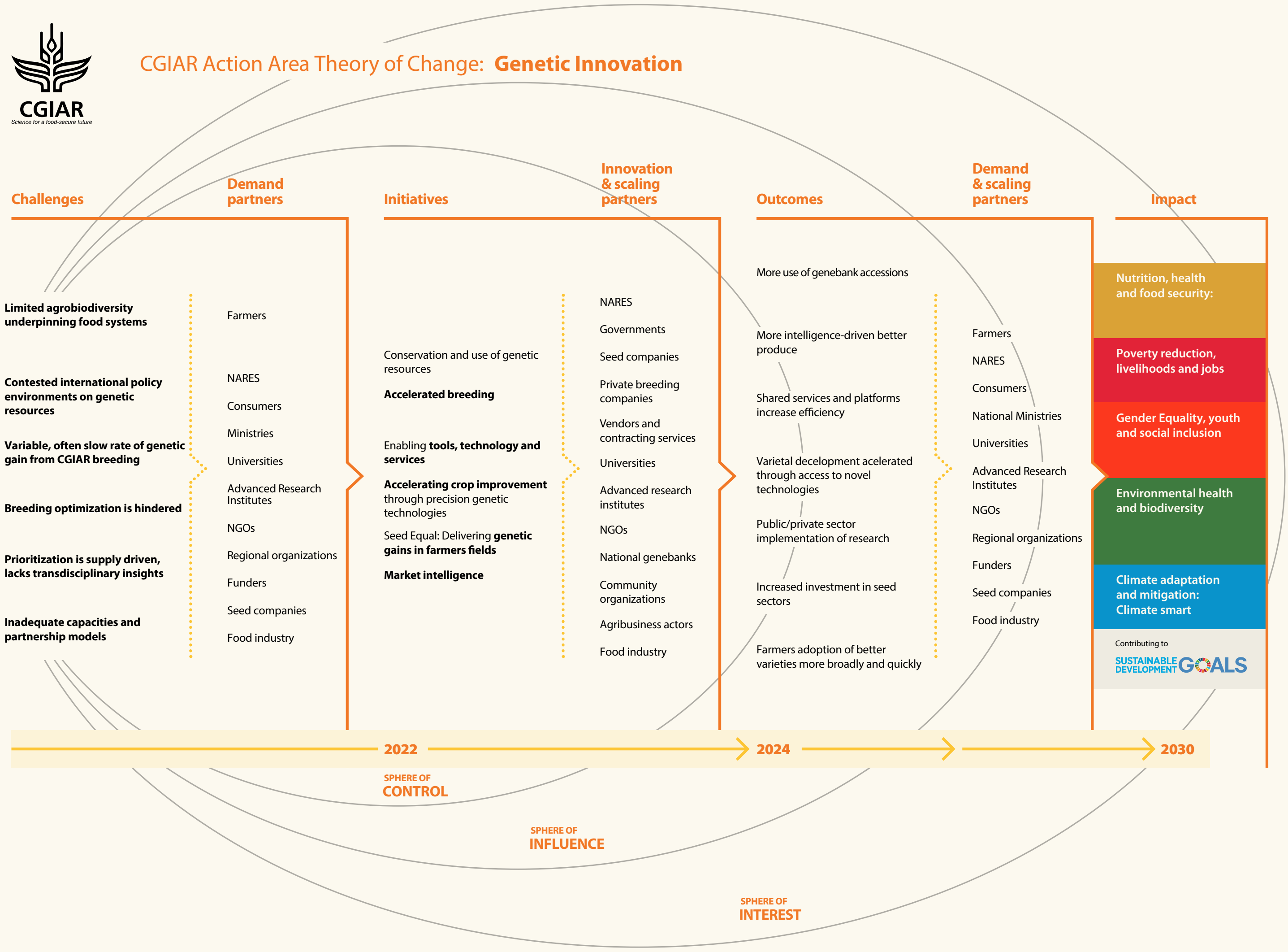
Imagine the nutritious, vitamin-A-rich varieties of orange-fleshed sweet potato and the fast-cooking ("fuel-efficient") beans that save firewood and women's time collecting it. Imagine the breakthroughs in plant architecture for enhanced grain yield in wheat. These are all examples of impactful uses of germplasm made possible by innovation in plant breeding.

Feeding the world's population this century will require innovation like this, generating nutritious food in sufficient quantities from increasingly sustainable, high-yielding, climate-adapted and resilient agricultural systems.

The role of plant breeding will be vital – performing to metrics of "genetic gain" (the rate of which needs to increase, particularly in resource-poor small farmers' fields) and varietal age (the average of which should decrease to allow farmers to benefit from recent plant breeding efforts). CGIAR's Genetic Innovation Action Area, already referred to above, proposes a strategy for advancement on both fronts: Research Initiatives working with innovation and scaling partners on clear pathways (see the theory of change outlined in **Figure 2**).

Documents found on CGIAR's website (from which I borrow here) define the Action Area's overarching goal in terms of the two metrics

Figure 2. CGIAR Action Area Theory of Change: Genetic Innovation



for traits in mandate crops to catalyse benefits in CGIAR's five impact areas: nutrition, poverty, gender, climate and environment, identified in Figure 2. This suggests the need for breeding for potentially complex traits in different dimensions, such as increased production under diverse environmental and crop management conditions, addressing the needs of women farmers, climate resilience, nutritional considerations (e.g. through biofortification), processing characteristics, and both end-use quality and consumer preferences.

The Action Area recognizes the opportunity for accelerated delivery of benefits in these dimensions under a shared approach that bundles the energy and contributions of different CGIAR Centers and their partners and innovates through:

- Systematic investment in market intelligence and product profiling to spawn relevant products with shorter adoption lags and increased adoption levels;
- The modernization of breeding methods highlighting data-driven, quantitatively optimized approaches for faster breeding cycles to facilitate the development of more complex, multitrait products matching product profiles, and enable "multiplier effects" across a range of crop-related innovations;
- Collaboration on data, network-enabled tools, technologies and shared services across CGIAR and in partnership with national agricultural research systems to allow innovations to be shared, work stages to be managed across teams, and fragmentation and costs to be reduced;
- A reset of partnerships with national agricultural research systems toward coordinated, networked efforts building consensus and capacity for agreed performance targets, while respecting comparative advantage to enable a vision and joint action toward a more holistic performance system; and
- The effective seed delivery to validate investment in genetic improvement by fostering adoption and allowing impact to materialize as benefits flow to farmers' fields.

Each of these aspects could be the subject of a keynote address of its own. Allow me to limit myself to three observations:

First, the Action Area's coordinated approach to breeding, aligned with objectives in target geographies and working with the benefit of standardized methods and tools, has become possible because of the 'One CGIAR' reform now being enacted. One CGIAR and the Genetic Innovation Action Area offer new opportunities as market intelligence and product profiles define the case for investment, and updates in breeding technology and procedures enable implementation.

Second, on the case for investment – which hinges on whether adoptable products can be designed, developed and delivered to farmers at scale: Design should be guided by market intelligence. Successful demand-led approaches combine insight into what could satisfy users with innovative plant breeding methods that seize on this and develop products that close "satisfaction gaps". But what are these gaps and what does the market want? Users are unlikely to "know" and report in advance. They can be expected to recognize merit when they see it – working with winning products and solutions, driving adoption from there. But the meaning of "merit" needs to be teased out in market research by interdisciplinary teams for different users and impact domains. Market intelligence thus gathered should be used to prioritize characteristics in variety design and investment decisions.

But what about "simpler", more supply-driven approaches to variety design that worked in the past in many instances and may still do so, offering users value on large surfaces that help drive the numbers of calculations documenting high rates of return on investment in plant breeding and agricultural research? This cannot be dismissed where it offers value, but even high rates of return may be below potential. The literature shows that the uptake of varieties developed by CGIAR and its partners is uneven and varietal turnover slow. There is evidence that product design is biased toward agronomic and stress tolerance traits (which are important!). But this happens to the detriment of identification and integration of traits that contribute environmental or social benefit without which SDG2 cannot be achieved. Market research is still recommended – for example so we can improve our understanding of the factors which hinder varietal replacement.

Third, on seed delivery systems. Seed systems can only be as good as the quality of the genetics of specific crops on offer and their relevance to farmer groups and markets. Progressive changes in performance are needed to trigger adoption by farmers. This requires, as previously mentioned, an understanding of target markets at the design stage. Extension services and the influence of community leaders and early adopters will help. But the core requirement is a product that meets the needs of potential users. Does it work under low-input conditions? Does it respond to end-user requirements in the market? Does it offer enough advantages to justify replacing existing varieties? These are the types of questions users can be expected to ask. Unambiguous answers are needed for genetic gain (achieved through varietal substitution) to occur in farmers' fields.

On the supply side, recurring seed systems challenges include policy and regulatory hurdles affecting varietal release, and "hand-over" processes involving interactions between breeders and those involved in the downstream activities of seed production and trade. Seed regulation is important, complex and difficult to get right. It deserves attention in the interest of quality assurance and the flow of improved products to users. Cross-border harmonization of seed regulation can foster innovation by widening markets and incentives to invest in breeding and the production of certified seed.

Public–private cooperation is a hallmark of seed systems and particularly important for less commercially attractive crops and markets serving resource-poor marginal farmers. Breeding tends to be commercially unviable for this segment. But the interests and skills of downstream seed value chain actors for selected crops and markets can be tapped and supported (farmers' organizations, NGOs, small and medium-size firms). The Alliance for a Green Revolution in Africa (AGRA) has played an important role in nurturing this now growing segment of the seed industry through capacity-building efforts and technical and financial assistance. A key aspect of success in the deployment of publicly bred varieties by private actors is an understanding of each other's role in a shared framework of what is to be achieved. There is a long way to go on this path, but recent achievements in Africa have begun to transform the seed industry landscape.

CGIAR's Genetic Innovation Action Area is committed to the approach of capacity building in public–private partnership models to enable uptake of publicly bred varieties by seed companies and other seed multipliers. This is the last mile of the journey of "impactful use".

Summing up

Improved seed is necessarily a key element of any strategy to promote food security and progress in CGIAR's five impact areas of nutrition, poverty, gender, climate and environment. Designing, developing and delivering improved seed to farmers, particularly the hundreds of millions of resource-poor family farms in the global South, is one of the daunting development challenges of our era. There has been progress in this space in the last 20 years or so. But much more remains to be done.

Protection and rehabilitation of biodiversity in the wild and on agricultural landscapes is a must, as is the conservation of germplasm *ex situ* and through special programmes in farmers' fields. The global system for conservation *ex situ*, while in place, is underfunded and hampered by disagreement on the terms of access and benefit-sharing.

While the use of conserved biodiversity in plant breeding and seed systems development looks back on a proud tradition over many decades, for some time it has shown signs of deficiency in terms of organization and the adoption of modern breeding approaches and methods. It is for this reason that CGIAR has reorganized its work as it has in its Genetic Innovation Action Area. The intention is that going forward this will enable accelerated impact on a larger scale with partners, in particular with national agricultural research systems. The ambition that every acre farmed benefit from access to adequate, high-quality seed is keenly alive. We must not waver but work to deliver on this vision. Even if the path forward is clear, there will be implementation difficulties. But this is no different from any other epochal process of transformation and change. There is no room for complacency.

Thank you for your attention.

1.5 Seed systems as enablers to seed choice

Michael Keller
Secretary General, International Seed Federation (ISF), Switzerland

Dear Director-General,

Dear representatives of countries,

Dear colleagues,

Dear friends,

Today we are honoured to be invited to this conference on "Green Development of the Seed Sector" in order to contribute to the Strategic Framework of the FAO.

The private seed sector sees itself as a partner to FAO and its motto "fiat panis – let there be bread", as seed is a crucial starting point for food security. Fiat panis should be a unifying driver for the public and private sectors, farmers, civil society, Indigenous Peoples. In complementing each other's actions, we can succeed together.

In 2009, in the executive summary of the 2nd World Seed Conference, it was stated that "Governments are strongly encouraged to implement a predictable, reliable, user friendly and affordable regulatory environment to ensure that farmers have access to high quality seed at a fair price." and that "Plant breeding has significantly contributed and will continue to be a major contributor to increased food security". Reading through the proceedings of the conference, several attendees were deeply concerned that the outcome of the conference would not be enough to succeed at the level of challenges we were facing. Some important follow up took place, **but it's time to go further together**.

During the next two days we will have certainly good exchanges and debates, but I wonder, ten years from now, in 2031, will we be convinced that we have done enough together?

Today I am here to highlight that the seed sector in its diversity of over 8000 seed companies – family-owned, cooperatives, small, medium size companies, or multinationals who are active in breeding, producing and trading hundreds of crops – all share the joint vision of "a world where quality seed is accessible to all, to support sustainable agriculture and food security".

Perhaps our perspectives and approaches differ in some ways – but business is a contributor to achieving society's goals, and we are here to stay. The private seed sector, like many other actors present here today, is equally committed and engaged in achieving the Sustainable Development Goals. I invite you to take a look, for example, at the Seed Declaration signed by hundreds of companies earlier this year, which outlines the private seed sector's sustained contribution to the SDGs until 2030 and beyond.

To speak in the name of the private sector is a lot of responsibility. I am speaking for a sector which started in 1740 with horticultural crops, which established the first gene banks in 1800. The private seed sector, aware of its responsibility as provider of the first and most critical input in sustainable agriculture production, has always seen the conservation and use of genetic resources as highly critical. To address the upcoming challenges, we need to ensure the conservation of genetic resources *ex situ* and *in situ*. The access, use and circulation of genetic resources is an essential driver to achieve the SDGs.

For the private seed sector, innovation is in our DNA. Continued genetic progress through plant breeding innovation is essential for meeting the challenges on agriculture and food production. We can look back and see that, over the past 50 years, it was the joint effort between public and private sectors that contributed and drove the yield increases up to 90 percent in different crops, in order to increase food production to feed an increasing population.

Are there many other sectors existing where every year up to 30 percent (annual turnover) is invested in R&D? Did you know that every year over 2500 new varieties are released to the market in the European Union alone, over 45 000 varieties are registered in the European catalogue, and close to 200 000 are accessible worldwide?

More and more crops, including underutilized crops, are being improved in collaboration between farmers, the public and the private sector. An example is cassava in Kenya, where companies are working hand in hand with public research on genetic resources through gene banks, and on seed quality control and resilient seed production systems.

Cooperation is a proven way of making progress on our goals, as we see in many countries where there are efficient partnerships between the private sector and public organizations. These partnerships play a significant role in variety demonstration, scaling out farmer-based quality seed production and outgrower schemes. The scale of production, processing and distribution of quality seed of improved varieties from those sectors has increased over the last years.

Increasing knowledge especially via field demonstrations is critical, to raise awareness of farmers on the variety of seeds available to them. Did you know that for example in Ethiopia, 50 000 smallholder farmers were offered the possibility to choose between landraces and commercial varieties of tomatoes or onions through information and education programmes organized by the private sector, and nearly 90 percent of them switched to commercial varieties as this allowed them to improve their livelihood thanks to increased yield from crops that withstand pest and diseases?

Did you know that in a recent independent dialogue for the UN Food Systems Summit, co-hosted by the World Farmers' Organisation and ISF, a survey showed that 82 percent of farmers considered new improved varieties as important to respond to climate change and 81 percent of farmers considered it as important for sustainability in the food systems?

Empowering farmers is a mission that the private sector carries out day by day, to develop together the most suitable solution for their needs at the local level. Improved plant varieties enable farmers to harvest better yields amidst the pressure of climate change and limited resources. The seed sector can only succeed if the relationship with the farmers is based on trust and the use of quality seed provides them sustainable positive outcome.

I could go on and provide many game-changing examples from the ground showing the importance of plant breeding innovation and the contribution of the seed sector. But we are not operating in a vacuum. Our capacity to empower farmers depends on an enabling, predictable and clear international and national regulatory environment.

For many areas of the seed sector such as seed quality, varietal identity, certification and seed health we have well-defined international standards, agreements and guidelines established by various intergovernmental organizations – OECD, International Seed Testing Association (ISTA), International Plant Protection Convention and others. These instruments form an integral part of the functioning of the seed sector worldwide and have proven beneficial for the agricultural production of those countries who joined these platforms. I call upon governments to join, implement and put in place the relevant systems thereby enabling farmers to have access to high-quality seed and new plant varieties.

The breeding of new varieties is a multiyear long process. Latest breeding methods such as genome editing can speed up this process and make it more efficient. What is even more important is that crops that have been left out of the much-needed breeding progress of the last decades can now get a second chance. Underutilized crops that are important for local communities can now benefit from these new applications.

Nevertheless, we need science-based, proportionate and predictable national regulations that can significantly lower the uncertainty for developers that are interested in using breeding methods such as genome editing as part of their breeding operations. For a globalized agriculture and seed sector, regulatory alignment is also very important as it supports the innovation capacity of developers and enables them to collaborate in research and development on a global scale, facilitates seed movement and reduces the risk of trade disruptions.

Beyond regulatory frame and seed policies, the contributions of the private seed sector depend on existing infrastructure that enables the supply chain from production to commercialization and ensures the delivery of the right seeds at the right places through local seed production and shipping.

I am not here to merely celebrate the private sector and its multiple contributions to the Sustainable Development Goals and to enumerate its asks; the moment is far too serious and the private sector is well aware of today's realities.

Because, while many of us continue to enjoy access to safe and nutritious food, over 800 million people are facing hunger.
Because, COVID-19 reminded us again, that no country can fully supply farmers with seed of their choice solely from their own production.
Because, the UN Food Systems Summit was a year-long call on the need to transform our food systems, and to transform the food systems we must review also the seed supply system and this cannot be done in a short span of time.
Because, the current discussion at the 2021 UN Climate Change Conference (COP26) shows the urgency to act together to mitigate climate change and to protect the world's biodiversity.

Are we not facing these challenges together? We have no time to lose to build joint actions at international and national levels and among the agricultural food value chain actors composed of the private and public sectors, farmers, NGOs and civil society organizations.

And we need much more than a new normal, as it is often called these days.

Today, we need a bold, novel, inclusive and better normal where the different layers of seed supply are working sustainably, inclusively and in an integrated manner to empower farmers through secured seed supply and seed choice.

Can this be a starting point for reshaping the discussion and building a transformative workflow within FAO, based on our complementarity and build on trust?

According to FAO:

> Seed security exists when men and women within the household have sufficient access to quantities of available good quality seed and planting materials of preferred crop varieties at all times in both good and bad cropping seasons (FAO, 2016).

I am here to make a call for a unified effort for **Seed Resilience** to ensure:

> The adaptability and capacity to contribute to food and nutrition security by making accessible sufficient, diverse, locally adapted, improved, high quality varieties to all farmers taking into account environmental, health and socio-economic aspects (ISF, 2021).

From agroecological, regenerative, conventional, organic, to biotechnology driven solutions in agriculture…you name them, all of them have a role to play but none of them should be structured in an exclusive way. There should be **interrelations among various approaches**.

Empowering farmers means accepting that there is **no one-size-fits-all solution**. The situation, needs and preferences of farmers are extremely varied in terms of size, profitability and activities in different countries, regions or even smaller geographic areas. Depending on the local and seed supply situation, they can benefit at the same time from either landraces or varieties coming from public breeding, community breeding, native seed or commercial varieties. There is no silver bullet that will solve everything in one go.

Allow me to go even a step further. FAO defines seed policy as:

> A statement of principles that guides government action and explains the roles of relevant stakeholders in the coordination, structure, functioning and development of the seed system comprising both formal and informal sectors (FAO, 2015).

Therefore, let's stop comparing or even setting in opposition formal and informal seed systems.

I will not open the debate here on the implementation of farmers' rights at the national level. This important topic is discussed at the International Treaty on Plant Genetic Resources for Food and Agriculture level and raises many debates, which shows the importance of exchanging and learning from experiences on the ground. One recommendation I would like to make is to not put breeders' rights and farmers' rights at odds with each other. This false opposition only gives rise to non-productive outcomes. Both the International Union for the Protection of New Varieties of Plants (UPOV) Convention and the International Treaty are working toward the same objective: food security. Let's work on implementing these internationally agreed conventions in a mutually supportive way so they can fulfil their mission for the benefit of farmers.

In building a bold, novel and inclusive normal based on **Seed Resilience**, we should also include a dialogue on "Emergency Seeds", which are in many countries an important part of seed supply and vital to decrease food insecurity and widespread hunger. Similarly, we need to find a long-term exit strategy for seed supply to stabilize.

This bold, novel, and inclusive normal focused on **Seed Resilience** would be a real opportunity for the farmers to have **Seed Choice**.

We need a unified enabling environment through sustainable seed systems at the national level, composed of a diversity and multiple levels of solutions. This requires different stakeholders to work together, by recognizing each other's strengths and contributions guided by a joint vision and some common principles. Could this be part of a **holistic approach** to FAO's workflow and to support discussions at national level?

Along the lines of moving forward together in a more inclusive way, I would like to highlight the proposal initiated by the Netherlands, International Seed Federation, the Dutch seed association Plantum, and the Seeds to Food Dialogues organized by the UN Food Systems Summit Food Champion Andrew Mushita of the Community Technology Development Trust in Zimbabwe "Towards inclusive and sustainable seed systems for food system transformation".

Let's build on existing game-changing examples at local or national level, and work on elaborating models of finding solutions together. Let's show that collaboration and a holistic approach could work.

Recognizing our diversity but recognizing that we all can contribute to the SDGs would be a real game changer.

The private sector fully recognizes, like in the past, that no single actor can solve alone all the questions raised by this conference, and we hope that we can agree on concrete joint action to move forward to achieve seed resilience to enable seed choice.

We have to act now.

Seed is life.

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1.6 The green development of China's seed industry

Hanzhong Wang
Vice President, Chinese Academy of Agricultural Sciences, China

Greetings! The subject of my keynote address is the green development of China's seed industry. The address is divided into three parts. First, I will talk about China's demand for the seed industry's green development. Then I will present its achievements in recent years. Finally, I will explain the challenges that the seed industry will face in its future development and related suggestions.

China's demand for the seed industry's green development

First, the seed industry ensures national food security. Currently, China imports more than 10 billion tonnes of food per annum, which accounted for 25 percent of the country's total food consumption in 2020. This is a serious problem. It is expected that by 2030, China's food production will need to increase by another 15 percent, and meat, egg and milk production will need to increase by 30–50 percent to meet the country's domestic demand. The development of green seed industries is the basis to ensure this demand is met. As a major means of production, the rate of contribution of improved seeds to China's increased food production has reached 45 percent.

Second is the need to improve the national health and nutritional level because at present the incidence of iron deficiency anaemia in China has reached 15–20 percent, the prevalence of hypertension has reached approximately 25 percent, and the prevalence of diabetes has reached 9.7 percent. There is an urgent need to create new varieties of functional and high-quality crops and develop nutrition-specific products to meet the needs of special groups.

Third is the need to ensure the ecological security of agriculture. About 20 million ha of land are affected every year, where pesticides and chemical fertilizers are overused, and China's use of chemical fertilizers now accounts for some 30 percent of the world's total. At the same time, about 47 million ha of China's farmland are affected by drought every year. There are 33 million ha of alkali soil to be developed. Therefore, there is an urgent need to cultivate new green varieties that are resistant to diseases and pests, resilient and nutrient-efficient to ensure the green development of agriculture.

Fourth is the need to promote high-quality agricultural development. Regardless of whether it is mechanization-suited, high-quality and multiresistant variety creation, or a new generation of facility-based, industrialized breeding, new varieties are needed. Therefore, the seed industry is the key.

Achievements of the green development of China's seed industry

The second part of my keynote address focuses on the achievements of the green development of China's seed industry. First of all, it should be said that China's seed market has grown remarkably fast. From 1999 to 2020, China's seed market increased in value from RMB 33 billion to RMB 140 billion, with an annual compound growth rate of about 7 percent, making it the second-largest seed market in the world.

At the same time, important progress has been made in cutting-edge research, especially in genomics, such as the genomes of rice, wheat, maize, soybean, cotton, rapeseed, etc. China is at the forefront of this effort. Significant breakthroughs have been made in the discovery of important trait genes, such as short-stalked genes. In addition, excellent progress has been made in the analysis of regulatory networks of important traits. For example, China is spearheading international research on the functional genome of rice and the cloning of related genes and has published 35 percent of the world's research papers on this subject. The genomes of some important crops have been deciphered by Chinese scientists together with their global counterparts.

Third, breeding technology has also significantly improved. Be it gene editing, whole genome selection, transgenic technology or synthetic biology, these emerging breeding technologies have been developed and widely applied.

Fourth, the breeding and application of new varieties have driven the past two green revolutions in Chinese agricultural production. In summary, more than 70 000 new varieties have been bred since the founding of New China, and 6–7 new varieties have been renewed and replaced, with the coverage rate of improved varieties reaching 96 percent. We know that before the founding of New China, the coverage rate of improved seeds was very low, and the contribution rate of improved seeds to crop yields reached more than 45 percent as mentioned earlier.

This promoted two green revolutions in the production of rice, wheat and maize and other major crops, effectively supporting the steady improvement of food production, quality and green development. For example, the first green revolution was driven by short-stalked breeding in the 1950s, and the second green revolution was driven by the use of heterosis in the 1970s, which put both rice and wheat centre stage. Some of the most well-known and representative varieties (in rice, for example, Aijiaoante) are leading varieties of the green revolution, spearheading rice heterosis. The same applies to wheat, in the first round we also saw how the utilization of short-stalked varieties led to the first green revolution. The second green revolution was led by multiresistant, compact leafy wheat varieties suitable for high-density breeding. The first green revolution of maize was accomplished with the use of heterosis, followed by the breeding of dense varieties and high-density breeding to bring about maize’s second green revolution. As someone involved in the rapeseed business, I saw that with the promotion and application of new varieties, rapeseed yield more than doubled from 450 kg/ha at the beginning of China's post-liberation period to about 2100 kg/ha today.

Fifth is the increased diversification of green quality varieties over the years, including multiresistant high-quality rice, water-conserving, scab-resistant wheat, machine harvested varieties of maize, oilseed rapeseed cotton and other mechanized-harvesting varieties, etc. The aforementioned factors drove the diverse development.

Challenges facing China's seed industry and related suggestions

Finally, I will talk about the challenges China's seed industry is facing and suggest a few countermeasures. First, there is an urgent need to strengthen the in-depth exploration of genetic resources. Currently, China has the second-largest germplasm resource bank in the world, with nearly 500 000 copies of crop germplasm. However, less than 10 percent of the germplasm resources have been identified and evaluated in-depth, with the majority still having to undergo this process. Moreover, research on genetic diversity and effective resource utilization rate is still relatively scarce, especially considering that the genetic similarity of new varieties used in production is relatively high, which affects food production capacity and market share.

The second problem is that basic research needs to be further strengthened, especially the mechanism of complex trait formation, which requires in-depth analysis. New genes with significant breeding value need to be discovered, while a breakthrough in the theory of molecular design breeding has yet to happen.

Third, there are still shortcomings in cutting-edge technologies, especially in key core technologies, and insufficient originality. Although China has made excellent progress, especially in developing new gene editing tools with independent intellectual property rights, models of whole gene selection, synthetic biology components, artificial intelligence algorithms, key core technology sources, etc. are still inadequate, not to mention the lack of major equipment and big data systems. The cross-fertilization of cutting-edge technologies also needs to be strengthened.

Fourth, breeding varieties alone is not enough to meet the needs of the new green revolution and diversity. For one, the new varieties have not increased much in terms of yield in the past decade or so, and it is difficult to give rise to a new green revolution. It is not easy to reconcile high quality, high yield and high efficiency in varieties. The gap between China and the United States of America is still relatively large, especially in the yield of maize and soybeans.

I shall now proceed to make a few suggestions: the first is to strengthen research on germplasm resources, including saving rare germplasm resources through conservation and research. At the same time, we should focus on the mechanism of germplasm resource formation and evolution. Another is to strengthen the depth, breadth and precision of phenotype and genotype identification. The innovation of superior germplasm also needs to be strengthened.

Second, strengthen basic research and solidify the theoretical basis of breeding, including the genetic laws of the formation and evolution of crop germplasm resources, the molecular mechanisms of crop trait formation and network regulation, crop environmental adaptation models and stress response mechanisms, including the theory of high-quality, high-yield, multiresistance and efficient synergistic improvement of crops.

The third suggestion is to break through the key core technologies to promote cutting-edge technology such as the development of biological breeding, fixing heterosis, gene editing, synthetic biology and whole genome selection to promote the transformation and upgrading of breeding technology. Furthermore, we should achieve precise, intelligent and industrial-scale breeding, and establish a big biological data platform to improve breeding efficiency.

The fourth suggestion is to breed breakthrough high-yielding varieties to lead a new green revolution. In the last decade or so, I met breeders of rice, wheat or maize, and I would enquire of my fellow rapeseed researchers: Where is the entry point for the new green revolution after the two previous green revolutions? Looking at rapeseed, we are currently exploring new routes to breed new breakthrough high-yielding varieties and through their application seeking to give birth to a new green crop revolution through improved leaf types and ultra-high density planting to achieve ultra-high yields. We cultivate new green and diversified varieties not only to meet the needs of an ever-increasing population but also to meet new development needs.

As stated earlier, in the past, people in China were mainly concerned with having enough food on the table, because with a population of 1.4 billion people, China feeds 22 percent of the world's population with 7 percent of its arable land. While this is a great achievement, it also presents a challenge. Now that they have enough to eat, the needs of Chinese consumers have become more diverse. They want to eat well, eat nutritiously, eat healthily and avoid diseases associated with an affluent society, right? The different diseases require different products with special features. While breeding new varieties, we must also adapt to the requirements of this green development: to be disease and epidemic resistant and to optimize resource efficiency, tailored to the needs of high-quality, specialized and clean mechanization.

Presently, urbanization has resulted in a large number of people moving from rural to urban areas, and now there is less and less rural labour available. We also need to strengthen the need for mechanization with new varieties. As stated earlier, China uses more dense fertilizers and more pesticides, so to solve these problems, on the one hand, production technology should be improved and, on the other hand, we should also strengthen the protection of intellectual property rights, including the construction of a comprehensive intellectual property protection system. We need to strengthen the protection of intellectual property rights and the study of international standards, regulate the transfer and transformation of intellectual property rights, and step up market supervision.

Finally, I would like to thank my colleagues for providing the relevant materials. I warmly welcome you to visit China. Thank you!

1.7 Policies and governance: Providing clarity and coherence to shape a robust and inclusive seed industry

Rachel Chikwamba
Council for Scientific and Industrial Research, South Africa

Key to establishing robust seed industries that cater inclusively to all who participate therein are effective governance frameworks that provide clarity and coherence to shape the industry. Policies must shape an environment where farmers have access to quality seed of well-adapted varieties that meet their needs as the basis of resilient farming systems, and ensure that other relevant players in the sector are suitably incentivized to play their respective roles. This is integral to food security and nutrition, livelihoods and environmental sustainability.

Genetic gains have contributed significantly to increased food production. Historically, growth in food production has been coupled to increases in land under cultivation, but this has significantly changed (OECD, 2021) as superior genetics and improved efficiencies have fuelled growth in crop productivity. Seed is the single most important input that harnesses superior genetics through advances in technology and leverages specific genetic traits from plant genetic resources to drive efficiencies in productivity and increase farm incomes. Policies and attendant regulatory frameworks enable or hinder the development of green seed industries that harness technology and genetic diversity through quality seed.

Framing policy and governance

National seed policy provides the principles that shape government action in defining stakeholder roles, coordination, structure, functioning and development of the seed sector. It informs all aspects of national seed laws and regulatory instruments. The policy framework must clearly set out the goals, targets and objectives of government for the sector, the institutional arrangements, investment strategies and mechanisms for achieving the said goals (Turner and Leria, 2018).

Seed law establishes specific principles, standards and procedures to be adhered to by specific role players, and the framework for enforcement by statutory bodies to ensure accountability. Policy and law should be complementary and, with the attendant regulations, guidelines, programmes, schemes and conventions, guide investment choices and other decisions that shape the environment for acquisition, production, conservation and use of genetic resources. Effective policies must improve the overall quality and reliability of seed in the marketplace, and improve access by the farmers, while bringing into effect the government strategy for agriculture and the seed sector, in harmony with sectors that have backward and forward linkages. They must create an enabling environment with regulations, laws and institutions that facilitate the participation of all relevant actors in addressing challenges in the system. The governance framework must inspire confidence, stability and foster national and international collaboration on seed and related matters and promote ownership of roles by actors in the system and adherence to the rules.

The role of effective institutions

Critical to the realization of policy intentions are underpinning institutions; the statutory bodies that play roles that are critical to the efficient functioning of the sector – enforcing the rules, facilitating trade, establishment of quality and health standards, certification and so on. However, not all elements of policy will be realized through laws and regulation, making civil society and non-profit organizations critical players in influencing the sector. The system must thus provide platforms for civil society to have a voice. In addition, strategic capabilities for research and development are equally of importance not only to drive evidence-based policy, but also to support research into improved varieties, as well as the development and adoption of technology. Regional organizations that facilitate cross-border seed trade are also important to leverage benefits of quality seeds across wider geographies and to facilitate development and sharing of related best practices. Importantly, policies can only be fully effective if the institutional arrangements that support them are fully functional, efficient and staffed with skilled professionals with the requisite infrastructure, tools, systems and processes.

Advanced technologies: Opportunity for green innovation

Advanced technologies represent major opportunities for green innovation in the development of quality seed. However, for successful innovation and adoption of improved seed, critical factors for policy consideration include investment in new breeding methods and tools that shorten varietal development cycles, strategic support to initiatives that drive development of new traits that address new and emerging biotic and abiotic stresses, reduced input use and attributes preferred by farmers and consumers. The policy environment must support the development of an enabling environment by reducing hurdles required to test, register and release new cultivars. Reasonable and science-based navigable regulations underpinned by efficient decisions through functional institutions will enable society to benefit from advances in technology. It is recommended that focused or common purpose partnerships be formed to ensure that appropriate innovations gain public trust by involving scientists, product developers, policymakers, regulators, companies, civil society and consumers to promote education, dialogue and transparency around products from advanced technologies. Other technologies that increase efficiency in genetic improvement such as synthetic biology, artificial intelligence, machine learning, data and data analytics and the attendant skills must be fostered.

Varietal adoption

Varietal adoption is a critical measure of the success and relevance of varietal development programmes, as farmers will not adopt varieties if they do not meet their needs and fit with their farming systems. National policies must strategically direct focus and resources at addressing current and emerging production vulnerabilities for improved food system resilience. Hence, enabling policy that encourages plant breeders to develop varieties according to farmers' and consumers' needs and systems must be instituted. Full information about the varieties and seed packages must be availed. Plant variety protection rewards breeders that develop new varieties of plants, only if farmers grow the varieties, thus policies and laws must be in place to ensure plant breeders obtain a return on their investment.

Plant genetic resources for agriculture

The conservation system must ensure the maintenance of plant genetic diversity for continuous crop improvement, maintain diversity in the food system and bring resilience to crop production systems. Ultimately the tangible outcomes of conservation efforts are quality seeds that meet the farmers' needs and fit with the farming system. Crop diversity resulting from farmer selection over centuries is a vital contributor to the genetic gains we have made to date, hence sharing benefits with traditional custodians of germplasm and associated local knowledge is key to equitable and fair seed sectors. Alignment with global treaties that facilitate international commitment to conserve, share and exchange genetic resources for the common good is vitally important. Thus, policies must facilitate PGRFA exchange, the sharing of data and underpinning information, enable benefit-sharing, conservation of habitats and collaboration while respecting the rights of Indigenous Peoples.

Seed systems

Seed systems must be cost-effective, responsive and dynamic suppliers of quality seeds that are accessible to, and provide options for, farmers. Seed must be delivered as complete packages, including environmentally benign treatments to enhance performance. Importantly, access to locally and internationally bred seed must cater for formal and informal sectors. National policies must therefore stimulate the development of seed businesses and encourage system innovation to expedite production, certification, storage, quality assurance and access by farmers – catering for players at all scales, in formal and informal sectors. National agricultural research organizations have played a pivotal role in breeding locally relevant seed alone and in partnership with others. Thus, the policy framework must provide long-term funding for public sector plant breeding.

Concluding remarks

To achieve dynamic green seed industries, seed systems and underpinning policies must be enabling to ensure food security, livelihoods and sustainability. To this end, three mutually reinforcing goals of inclusion, growth and sustainability are critically important. Inclusion is facilitated by availability of quality seed of farmer-preferred varieties that are suitable for the relevant farming systems. This in turn creates new demand as farmers emerge out of poverty and fuels growth in productivity, quality and revenues for the sector and individual players. Growth in revenues provides resources for transitions required for inclusivity, funding of long-term strategic programmes and innovations that improve decarbonization for a lighter ecological footprint, thus positioning humanity to meet current needs and growing future demands for food and feed.

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2. PARALLEL SESSIONS: ADVANCED TECHNOLOGIES

Parallel session: Modern plant breeding technologies

2.1 Next generation genomics and genomics-assisted breeding for international agriculture

Rajeev K. Varshney
International Crops Research Institute for the Semi-Tropics, India and Murdoch University, Australia

Crop production systems need to expand their outputs sustainably to feed a burgeoning human population. Advances in genome sequencing and other genomics technologies combined with efficient trait mapping procedures accelerate the availability of beneficial alleles for breeding and research. Next generation genomics has made it possible to assemble genomes of almost all key crop species. Targeted and rapid assembly of beneficial alleles using genomics-assisted breeding approaches are delivering ideal crop varieties for the future.

The International Crops Research Institute for the Semi-Tropics and its partner institutes have decoded genome sequences and integrated advanced genome discoveries in crop improvement programmes in several crops. Several high-yielding varieties with enhanced tolerance to biotic/abiotic stresses and higher nutrition have been developed in chickpea, pigeonpea and groundnut. Translating crop productivity gains from genomics-assisted breeding in farmers' fields, however, requires improved farmer access to innovative technologies and their adoption. A robust seed system – delivering improved cultivars steadily to replace old cultivars – is plausible for adapting agriculture to climate change.

2.2 Genome design of hybrid potato

Sanwen Huang
Agricultural Genomics Institute at Shenzhen, Chinese Academy of Agricultural Sciences, China

Potato is the most important tuber crop, feeding over 1 billion people worldwide. Cultivated potato is autotetraploid, the genome of which is highly heterozygous. Due to the complexity of tetrasomic inheritance, the genetic gain in potato breeding is limited. Some century-old potato cultivars, such as Russet Burbank (released in 1902) and Bintje (bred in 1904), are still widely grown. Moreover, its clonal propagation bears a considerate carbon footprint.

To overcome these drawbacks, we initiated the Upotato Plan, reinventing potato into an inbred line-based diploid crop propagated by seeds. However, self-incompatibility and severe inbreeding depression are two obstacles to hamper the development of inbred lines. We overcame the first obstacle by knockout of the *S-RNase* genes that control self-incompatibility, or application of natural self-compatibility genes. Then, we analysed the genetic basis of inbreeding depression, and found that the mutation burden in potato is line-specific, suggesting crosses of different inbred lines will mask the effects of deleterious mutations and produce strong heterosis. Based on these, we developed the pipeline of genome design of hybrid potato.

Using this strategy, we developed vigorous and fertile inbred lines (up to 99.94 percent homozygosity), derived from different lineages, and generated the first uniform F_1 hybrid "Upotato1" by crossing two inbred lines with different lineages. Due to the genomic complementarity, the F_1 hybrid showed strong heterosis in growth vigour and yield.

To further accelerate hybrid potato breeding and enrich our understanding of the evolution and biology of potato, we constructed the potato pangenome map by integrating the genomes and variants of 44 diverse potato accessions, providing critical insights for improving inbred lines and precluding potential linkage drag. Our study transforms potato breeding from a slow, non-accumulative mode into a fast-iterative one, thereby potentiating a broad spectrum of benefits to farmers and consumers.

2.3 Genome editing: Opportunities and challenges

Dave Bubeck
Corteva Agriscience, Johnston, the United States of America

The outlook for genome editing to increase the rate of improvement of seed products is very promising for the seed industry, agriculture and consumers. The plant breeder's perspective on the opportunities that genome editing provides to crop improvements will be critical to fully leverage genome editing in the future. The areas addressed include plant breeding systems and why genome editing offers opportunities to improve the effectiveness of plant breeding. A brief description about the plant breeding process and resulting genetic variation trends was provided, as well as the complexity and highly quantitative challenge that a plant breeder faces. Finally, specific ideas about the potential for genome editing to address some of the breeding challenges were proposed.

In all breeding programmes, both in public and private sectors, multiple components are required in the process of cultivar improvement:

1) A germplasm pool contains the entire set of genetic material for a given species from which a plant breeder can choose to make breeding crosses.

2) Breeders create selected breeding crosses and produce progeny.

3) A set of targeted environments are selected.

4) Key traits are recorded.

5) Data sets are generated on the genetic material tested.

Plant breeding requires many years, advancing highest-performing progeny to selected products, and recycling selected genetic material. Through such breeding efforts one can expect a commensurate decline in genetic diversity. The plant breeder's timeline to commercialization is rigorous and thus it should be acknowledged that adding additional technologies into the cycle must result in systematic adjustments to these outlined steps.

For additional context on the breeding challenge related to genetic diversity decline, multiple statistical methods by which diversity can be measured, such as co-ancestry coefficients based on pedigree or molecular analysis, are conducted. But in isolated breeding programmes, invariably the trend will demonstrate a reduction in diversity over time. Therefore, to continue to make performance progress, breeders must identify novel germplasm or unique technologies that can add to favourable genetic variance. In maize, some estimates have indicated that about 60 percent of the genome does not recombine, but certainly unlocking some of this underutilized genetic variation through genome editing efforts could be an approach to furthering performance improvement.

Another dilemma of the plant breeder is the long list of traits that a breeder could have as a target for selection. This includes many traits in categories of agronomic performance to pest resistance, to end-use considerations. If plant breeders could "solve" some of these traits via genome editing technologies, so that those traits would no longer be required for selection, it would enable the breeder to focus on a shorter list of targeted traits, thus placing higher selection emphasis on a fewer number of traits.

One of the critical steps in conducting any genome editing effort is a requirement to have some prior gene knowledge. Plant breeders of virtually all species have their own specific plant pathogens for which genetic resistance to the disease is often essential. It is imperative to have some prior gene knowledge before leveraging genome editing. At Corteva, disease traits are possible targets to leverage genome editing. For northern corn leaf blight in maize we have sufficient knowledge about genetic resistance.

Additional examples of utilizing CRISPR technology represented in current efforts and collaborations of Corteva Agriscience include maize lethal necrosis, striga resistant sorghum, pearl millet with improved flour stability and reduced rancidity, and disease resistant cassava. For these efforts to find their way to farmers and consumers, clarity on a path to market is essential, including clear global regulatory policies without costly and burdensome requirements for native genes. Previous and current plant breeding methods could produce similar results, however, requiring more time and often burdened with negative linkage drag from neighbouring unfavourable genes.

Genome editing will provide a powerful tool for the plant scientist to go beyond current tools utilized in plant breeding. Some examples of what could be possible now or in the future include:

1. Chromosomal rearrangements unlocking genetic variation and mechanisms to control recombination.

2. Genome editing as a means of identification of gene expression for genomic regions that have become fixed during breeding.

3. Tools to develop hybridization systems for biologically self-pollinated species.

4. Genome rearrangements enabling co-location of native traits, unleashing portions of the genome for further breeding and selection.

5. Multiple simultaneous edits across numerous traits as genome editing tools advance.

6. Renewing efficacy of native disease resistance genes through targeted edits.

7. Reduce or eliminate certain traits during "plant breeder selection", via genome editing solution.

8. Enable highly quantitative and small-effect genes to express with larger effect.

9. Engineer a gene identification and utilization system to be used for genes of value in unadapted/exotic/germplasm collections/wild relatives, where currently these genes are buried within unadapted genomes, thus preventing their favourable characterization. Genome editing may provide an approach to utilize genes of value from these germplasm accessions.

We need regulatory frameworks around the world that are aligned, consistent and not burdensome from a financial perspective and do not delay product introductions to the grower or consumer. The current state of global policy framework is inhibiting the current R&D investment levels towards genome editing, due to the uncertain global regulatory situation. We will need the world to come together from both a science and a social license perspective.

Numerous landmark science and technology moments have occurred over the last century of Corteva maize breeding. Genome editing is in a current state with intriguing opportunities to deliver cultivar improvement. However, this is shadowed with uncertainty regarding the global regulatory framework as well as social acceptance. Current global investment in R&D opportunities are substantially constrained due to uncertain paths for product approvals. Hopefully, conferences, such as this very gathering, will drive global alignment for the potential of CRISPR to impact cultivar improvement for the benefit of the producer, food processors and consumers.

2.4 Policy and regulatory issues of new breeding technologies in the European Union

Irene Sacristán Sánchez
Directorate-General for Health and Food Safety, European Commission

The European Green Deal sets out how to make Europe the first climate-neutral continent by 2050. It is the Commission's commitment to tackling climate and environmental-related challenges. The Farm to Fork Strategy is at the heart of the European Green Deal aiming to make food systems fair, healthy and environmentally friendly. The Strategy attempts to address comprehensively the challenges of sustainable food systems and recognises the inextricable links between healthy people, healthy societies and a healthy planet. The strategy acknowledges that biotechnology has a role to play when it comes to food sustainability.

In this context, the European Commission is working to ensure that the regulatory framework for products derived from biotechnology in the plant, food and feed areas is fit for purpose. The ongoing work is in follow-up to a recent study on new genomic techniques, requested by the Council of the European Union and published in April 2021 (European Commission, 2021).

The study found that plants obtained from new genomic techniques have the potential to contribute to the objectives of the European Green Deal and the Farm to Fork Strategy for a more resilient and sustainable agrifood system. It also concluded that the legislation on genetically modified organisms (GMOs) needs adaptation to scientific and technological progress as regards products of new genomic techniques. At the same time, stakeholders reported various concerns that need to be addressed when considering any future policy action related to plants derived from new genomic techniques (as regards e.g. their potential safety and environmental impacts and the coexistence with organic and GM-free agriculture).

Based on the outcome of the study and other information available, the Commission concluded that there is sufficient evidence and scientific basis to initiate a policy action on plants derived from targeted mutagenesis and cisgenesis, and their food and feed products. The policy action will aim at a proportionate regulatory oversight tailored to the plants concerned and their products. It intends to maintain a high level of protection of human and animal health and the environment, and should allow reaping benefits from innovation, in particular to achieve the goals of the European Green Deal and Farm to Fork Strategy.

The roadmap for the initiative was published in September 2021.[2] It identified the different policy elements that will be considered in the subsequent development of policy options for the initiative. These include risk assessment and approval requirements proportionate to the risk involved; a sustainability analysis to examine whether, and in which way, these products contribute to sustainability; and appropriate traceability and labelling provisions.

The Commission services will conduct an impact assessment, including various consultation activities, in the course of 2022. If further action is warranted, the Commission will adopt a legislative proposal in 2023 and submit it to the European Parliament and the Council of the European Union for consideration and adoption in the legislative procedure.

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2.5 Gene editing of banana for disease resistance

Leena Tripathi
Eastern Africa Hub, International Institute of Tropical Agriculture, Dar es Salaam, the United Republic of Tanzania

Banana (*Musa* spp.), including plantain, is one of the major staple food crops grown in over 136 countries in the subtropics and tropics, with annual global production of around 163 million tonnes, feeding about 500 million people. It is a valuable food security and cash crop as it can be cultivated in diverse environments and produces fruits throughout the year in favourable weather conditions.

Smallholder farmers mainly cultivate bananas for domestic consumption and local or regional markets; only about 15 percent of production enters international markets. Africa contributes one-third of the world's production, with East Africa being the most significant banana-growing region accounting for about 40 percent of the total output in Africa. Its production is constrained mainly by diseases and pests in addition to other factors like declining soil fertility, narrow genetic diversity in germplasm and inadequate availability of clean planting material.

The production is significantly reduced by many bacterial, fungal and viral diseases such as banana Xanthomonas wilt (BXW), moko disease, blood disease, black Sigatoka, yellow Sigatoka fusarium wilt, banana bunchy top disease and banana streak disease, and pests like nematodes and weevils. The use of disease-resistant banana varieties is one of the most effective options to mitigate the negative impacts of pathogens and pests in banana production.

Developing improved varieties of bananas using conventional breeding is challenging because of the low genetic variability in *Musa* germplasm, polyploidy, lengthy production cycle and sterility of the majority of the cultivars commonly grown by farmers. Modern breeding tools, including genetic modification and genome editing, can be applied to improve bananas bypassing the natural bottlenecks of traditional breeding.

Intensive efforts using genetic modification have developed improved banana varieties with resistance to biotic stresses. However, the commercialization of genetically modified crops faces hurdles due to the complicated regulatory approval process.

CRISPR/Cas-based genome editing has emerged as the most powerful tool for crop improvement due to its capability of creating precise alterations in plant genome and trait stacking through multiplexing. The availability of a well-annotated, whole genome sequence of bananas coupled with established genetic transformation regeneration protocols makes the banana a strong candidate for gene editing.

Recently, the robust CRISPR/Cas9-based genome editing of bananas has been established using the *phytoene desaturase* (PDS) as a visual marker gene. The establishment of the CRISPR/Cas9 tool has paved the way for the application of genome editing for the improvement of bananas for important traits such as disease-resistance.

The CRISPR/Cas9-based editing was applied to inactivate the integrated endogenous banana streak virus (eBSV), a double-stranded DNA badnavirus, integrated into the B genome of plantain (AAB), overcoming a major challenge in breeding and the dissemination of hybrids. Banana streak virus sequences integrate into the host plant genome as eBSV, and under the stress conditions such as temperature change, drought, hybridization and micropropagation, the integrated virus sequences get activated and produce the infectious episomal form of BSV, and plants develop symptoms. The gene edited events of plantain 'Gonja Manjaya' were generated with mutations in the targeted sites of integrated eBSV sequences in the host genome. Sequencing and phenotyping of the edited events showed targeted mutations and confirmed the inactivation of eBSV for its ability to be converted into infectious viral particles.

The International Institute of Tropical Agriculture is currently advancing the application of gene editing to control BXW, the most destructive banana disease in East Africa. This disease, caused by the *Xanthomonas campestris* pv. *musacearum* (*Xcm*) bacteria, can be controlled by disrupting the function of disease-causing susceptibility ('S') genes, nutrient transporters, or negative regulators of plant defence. The target genes have been identified through the literature or comparative transcriptomics of BXW-resistant wild progenitor banana *'Musa balbisiana'* and BXW-susceptible banana cultivar during early infection with Xcm. Recently, we demonstrated that disruption of the banana orthologue of the *downy mildew resistance 6* (*MusaDMR6*) gene showed enhanced resistance to BXW disease. Knocking down of MusaDMR6 had no detrimental effects on plant growth.

The advances in gene editing have the potential to develop disease-resistant varieties of bananas, which will contribute to food security, particularly in Africa. However, the commercialization of gene edited products has some challenges due to the regulation of genome edited products in various countries. The use of gene editing in crop improvement programmes for bananas will be boosted by developing science-based guidelines, which will treat the gene edited varieties similar to those generated through conventional breeding, particularly where no foreign gene is inserted. The gene edited crop varieties lacking any foreign gene remain indistinguishable from those developed through traditional breeding.

Genome edited crop varieties with no foreign gene integration are not regulated as GMOs in several countries such as Argentina, Australia, Chile, Brazil, Colombia, Paraguay, Ecuador, Honduras, Guatemala, Canada, Japan and the United States of America. Africa is also making progress in creating the enabling environment for the commercialization of gene edited crop varieties. In Africa, Nigeria is the first country to publish the national biosafety guidelines for the regulation of gene editing. Kenya has recently approved the regulatory guidelines for gene editing. Many countries are still in the process of developing regulatory guidelines for gene edited products. There is a need for the coordination of regulatory approaches globally.

A synopsis of recent advancements in the application of gene editing of bananas will be presented during this conference. It will also briefly describe the status of regulatory requirements for the release of gene edited crop varieties in different countries.

2.6 Genetically modified pulses

T.J.V. Higgins and Jose Barrero
CSIRO Agriculture and Food, Canberra, Australia

Pulses are much underutilized food plants but there is growing interest in their role in sustainability and a renewed interest in the nutritive value of their grain, with a recent push towards foods with plant protein formulations. Plant breeding has made great progress in enhancing yield of pulses (some more than others), over the past two decades, but several abiotic and biotic stresses are not readily amenable to conventional genetic approaches. Gene technology and gene editing have potential to address some of these constraints.

Although not generally considered a pulse, soybean, a closely related grain legume which is identified as an oilseed, serves as a good model for a genetically modified (GM) pulse. For instance, a very large proportion (over 70 percent) of global soybeans are GM. These soybeans have led to increased farm incomes due to increased yields and reduced input costs. They are also credited with improved health and environmental outcomes because of reduced use of certain synthetic chemicals and their replacement with pest and weed control measures that are better for both health and the environment.

More recently, similar approaches have been taken to improve several of the commonly used pulses, including chickpea, pea, common bean, cowpea, lentil, lupin and pigeon pea. In most cases, the first target for improvement is insect resistance, but virus resistance and weed control have also received attention. In all these pulses there are gene transfer systems available, so it is possible to consider GM and gene editing approaches. The systems are generally of low efficiency but are workable as illustrated by the very extensive literature on the topic.

Many of the advances in GM pulses have not yet reached the commercialization stage, in part because pulses are still generally not grown on a sufficiently large scale to warrant the investment to take them through the entire regulatory approval process which is still costly. Two exceptions to this are common beans, that are resistant to bean yellow mosaic virus which has been commercialized in Brazil. The second GM pulse is the Bt cowpea which is resistant to the podborer, *Maruca vitrata* and has been recently commercialized in Nigeria. It is worth noting that these two pulses are staples in their respective countries and this may account for their progress in commercialization. It is expected that these improved crops will be important tools in achieving some of the UN's Sustainable Development Goals by 2030.

2.7 Genome editing for cassava (*Manihot Esculenta* Crantz) improvement

Ihuoma C. Okwuonu
National Root Crops Research Institute, Umudike, Nigeria

Cassava is an important staple for over 800 million people and a critical component of food and economic security due to its resilience to climate change and tolerance to drought and marginal soils. However, the potentials of cassava are not fully maximized due to the impact of pest and diseases, deficiency in essential nutrients such as protein, minerals and vitamins as well as breeding difficulties including long breeding cycles, heterozygosity, low seed sets, high genetic load and high polymorphisms.

Different improvement strategies, including hybridization breeding, marker-assisted selection, genomic selection, transgenic breeding and genome editing are being employed for genetic improvement of cassava. Novel breeding technologies such as genome editing provide a platform for tackling breeding bottlenecks and have the advantage of precision and speed in producing cassava varieties with improved characteristics.

Thus far, genome editing is being explored to achieve a variety of targets in cassava, spanning from disease resistance, toxin elimination, developing improved processing qualities and herbicide resistance. Work on engineering resistance to cassava bacterial blight disease by the disruption of a susceptibility gene (*MeSweet10a* gene) is underway and shows very promising outcomes in developing resistant cassava varieties. Likewise, reduced disease severity and incidence of storage root necrosis with suppressed disease symptoms caused by cassava brown streak virus has been achieved by simultaneous mutation of multiple genes including novel cap-binding proteins-1 (nCBP-1) and 2 (nCBP-2) in cassava.

CRISPR/Cas9 genome editing is also being explored for the elimination of glycogenic cyanide, a poisonous component found in unprocessed forms of certain cassava varieties by knocking out singly or in combination, CYP79D1 and CYP79D2, key enzymes which are responsible for cyanogen production in cassava. Efforts are also being made towards improving processing quality of cassava starch by adjusting the genes that produce varying levels of amylose with the aim of achieving waxy starch essential for processing. Also critical to cassava production is the development of herbicide-tolerant cassava geared towards reduction of production costs accrued to manual weeding. CRISPR/Cas9-mediated mutation of the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) gene is underway to achieve this.

2.8 Policy and governance of new breeding technologies

John McMurdy
CropLife International, Arlington, the United States of America

The ultimate ability of genome edited products to contribute to sustainable productivity and nutrition goals is predicated on three pillars, (a) technical feasibility and utility as part of a breeding programme, b) regulatory policy landscape and (c) consumer perspective and preference.

Around the technical feasibility pillar, the published literature base has strongly demonstrated that genome editing is a valuable tool for inducing targeted mutations in a precise and targeted fashion. Further, the literature shows that genome editing tools are valuable across many crop species from fruits and vegetables to grains, oilseeds and textiles.

Next, around the regulatory policy pillar, discussion and formulation of policy approaches to genome editing are happening in many countries. The position of the seed industry is the varieties produced by genome editing or other newer methods ***should*** not be differentially regulated if they are similar or indistinguishable from those that could have been produced through earlier breeding methods. Following this principle leads to an outcome where certain breeding techniques are not discriminated against. Looking around the world, with a few exceptions, governments that have issued regulations, policies, circulars or clarifying guidance have also come to this conclusion. Rationale that has been shared by some of these regulators/government officials is that they want to ensure that local and regional universities and companies are able to use modern tools to develop sustainable products and solutions.

Lastly, on the consumer preference pillar, surveys conducted in a number of markets indicate that, for the most part, there is not strong public awareness of how editing can and may be used in agriculture. Communicating to consumers about genome editing and how it is used in plant breeding and, subsequently, contributes to sustainability is dependent on parallel communications more generally on plant breeding. Without a baseline understanding of what plant breeders do, understanding how a tool like genome editing contributes is challenging and presents only a partial picture. The fact that editing is being used more to develop consumer-focused benefits (e.g. food quality, taste, storage) and environmental benefits (around climate adaptation and mitigation) underline the opportunity to engage interested consumers in this conversation.

In conclusion, from the seed industry perspective, there is hope and optimism that governments broadly will continue moving toward a policy climate that supports delivery of breeding innovation, but it is important that stakeholders more broadly continue with consumer education and awareness building generally around plant breeding.

2.9 Principles for the governance of gene editing

Gregory Jaffe
Center for Science in the Public Interest, Washington DC, the United States of America

This short talk discussed the correspondence letter entitled "Responsible governance of gene editing in agriculture and the environment" published in Nature Biotechnology in September 2021. That paper, written by six non-governmental organizations, sets forth principles for responsible governance of gene editing. The authors see potential benefits from gene editing applications but believe responsible governance is necessary to achieve the consumer trust and marketplace success of those products. The principles are designed to be implemented by many stakeholders, including government officials and regulators, industry seed developers, academics and public researchers, and NGOs. The principles and the paper are an invitation for stakeholders to join in a conversation to discuss the details that would implement them.

The six principles for responsible governance are as follows:

1. Gene editing technologies should be applied safely and ethically; care should be taken to avoid substantial risk and deliver tangible societal benefits.

2. Robust, inclusive societal engagement is essential. This should start early in the development process to help prioritize products that would give multiple benefits.

3. Effective, science-based government regulation is required for realizing the full benefits of gene editing and managing potential risks. This should involve the best scientific evidence and have a tiered approach that is proportionate to the likelihood of potential risk.

4. Voluntary stewardship and best practices should supplement voluntary oversight.

5. The public should have access to clear information identifying which gene editing applications are in use in food, agriculture and the environment.

6. Inclusive access to gene editing technology and resources can help drive societal benefits.

Parallel session: Emerging biotechnologies and informatics technologies

2.10 Plant microbiomes

Vittorio Venturi
International Centre for Genetic Engineering and Biotechnology, Trieste, Italy

The advancement and low cost of next generation sequencing technologies and the development of meta-omics with computational tools is beginning to generate extraordinary insights into the taxonomic and functional composition of microbes associated with plants. The totality of micro-organisms that exist in a particular environment is most often referred to as the microbiome. Importantly, plant microbiomes have key roles in biotic and abiotic stress tolerance as well as nutrient acquisition.

Plant–microbe associations occur mainly at the leaf aerial parts in the phyllosphere and at root level in the rhizosphere. Biotic and abiotic factors and the plant genotype are the major drivers of the phyllosphere microbiome. The rhizosphere (the nearest soil area to the roots) hosts a rich microbial plant community which provides a pivotal series of beneficial outcomes related to plant growth. Plant roots recruit their rhizosphere microbiome from bulk soil and a small number of the microbes from the rhizosphere enter the plant, colonizing the root endosphere and some then move to other plant organs.

The phylogenetic conservation of plant microbiomes infers an organized assembly of microbiomes which is directed by mechanisms which are at large unknown. These most likely involve cell–cell interactions amongst microbes, plant–microbe signalling and root exudate effects. Plant genotype affects composition of the rhizosphere microbiome mainly via the selective drive influenced by root exudation, the immune system and root architecture.

Future work will need to focus on the plant and microbial mechanisms responsible for the formation of plant microbiomes using a variety of experimental approaches involving a combination of traditional genetics/molecular approaches, synthetic microbial communities (SynComs) and up-to-the-minute novel technologies like meta-omics, computational biology, mass spectroscopy and imaging. This presents a wealth of exciting research possibilities which will also lead to the development of prebiotic compounds as well as microbial probiotic competence for a more sustainable agriculture of economically important crops.

2.11 Artificial intelligence and big data: Advancements, opportunities and threats

Dionysis Bochtis
Institute for Bio-Economy and Agri-Technology, Centre of Research and Technology-Hellas, Thessaloniki, Greece

For the last three decades, the term "precision agriculture" has been associated with any development in agricultural technology. The principle of managing crops not uniformly but based on the identified needs of each part of a field, i.e. the principle of precision farming, is nothing new. For generations, farmers used to apply additional fertilizer to the "yellow" areas of a wheat field. What enabled the effective application of this principle, however, was the introduction in agricultural production of technologies such as the global positioning systems (GPS) and geographical information systems (GIS), among others.

Nevertheless, precision agriculture remained mainly an approach in "theory" rather than a widely practiced approach. This happened for many reasons. On the one hand, the research community failed to convince farmers about the economic benefits of the implemented technologies while, on the other hand, these technologies have never reached the level of being affordable for small- and medium-sized holdings.

Still, the main reason for the limited implementation of precision agriculture practices is of a technological nature. It lies in the fact that for the application of precision agriculture solutions, the integration of associated "pieces" of information from different sources (e.g. satellite, meteorological, machinery and soil data) is needed. This integration requires in most cases the involvement of the farmer. The result is that the farmer prefers to follow the process he or she already knows rather than engaging in a new complex process. The solution in this technological deadlock has been provided by the internet of things and cloud technologies, where the interconnection of all the required information became possible without the intervention of the farmer.

However, this change in data management does not simply bring a solution to the application of precision agriculture, but rather an entire change in the ecosystem of agricultural production. Data interconnection creates data accumulation – what we call big data. Big data, in turn, provides the fertile ground for machine learning technologies and artificial intelligence in general (Benos *et al.*, 2021).

Until now, automation and robotics applications in agriculture have been considered in (physical) tasks performed in a repetitive manner. This is because, for the specific tasks, the sequence of procedures and rules can be accurately described and subsequently be imitated by "machines" (Autor, Levy and Murnane, 2003). However, with the advent of artificial intelligence and the large data sets available, these "machines" are becoming increasingly better at "perceiving" and performing non-routine tasks that require cognition abilities that until now only humans have been able to develop and use (Marinoudi *et al.*, 2019). Several applications are already entering agricultural production, such as disease identification, weed control, forecasting, assessment of the nutritional needs of the crop, as well as perception of the field as a working environment for the effective operation of robotic vehicles (Bechar and Vigneault, 2017).

A direct consequence of the above is that while mechanization and automation in agriculture have largely replaced low-skill jobs, artificial intelligence has come to replace mainly medium- and some high-skill jobs. This leads to the phenomenon of work polarization (Marinoudi *et al.*, 2021). Medium-skill jobs "disappear" and those of low-skills (mainly for performing residual tasks) and some high-skills remain. This phenomenon has dramatic consequences for the agricultural workforce but also for rural development.

The phenomenon of polarization does not stop here. Simply put, "information" contains value, and the value of accumulated "information" increases exponentially. In the business world, accumulated information works in favour of larger organizations. Here again, medium-sized agribusinesses may be threatened by leaving space for larger but fewer organizations and, of course, small agribusinesses for "residual" activities.

The purpose of the above issues has nothing to do with the "demonization" of these new technologies. The opposite. The benefits of new technologies for agriculture growth have been widely presented and are unquestionable. What needs to be understood is that since the application of these technologies in agriculture is still in its infancy, there is ample time to predict any negative consequences and mitigate them by applying appropriate measures so that the widespread development and adoption of artificial intelligence technologies in agriculture can highlight as much as possible their positive side.

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2.12 A scale-based framework for governance and risk of emerging biotechnologies

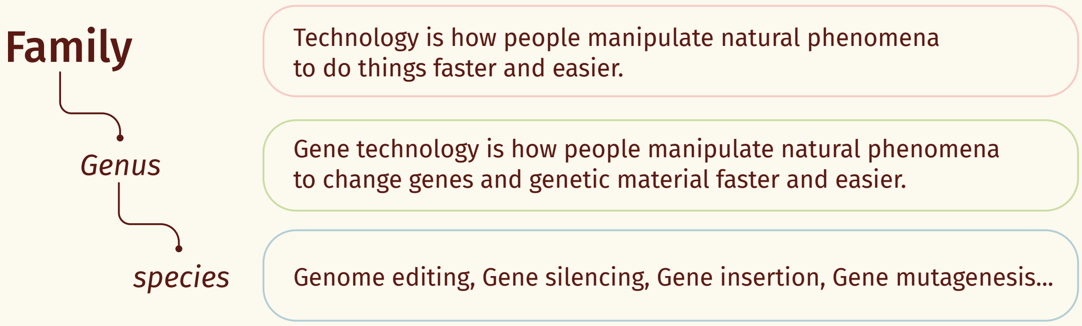
Jack A. Heinemann
School of Biological Sciences, University of Canterbury, New Zealand

Limiting harm is the purpose of biosafety legislation specific to gene technology. Short of prohibiting the technology, and in the words of the Cartagena Protocol on Biosafety, legislation also can promote responsible use. Lately, the challenge has been how to describe gene technology to ensure adequate legislative scope and efficient risk assessment and risk management (Heinemann *et al.*, 2021a).

As of this writing, both the European Union and Australia are consulting on these questions. Not surprising, both are also stuck in a semantic mud over definitions and blame what they call "new techniques" for this confusion. Are the new techniques fundamentally different in defining attributes that either make them difficult to describe for legislative and risk management purposes, or make them simply not worth regulating? Among the alternative options consulted is a form of tiering where the uses of, or the products made from, some techniques are effectively deregulated.

Most of the inconsistency in regulation is due to an attempt to work around changing notions of such things as genes, and missing the key term – technology. The latter provides a continuity across all the tools and techniques of gene technology (**Figure 3**). By remembering why we regulate any technology, it becomes easier to see how to regulate *gene* technology.

Figure 3. Technology viewed as a classification. Homology is relatedness by descent. Gene technology is a branch of the evolutionary lineage of human technology. The adjective – gene - in front of the word technology is the focus of semantic-type governance while technology is the focus of safety governance. For the same reasons we regulate nuclear technology we should regulate gene technology.



Critical control points

We have proposed a critical control points framework for this purpose. Under this framework, uses and products of a technology are regulated because of the ubiquitous feature of technology: *it is a way that people speed up or concentrate natural phenomena*. Both Archimedes' lever and a random asteroid could shift the Earth, but the lever would be available on demand and could be used repeatedly. So, his lever was a technology (Heinemann *et al.*, 2021b).

DNA biochemistry is a natural phenomenon. The tools of technology speed up or focus it. Evolution is a natural process, but if we substitute our tools for the invisible hands of natural selection, that is a technology. Conventional breeding to radiation mutagenesis to CRISPR/Cas9 are all techniques of gene technology. They are not equally powerful techniques and do not have all the same critical control points, allowing for a differentiation of regulatory risk categories.

Individual critical control points define junctions where the use of the technology or product could accelerate harm. These are true scales and not like the "pseudo-scales" such as size of change, foreignness of DNA, or naturalness of the change.

The characteristic of gene technology that justifies social governance through legislation is that it can amplify the rate and magnitude of harm by increasing the ease of use, number of people using it, range of types of organisms and numbers of individuals that it is used on, and the number of environments where it can be applied. Each gene technology technique does this relative to conventional breeding.

Tiering a technology's critical control points provides a pathway of escape from endless divisions of an analogue continuum of size, DNA similarities or our favourite for clarity "changes that can be...produced in nature (i.e. naturally)" (Commonwealth Department of Health, 2018).

None of these have scientific thresholds or in some cases even meaning. They invite mischief to evade the regulations or confuse the lay public and rely upon courts to set arbitrary boundaries as solutions.

The example of gene technology used in a containment facility illustrates a critical control point. It does not matter what technique is done in the facility provided that the facility can confine it and thereby protect human health or the environment.

Containment for the purposes of research was the first approach adopted when the new technique of ligating together DNA restriction fragments became possible (Hurlbut, 2018). All uses and products in containment may possibly form a single category if their potential for harm scale change is controlled by containment. If the intention instead were to say cause genetic changes *in situ* rather than in containment (Heinemann, 2019; Heinemann and Walker, 2019) then that use would be in a different category needing a risk assessment appropriate for that category.

The critical control points framework is not the same as a tiered regulatory framework which attempts to categorize techniques or products by a notion of their similarity to what occurs spontaneously. Once a tool is deregulated, then all uses by all those inclined to use a technique becomes possible. This is what does not happen in nature. Deregulation erases a critical control point.

We can attempt to control nature, but we ultimately can't decide which laws of physics she uses – and we use the same ones. It isn't the physics of mutagenesis that is the root of harms that are mitigated by regulations. It is how people focus underlying natural processes that is a source of scalable harm. Regulation around critical control points gives us power over the sources of harm we create.

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2.13 Policy and governance issues in synthetic biology

Marianela Araya
Secretariat of the Convention on Biological Diversity, Montreal, Canada

Synthetic biology is a cross-cutting and rapidly advancing discipline with increasing relevance for numerous sectors. Synthetic biology carries hopes and aspirations to address a multitude of global challenges related to biodiversity, climate change, safety, food and agriculture, the environment and others, but at the same time inspires concerns about potential impacts including those associated to biodiversity. For synthetic biology to live up to its perceived potential, an enabling policy and regulatory environment is needed, which could facilitate taking advantage of potential benefits while minimizing risks derived from its application.

One of multiple factors influencing the governance of synthetic biology is its cross-cutting nature, which fosters the participation and engagement of a wide range of actors who are currently active in synthetic biology related discussions and activities.

Governance of such a broad and cross-cutting issue may also bring challenges for regulatory frameworks, including, without limitation, those governing public health, conservation, commerce and trade, risk of harm, free prior informed consent, and access and benefit-sharing. At the international level, several UN organizations as well as other initiatives are active and supporting discussions on synthetic biology related issues. This opens opportunities for cooperation and knowledge sharing.

Some of the challenges and key issues influencing the international governance of synthetic biology have been presented, and examples were provided in the context of the Convention on Biological Diversity, including what synthetic biology's governance could imply for this and other international instruments.

2.14 Germplasm meets systems biology – understanding and exploiting intraspecific crop plant adaptation to the climate crisis

Wolfram Weckwerth
Department of Functional and Evolutionary Ecology, University of Vienna and Vienna Metabolomics Center (VIME), Austria.

Genotyping-by-sequencing has enabled approaches for genomic selection to improve yield, stress resistance and nutritional value. More and more resource studies are emerging providing a thousand and more genotypes and millions of single nucleotide polymorphisms (SNPs) for one species covering a hitherto inaccessible intraspecific genetic variation.

The larger the databases are growing, the better the statistical approaches for genomic selection that will be available. However, there are clear limitations on the statistical, but also on the biological, part. Intraspecific genetic variation is able to explain a high proportion of the phenotypes, but a large part of phenotypic plasticity also stems from environmentally driven transcriptional, post-transcriptional, translational, post-translational, epigenetic and metabolic regulation. Moreover, regulation of the same gene can have different phenotypic outputs in different environments. Consequently, to explain and understand environment-dependent phenotypic plasticity based on the available genotype variation, we have to integrate the analysis of further molecular levels reflecting the complete information flow from the gene to metabolism to phenotype which we call a PANOMICS platform – integrating genomics, transcriptomics, proteomics, metabolomics and phenotyping (Weckwerth *et al.*, 2020).

We apply the PANOMICS platform to the crop plants millet, wheat, barley, potato, tomato, legumes, grapevine, lotus, cacao, model systems for third generation biofuels *Chlamydomonas reinhardtii*, and other model systems. Interestingly, metabolomics platforms are already partially more cost-effective than next generation sequencing platforms and are decisive for predicting stress resistance but also nutritional value (Ghatak, Chaturvedi and Weckwerth, 2018; Weckwerth, 2003, 2011a).

Recently, I coined the term "green systems biology", the need to apply these systems biology technologies to environmental research, ecosystem analysis and biotechnology (Weckwerth, 2011b). In the framework of green systems biology we propose three fundamental pillars for future breeding strategies (Weckwerth *et al.*, 2020):

(i) Combining genome selection with environment-dependent PANOMICS analysis and deep learning to improve prediction accuracy for marker-dependent trait performance.

(ii) PANOMICS resolution at subtissue, cellular and subcellular level provides information about fundamental functions of selected markers.

(iii) Combining PANOMICS with genome editing and speed breeding tools to accelerate and enhance large-scale functional validation of trait-specific precision breeding.

A reference will be given to the application of proteomics to drought stress adaptation processes in pearl millet and wheat, demonstrating the superior stress resilience of pearl millet genotypes and their corresponding stress marker (Ghatak *et al.*, 2021). Another example is given for tissue-specific proteome maps of wheat seed development (Zhang *et al.*, 2021).

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2.15 International treaties and genetic resources

Emily Marden
Department of Botany and Biodiversity Research Centre, University of British Columbia, Canada

It is well established that the advent of genomics, and associated emerging biotechnologies and information technologies (sometimes collectively called "synthetic biology"), are dramatically impacting research and innovation in the plant and agriculture sector, and that it is challenging for regulatory systems to keep apace of these developments. My short intervention is focused on the fact that synthetic biology also raises issues for existing international agreements on access and benefits sharing of genetic resources. These international agreements include the Convention on Biological Diversity (CBD) and Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (Nagoya Protocol) as well as the International Treaty for Plant Genetic Resources in Food and Agriculture (Plant Treaty).

The CBD was developed in 1992 and applies to all genetic resources, with some exceptions including human genetic resources and those plant genetic resources for food and agriculture (PGRFA) explicitly addressed by the Plant Treaty. The CBD is in effect with respect to applicable genetic resources in signatory countries, as well as, generally, in the countries that import applicable genetic resources. The CBD requires parties to engage in a bilateral agreement (specifically including "mutually agreed terms" and "prior informed consent") with the provider each time genetic resources are accessed, and these bilateral agreements require the parties to agree to benefit-sharing. The Nagoya Protocol was subsequently ratified in 2014 to more clearly address the issue of utilization of genetic resources that should give rise to benefit-sharing in this context and has been separately ratified by many of the CBD parties.

The Plant Treaty is a separate international agreement, and was negotiated after the CBD, to specifically address access and use of PGRFA. The Plant Treaty was developed, in part, because parties agreed that the bilateral agreements requiring mutually agreed terms and prior informed consent pursuant to the CBD, could potentially obstruct long-standing practices associated with the sharing of seeds and, as such, the CBD could be a hindrance to ongoing research and innovation in agriculture. Thus, instead, the 2004 Plant Treaty establishes a multilateral system in which plant genetic resources from an identified list (in Annex 1) of 64 crops and forages are shared, subject to a standard material transfer agreement, which must be utilized in toto as written, so there is no need for bilateral negotiation each time the PGRFA subject to the Plant Treaty are accessed.

The standard material transfer agreement includes benefit-sharing terms, with monetary benefits arising from commercialization going to a Plant Treaty-administered Benefit-sharing fund for distribution. It is worth noting that for all of these agreements, "genetic resources" are defined as "genetic material of actual or potential value" and "genetic material" is further defined as "any material of plant, animal, microbial or other origin, containing functional units of heredity."

The challenge with respect to synthetic biology is that access to genetic sequence information (also sometimes called "digital sequence information") is critically important for research and innovation, but the benefit-sharing associated with the access and use of such information is **not** explicitly addressed or mandated in the international agreements. At present, there are significantly different perspectives as to how to correct this problem, including by introducing a subscription model that would account for access and use *or* by explicitly tying benefit-sharing to access of genetic sequence information associated with plant genetic resources. There continues to be active discussions in the CBD, Nagoya Protocol and Plant Treaty fora. In addition, in the absence of clarity in the international arena, there are a number of individual countries that have passed their own domestic legislation obligating users of genetic sequence information to engage in appropriate benefit-sharing. In addition to these discussions, there are ongoing efforts to identify the scope of *non-monetary* benefits that can be generated and acknowledged as complying with benefit-sharing obligations under the international agreements.

What does all of this mean for those undertaking research and/or innovation in the synthetic biology space? These issues remain complex for researchers and innovators alike. It is important that researchers and innovators understand that there are international treaties that attach benefit-sharing obligations to access and use of plant genetic resources and that the scope of such obligations arising from access and use of genetic sequence information is currently under discussion. In the intervening time, it is important to take steps to identify and document the types of benefits generated by work in synthetic biology. The Nagoya Protocol Annex listing non-monetary benefits can be useful in this regard. It is also worth noting that certain journals, including for example Molecular Ecology, have started requiring the identification of such benefits in authorship requirements. International agreements play a significant role in research and use of genetic resources and it is important to remain aware of, and in compliance with, these agreements.

2.16 Report of outcomes from the two parallel sessions dedicated to the theme of advanced technologies

Rajeev K. Varshney[1] and Vittorio Venturi[2]
[1] *International Crops Research Institute for the Semi-Tropics, India and Murdoch University, Australia*
[2] *International Centre for Genetic Engineering and Biotechnology, Italy*

Two parallel sessions were dedicated to the theme of "advanced technologies". The first session, entitled "Modern plant breeding technologies", was co-chaired by Rajeev K. Varshney and Catherine Ziymo and its rapporteurs were Ndjido Kane and Rhodora Romero-Aldemita. There were four presentations (by Rajeev K. Varshney, Sanwen Huang, Dave Bubeck and Irene Sacristán Sánchez) and five brief interventions (by Leena Tripathi, T.J.V. Higgins, Ihuoma C. Okwuonu, John McMurdy and Gregory Jaffe) as well as a discussion moderated by the co-chairs where the presenters responded to questions posted in the chatbox by the conference participants.

The second session, entitled "Emerging biotechnologies and informatics technologies", was co-chaired by Vittorio Venturi and Sobhana Sivasankar, and its rapporteurs were Anandita Singh and Kassahun Tesfaye. There were four presentations (by Vittorio Venturi, Dionysis Bochtis, Jack A. Heinemann and Marianela Araya) and three brief interventions (by Wolfram Weckwerth, Emily Marden and Mark Watne) followed by a discussion moderated by the co-chairs where the presenters responded to questions posted in the chatbox.

The main points from session 1.1 on "Modern plant breeding technologies" were as follows:

- The fast-forward breeding framework, including haplotype-based breeding, genomic prediction in combination with speed breeding, is very useful.
- Rapid delivery systems for new varieties should be in place to get the technology to the farmers.
- The genome design approach has been used successfully to produce superior hybrid potatoes. The same approach can also be used to develop better hybrids in other crops.
- Advances in genome editing should be made available to farmers with a systematic delivery system.
- To continually enable success in genome editing, there should be a continuous development of innovative technologies supported by enabling regulatory policies and social licensing
- Current regulatory oversight and risk assessment requirements of novel genomic technologies are not tailored to diverse risk profiles.
- Novel genomic technologies can contribute to the European Green Deal and the Farm to Fork Strategy objectives, as well as to a more competitive economy.
- Concerns expressed about novel genomic technologies should be addressed in any future action and novel genomic technologies application should not undermine other aspects of sustainable food production, such as organic agriculture.
- Genome editing is a powerful approach for crop improvement.
- Genetically modified crops have reduced the need for chemical sprays and provided enhanced income for smallholder farmers.
- Efforts are underway to develop bacterial blight resistant, cassava brown streak disease resistant and herbicide tolerant cassava as well as to improve the overall starch quality and quantity of cassava.

- Latin America is leading in developing policies which exclude genome edited products from GMO regulatory oversight. A gene edited tomato is also on the market in Japan.
- It is hoped that genome editing can advance achievement of the SDGs and climate change goals.
- Principles for responsible governance of gene editing include transparency and access, equity and inclusion, and private and public engagement.

The main points from session 1.2 on "Emerging biotechnologies and informatics technologies" were as follows:

- The plant microbiome is an important tool towards development of new-age biofertilizers and biopesticides.
- Microbiomes promise reduction in widespread usage of agrochemicals, paving the way for future sustainable agriculture.
- Future work should focus on unravelling the role of these microbes with an integrated use of both conventional microbiology and genomics including computational biology, mass spectroscopy and imaging.
- Recent studies suggest high absorption but disruptive nature of artificial intelligence technologies in farming practices and agrobusiness.
- However, uncertainty about value addition and benefits, via adoption of artificial intelligence based technologies, contributes to risk perception by the farmer community leading to hesitancy.
- Use of artificial intelligence will plausibly result in business polarization in favour of big companies and manual skill labour could also be at risk because of automation.
- Penetration of artificial intelligence forecasts major socioeconomic problems meriting urgent attention.
- New techniques scale potential for harm but not biosafety or socioeconomic safety upon use.
- Non-linearity between use and risk; scalability is not always tenable.
- A "critical control framework" has been thus proposed to guide regulation at the critical interface of use and risk.
- Despite the promise of synthetic biology, potential adverse impacts on biodiversity need to be regulated.
- In synthetic biology, stakeholders aim to shift the discourse towards establishment of policies and regulatory framework.
- The policy framework is to be applicable to international, national and regional contexts, which make it very complex since the context/concern varies at these levels.
- Scope of governance for synthetic biology could therefore prioritize on integration; knowledge and information sharing; strategic planning and coordination; support systems for implementation; and adaptation contextual to national or regional policy instruments.
- Future breeding strategies need to incorporate panomics with genome selection, genome editing and speed breeding tools for precision breeding.
- Policies governing access and use of genomics data are not structured yet and they need attention.
- Lack of awareness on key issues and bottlenecks at various levels hinder swift adoption of emerging technologies.
- Researchers should also ask what farmers need to improve farm productivity.
- Support from the public sector to the farming community (e.g. public variety) can accelerate the rate of adoption of new technologies including genetically modified and genome edited crops.

3. PARALLEL SESSIONS: CONSERVATION OF PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE


Bambara groundnut

Parallel session: The global conservation system

A. The global conservation system – how it works:

3.1 Plant genetic resources for food and agriculture (PGRFA) conservation: Global overview of diversity *in situ*, *ex situ* and on-farm, how it is conserved and used

Nigel Maxted[1] and Mariana Yazbek[2]
[1] *School of Biosciences, University of Birmingham, United Kingdom of Great Britain and Northern Ireland*
[2] *Genetic Resources Section, International Center for Agricultural Research in Dry Areas (ICARDA), Beirut, Lebanon*

Plant genetic resource for food and agriculture (PGRFA) conservation focuses explicitly on the conservation of the taxon's breadth of genetic diversity and links the conserved resources to utilization in farming and breeding. Traditionally, PGRFA conservation has focused almost exclusively on crops and, lately, their wild related species, a relatively small subset of all plant species, but a subset which underpins global food security and so sustains humankind itself. These resources are themselves threatened by the climate change, anthropogenic habitat modification and existential human population growth, which each cause genetic erosion and extinction of these fundamental important resources.

The use of PGRFA to sustain food and nutritional security is only possible if wasteful duplication of effort is reduced and efficiency of conservation and use are increased. More effective joined-up integration of conservation planning with conservation implementation, and of conservation implementation with the utilization of conserved resource is required. As such, a critical review of the key steps in conservation and the use of plant genetic resources is provided to help secure PGRFA diversity for the future. Such a holistic approach to plant genetic resources conservation/use continuum is needed to address the post-2020 conservation priorities currently being drafted, while also ensuring the UN Sustainable Development Goals for people and planet are achieved by 2030.

3.2 Facilitating conservation of and access to PGRFA diversity through new technologies, approaches and data

Fiona R. Hay
Department of Agroecology, Aarhus University, Denmark

Management of seed collections in crop genebanks has a defined workflow from the arrival of new material, including seed multiplication, drying, sorting and packing, characterization, and viability monitoring of seeds in storage (Hay and Sershen, 2021). Underpinning everything, is the genebank information management system, with data collected at every stage of genebank operations.

The importance of the information management system was emphasized when we were trying to analyse the historical viability monitoring data from seven of the CGIAR genebanks to get a better understanding of the longevity of the seeds in genebank storage (Hay *et al.*, 2021). We found errors such as inconsistent formating of data in certain fields, obvious errors in dates or results, and duplicated entries or results. Many of these types of errors are less likely with the use of barcode labels and more digital data collection, but it is important to recognize the amount of investment in data management that is needed to ensure genebanks run smoothly.

From our analysis we were able to conclude that it would be possible to extend the first viability monitoring interval if the initial viability test result was high, rather than simply keeping all the monitoring intervals at five or ten years. We also concluded that it would be helpful to continue regularly testing the viability of older seed lots, even after viability has fallen below the threshold, to get a better understanding of seed longevity in genebank storage.

Automation, where possible, has the potential to improve the efficiency and consistency of operations. At the rice genebank at the International Rice Research Institute (IRRI), we automated seed sorting by installing a custom-machine that sorted bulk seed lots based on image analysis of individual seeds. We also automated the measurement of some of the seed characterization traits that are recorded for all accessions – using scanned images, but also using multispectral image analysis which has the potential to detect subtle differences in the outer surfaces of the seeds, including texture or, for example, chlorophyll content.

Improving efficiency in how we conserve plant genetic resources requires coordinated action comprising (i) effective long-term data management; (ii) development of evidence-based protocols based on the analysis of existing data and/or of new data collected through (iii) focused research; (iv) critical thinking; and (v) openness in relation to adoption of new technologies. As an example, bringing these different aspects together in relation to viability monitoring of seed lots in genebank storage, we should be able to set genebank monitoring intervals customized to species, groups of accessions, or even to the level of individual seed lots.

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3.3 Data analysis for finding adaptive traits in crop diversity

Ahmed Amri and Zakaria Kehel
International Centre for Agricultural Research in the Dry Areas (ICARDA), Rabat, Morocco

Genetic resources are key to sustaining agricultural development in the face of climate change and other challenges. They are conserved *ex situ* in genebanks while larger populations are available on-farm in farmers' fields and *in situ* in the remaining undisturbed natural habitats. These genetic resources are raw material for crop improvement efforts to develop productive varieties, resistant to major diseases and insects, tolerant to drought, heat and salinity and having quality and nutritional attributes needed by consumers, but they can also serve for restoration and rehabilitation of degraded systems.

Access and exchange of genetic resources needs to be facilitated and efficient in finding needed diversity. There are large collections conserved in some genebanks for crops of global significance, as in the case of CGIAR genebanks which are the major distributors of genetic resources and germplasm. As alternatives to random subsetting and to core/mini core and reference set collections, the filtering and predictive modelling approaches using focused identification of germplasm strategy (FIGS) are proposed to target traits requested by users.

Predictive modelling can also be used to target adaptive traits *in situ* and on-farm to fill the gaps in the existing collections. The success of the predictive approaches is tightly linked to the availability of accurate passport data, environment and soil layers, information on onset data for different crops, and expert knowledge on the traits targeted. While gap analysis using geographical representativeness can allow more accessions in the collections, traits-targeted collecting needs to be more adopted as it can add novel diversity for major challenges.

The FIGS approaches are fully adopted at the ICARDA genebank and have been successful in identifying breeders-sought adaptive traits including disease and pest resistance and heat and drought tolerance in manageably sized subsets of barley, chickpea, faba bean, lentil and both bread and durum wheats. Predictive modelling can also allow the identification of areas for promoting *in situ*/on-farm conservation of agrobiodiversity, including the establishment of protected or managed natural habitats for conservation of crop wild relatives and range and pastoral species.

The efficiency of predictive approaches can be augmented significantly by availability of phenotyping data and the flow back from requestors, and by the availability of genotyping data which will allow to identify more allelic variations and genomic regions associated with environmental factors.

B. The global conservation system – what impact has it had?

3.4 Cherokee heirloom genetics: A 20-year search for calories and culture

Pat Gwin
Cherokee Nation, the United States of America

Cherokee are a people of plant culture. In 1838, the Cherokee were force marched from their homes in southeast North America to the Southern Plains, over 2200 miles west. This journey became known as "the trail where they cried". The Cherokee had to abandon not only their physical possessions, but also their agriculture which represented not just unique varieties for cultivation and consumption, but were an integral part of their culture, identity and ceremonies.

Over the past 20 years, Cherokee Nation has been pursuing an ambitious project to gather together the heirloom varieties that were lost at the time of the forced march. This has been done through interviewing elders, visiting academic institutions, contacting museum facilities with Cherokee artefacts and through other sources. As a result, more than 20 crop species are now conserved. In 2019, some of material was safely duplicated at the Svalbard Global Seed Vault. Maize, beans and squash (the 'three sisters') are conserved. Every plant had several uses.

The conserved varieties include white eagle corn which was one of the only varieties that was saved from the original lands and brought on the trail of tears. It has a ceremonial function. Some of these populations have been developed from small founding populations and much effort is invested in hand selecting and phenotyping materials to ensure their trueness to the ancestral types. Every year a large part of the harvest is distributed to members of the Cherokee Nation community located around the world. Around 10 000 samples are distributed annually and they are accompanied by traditional knowledge provided in English and Cherokee language, so the project is also helping to save the Cherokee language.

3.5 Farming systems based on PGRFA diversity – impact on livelihoods and resilience in the Pacific

Karen Mapusua
Land Resources Division, Pacific Community (SPC), Fiji

Farming systems in Pacific Island countries are varied and complex and have proven to be robust and productive. Smallholder agriculture based on shifting agroforestry systems has generally provided a high level of food security and has been a "hidden strength" of food security in the region (McGregor *et al*., 2011). However, Pacific Islands traditional crops are now vulnerable to climate change impacts due to their narrow genetic base. This situation is exacerbated in many areas of the Pacific as agricultural and food systems are being rapidly degraded, and their biodiversity lost (Thaman, 2002). Of particular concern, according to Thaman (2002), is the breakdown of traditional shifting agroforestry systems in which a wide range of fruit trees and other culturally and ecologically valuable trees, plants and wild and domesticated animal life were deliberately protected within a matrix of ground and tree crops and various stages of fallow vegetation.

Climate change and increasing weather variability affects coastal areas that are vulnerable to the usual variations of the El Niño–Southern Oscillation (ENSO) events and storm surges, resulting in salinization of coastal farming areas as well as sea level rise. While it is expected that these impacts will increase over time, farmers are already experiencing climate change effects such as changes in flowering patterns, crop success over different altitudes and decreases in crop yields. Changes in temperature and humidity conditions are also contributing to changes in pest loads and outbreaks of pests and diseases. (McGregor *et al*., 2011)

Agrobiodiversity is widely accepted as the basic foundation for food security because it performs functions and delivers services on which agriculture depends (Jackson *et al*., eds, 2005) However, there has been limited quantifiable assessment in the Pacific Islands region of the impact of diverse PGRFA farming systems on livelihoods and resilience – either traditional or modern. There is, however, a range of anecdotal evidence of benefits, in addition to a cost–benefit analysis conducted by McGregor *et al*. (2011) of germplasm conservation and crop improvement as a climate change adaptation strategy, that are useful in illustrating impact.

Anecdotal evidence – biodiversity for pest management and livelihoods

- An organic passion fruit farmer in New Caledonia suffered production losses due to mites. He observed that where chayote (*Sechium edule*) was growing, the mite infestation drastically reduced. He introduced chayote plants every second row and mowed between rows only after flowering. This approach reduced losses through mite infestation and opened a secondary market for chayote.

- To manage anthracnose in local varieties of yam, Vanuatu introduced five high-yielding and resistant varieties for use as breeding stock. Within two years of the hybrids being released, farmers reported that 50 percent of their harvest consisted of the new varieties, which helped to secure their income.

Cost–benefit analysis – assessing the social and economic value of germplasm and crop improvement

A cost–benefit analysis conducted in Vanuatu and Samoa in 2011 analysed two case studies utilizing crops provided by the Centre for Pacific Crops and Trees (CePaCT) to increase biodiversity (McGregor *et al*., 2011):

- A study on reactive response to taro leaf blight in Samoa led to establishment of a breeding programme in response to taro leaf blight decimating the Samoan taro industry and severely impacting food security. Assessment showed that the value of taro production over the analysed breeding programme period (1994 to 2010) was ten times the cost of the breeding and germplasm conservation programme; the imputed economic value of this consumption equalled the value of the rice that would have been imported had the taro not been available. It was also assumed that there were substantial health and nutrition benefits from consuming taro and taro leaves (McGregor *et al.*, 2011).

- A study on a proactive climate change adaptation strategy in Vanuatu evaluated local diversity and introduced exotic varieties which were distributed in large volumes. This approach to expanding the diversity of genetic resources on farms relied on the interest of the farmer to want new diversity, and not abandon traditional crop varieties. The approach significantly increased diversity in pilot village fields. Benefits were measured in terms of the cost of importing grain to ensure food security if there is a catastrophic loss of a subsistence crop. It was assessed that the probability of Vanuatu having a root crop biological disaster over the following decade resulting in at least 5 percent increase in grain imports was seen as quite high. A 5 percent increase in Vanuatu's grain imports would have a cost of EUR 350 000 per annum and a 25 percent increase would have a cost of EUR 1.7 million (McGregor *et al.*, 2011).

Conclusion

Though genetic diversity in farmers' fields can provide insurance against future shocks, it is important to adopt a holistic and systematic approach to promoting PGRFA. More and longer-term studies that quantify the benefits – including farmer identified and traditional practices utilizing PGRFA – are required. It is also noted that cost–benefit analysis is a valuable tool, but given the cultural importance of many staple foods, traditional practices and the science around production and consumption, as well as health impacts research to assess benefits, solutions must not be confined only to those focused on economic values.

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3.6 Economic impacts of using PGRFA diversity in crop improvement

Nelissa Jamora
Global Crop Diversity Trust, Germany

We highlight three recurring, salient points on the economics of crop diversity conservation. First, the sources of genebank values are diverse. Hence, a diversity of approaches is also needed to document varied ways that genebanks benefit society. No single methodology can capture the multiple kinds of market and non-market values from the germplasm conserved in genebanks and the services they provide to users from both low- and high-income countries.

Second, the conservation of crop diversity is a global activity, and no country can do it alone. We present several examples of the importance of germplasm exchange in the development of crop varieties from one country to another. Crop diversity conservation requires interorganizational cooperation and global commitment to safeguard valuable genetic resources and find solutions to agricultural challenges.

Finally, we recognize that the conservation of PGRFA is a long-term effort and requires continuous documentation of use and impacts, in parallel to the breeding and research programmes. Why are we obliged to continue making the case for the impacts of genebanks? Because conserving and delivering plant genetic resources will require long-term investment in routine operations and supportive research and various optimization processes. None of these investments will be easy to obtain without an understanding of the evolving values embedded in genebanks and in the resources they manage.

For further reading:

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Parallel session: Access and benefit-sharing

3.7 Twenty years of the International Treaty on Plant Genetic Resources for Food and Agriculture: Where are we now?

Kent Nnadozie
Secretary, International Treaty on Plant Genetic Resources for Food and Agriculture

All countries are interdependent when it comes to PGRFA. No region or country is self-sufficient regarding the crop genetic resources needed for agriculture and food production. Therefore, we need to continue sharing and making available the resources that are the foundation of our food production and agriculture.

One of the current problematic trends in food and agriculture production is that fewer and fewer crops and varieties within those crops are feeding more people around the world. Globally, 400 000 plant species have been identified for our food needs. But only about 150 plant species are under reasonably extensive cultivation. Of those, just nine plant species supply nearly 66 percent of our total crop production. That is neither a viable situation nor a sustainable trend.

The reduction in the number of different crop species being grown for food and the erosion in genetic diversity within crop species have been and still are issues of major concern for the global community.

Given our interdependence, it is necessary to have multilateral approaches to these issues, vis-à-vis access to, conservation of and sharing of benefits from PGRFA. This need for a multilateral approach, combined with the alarming loss of diversity and genetic erosion led to the adoption of the International Treaty on Plant Genetic Resources for Food and Agriculture on 3 November 2001, by the Thirty-first session of the FAO Conference. The International Treaty has been in force since 29 June 2004.

The International Treaty is an international instrument that:

1. establishes the global framework for the conservation and sustainable use of PGRFA;

2. ensures that farmers and plant breeders access the genetic material needed to develop new crop varieties, including those with higher yields and those that are resilient to climate change; and

3. facilitates the sharing of benefits arising from the utilization of PGRFA.

The International Treaty also provides the legal framework for connecting the local to the global – from community seed banks and national genebanks to the Svalbard Global Seed Vault.

In the 20 years since its birth, the International Treaty has gained a membership of 148 (soon to be 149) Contracting Parties, including the European Union. It provides a global forum to address the challenges of crop diversity loss and climate change adaptation through robust mechanisms, which include the largest global exchange system for PGRFA, known as the Multilateral System of Access and Benefit-sharing (MLS), which facilitates an average of 1000 transfers per day. The MLS facilitates access to PGRFA, and the sharing in a fair and equitable way of the benefits arising from their use.

The Treaty's truly innovative solution to access and benefit-sharing puts 64 of our most important crops – crops that together account for 80 percent of the food we derive from plants – into an easily accessible global pool of genetic resources that is freely available to potential users for specific uses (e.g. research, plant breeding, training).

The International Treaty systems have been operational since 2007, and include:

1. The Multilateral System of Access and Benefit-sharing – facilitating access to the largest global gene pool of PGRFA.

2. Sustainable Use and Conservation – promoting the conservation and management of all crops, including local/traditional crops, biologically diverse production systems, and strengthening research.

3. Global Information System – facilitating access to data/information on PGRFA through a global portal using latest standards.

4. Farmers' Rights – recognizing and promoting local seed systems, active participation of farmers as custodians of biodiversity, and protection of traditional knowledge.

5. Benefit-sharing Fund – essential component of the Funding Strategy, promoting PGRFA management and use in developing countries.

The current global pandemic has served as a reminder of the vulnerability of the human species and of our interdependence. Multilateralism is essential in addressing global challenges. Genetic diversity in PGRFA is a public good that benefits the global community, and must continue to do so.

Consequently, there are still a number of challenges to be addressed, including:

- need to eliminate unnecessary barriers to germplasm exchange and utilization;

- need to expand the coverage of the MLS;

- need to have concerted political commitment to ensure long-term public sector investment and support to different seed systems; and

- need for continued international cooperation.

In this context, the International Treaty provides the international legal framework needed for the governance of the management and exchange of PGRFA, as well as providing a global policy forum for decision-making.

3.8 Implementing access and benefit-sharing measures for agriculture in Brazil

Simone Nunes Ferreira
Nogueira Ferreira Advogados Associados, Brazil

Brazil was one of the first countries to regulate access and benefit-sharing (ABS) through a national law. Starting in 2000, the country established a complicated system based on case-by-case prior informed consent and mutually agreed terms (Provisional Act 2186-15/01). At this time, the difficulties were numerous. The law was complicated to implement, there was a lack of clarity on the requirements, terms and scope while overly bureaucratic and time-consuming procedures were in place. As a result, there were few permits, disincentives for research and development of products based on biodiversity, and reduction in genetic resources for food and agriculture collecting and exchange.

In 2014/15, after several companies and institutions faced compliance problems, a new law was discussed and approved by the National Congress: Law 13,123 (Brazilian ABS Law or the Brazilian Biodiversity Law). This new framework made relevant modifications in the Brazilian ABS legal system, highlighted the importance of the International Treaty on Plant Genetic Resources for Food and Agriculture and recognized the need for special rules for genetic resources for food and agriculture.

Regulation moved from an authorization system to a registration system. Before 2015, biodiversity users needed an authorization prior to accessing genetic resources and benefit-sharing was negotiated case by case, sometimes with multiple providers. Under Law 13,123, biodiversity users need to register the access prior to economic exploitation. Second, benefit-sharing rules are clearer and more stable. There is also a fixed amount of benefit-sharing for genetic resources access: 1 percent of net sales. In the case of genetic resources, it is not necessary to negotiate ABS with private providers, only with the Brazilian Government.

One of the main improvements of the new law is a different treatment for genetic resources for food and agriculture. The framework adapted the access and benefit-sharing measures for genetic resources for food and agriculture. In this way, agricultural activities have facilitated rules for access and benefit-sharing.

The concept of agricultural activities was established to delimit the application of differentiated treatment. For this purpose, agricultural activities mean "activities of producing, processing and commercializing food, beverages, fibers, energy and planted forest". It is important to note that this concept excludes ornamental and medicinal use as well as companion animals. ABS general rules prevail for these uses.

Agriculture differentiated treatment under the Brazilian Biodiversity Law consists in some measures adapted for the needs of this sector. Some problems that occurred under the old law were resolved. These measures are publication of lists of animal and plant species, exclusive benefit-sharing in reproductive material, no benefit-sharing obligations for agricultural inputs, traceability in product registration and plant variety protection, and compliance under shared competence between Agriculture and Environment ministries.

Genetic resources for food and agriculture are all genetic resources (genetic heritage) used in agricultural activities, including wild species, crop wild relatives, domesticated and cultivated species occurring in *in situ* conditions, landraces, micro-organisms isolated from national territory, substances derived from their metabolism and, finally, information.

Sometimes, it is very difficult to determinate whether a particular genetic resource is within the scope of national legislation or not. Introduced species lists are published to resolve this lack of clarity. These lists contain species that have been introduced into the country and are not found in *in situ* conditions. In other words, if the species is on the list, the ABS rules established in the Biodiversity Law do not apply. Animal and plant species lists are published by the Ministry of Agriculture.

In the case of micro-organisms, determining the origin is more complicated, especially for those that are widely spread. For this question, there is no adequate ecological answer to guide the legal decision. So, the legislator chose to consider as genetic heritage the micro-organisms isolated from any resource from the Brazilian territory.

All users of genetic resources are required to register their research and technological development in the electronic system, called SISGEN. The triggers for the registration are shipment of samples abroad, intellectual property right's application, intermediate's product commercialization, publication of results in scientific or communication media, and notification of a finished product or reproductive material developed as a result of the access.

Benefit-sharing for agricultural activities is exclusively on reproductive material developed as a result of the access. It is mandatory to notify the reproductive material before the beginning of its sale. Benefit-sharing can be monetary or non-monetary. Monetary benefit-sharing is 1 percent of net sales of seeds and seedlings. Non-monetary benefit-sharing can be under benefit-sharing agreements with the purpose of conservation and sustainable use of genetic resources for food and agriculture, for example.

Exchange and dissemination of genetic heritage and associated traditional knowledge practiced by Indigenous Peoples, traditional communities or traditional farmers for their own benefit and based on their usages, customs and traditions are considered as benefit-sharing exemptions.

The Brazilian ABS system has specific checkpoints for genetic resources for food and agriculture. These checkpoints enable the country to monitor how genetic resources for food and agriculture are used along the value chain for commercial use. Checkpoints performed by the Ministry of Agriculture are the systems' databases on protection and registration of cultivars, seeds and seedlings, of products, establishments and agricultural inputs, as well as information on the international transit of goods and agricultural inputs.

The bodies responsible for enforcing ABS rules for genetic resources for food and agriculture are the Ministry of Agriculture and the Environmental Protection Agency (IBAMA). The compliance mechanisms are the administrative verification procedure, monitoring of utilization and checkpoints, infractions and administrative sanctions. Administrative offences shall be punishable by the following penalties: warning, fines (from BRL 10 000 to BRL 10 million, when the infraction is committed by a legal entity), apprehension, temporary suspension of the manufacture and sale of the product, etc.

The monetary benefits are deposited by users directly in the National Benefit-Sharing Fund. The received fund will then be used for projects aimed at promoting the conservation of biological diversity and/or traditional knowledge. They also can be used by food and agriculture sectors, including germplasm banks and collections.

After five years of implementing the Biodiversity Law, there are still challenges. These include improving traditional farmers' participation, promoting the native biodiversity's sustainable use, making efficient regulation, and regulating access to digital sequence information, monitoring the ABS regulation system, using ABS funds to promote the sustainable use, and Nagoya Protocol adequacy.

3.9 Evolving access and benefit-sharing systems in China for sustainable development and food security

Qingwen Yang
Institute of Crop Sciences, Chinese Academy of Agricultural Sciences

China is recognized to be the mega-diversity country, and one of the eight origin centres of crops and the three origin centres of agriculture in the world. It is abundant in genetic resources and related traditional knowledge. The Chinese Government has paid much attention to collection and conservation of genetic resources and achieved much progress.

However, there is no legislation on access and benefit-sharing (ABS) at present to deal with international issues of ABS. Since early in this century, the Chinese Government recognized the importance of ABS for the conservation and sustainable utilization of genetic resources. In 2005, the revised Animal Husbandry Law provides that "for private export and cooperation with foreign organizations, the utilization of animal and poultry resources in the protection name list, the user shall apply husbandry administration department at the provincial level, and provide a measure of benefit-sharing at the same time". It was the first regulation of ABS in laws. Since then, the Patent Law and some policies provided more regulations to deal with ABS at both international and national levels.

Based on the analyses of the reasons to cause that China has no ABS laws or regulations, we found that there are some conflicts of ABS with the Constitution of the People's Republic of China, and China has not ratified the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). To put forward the implementation of ABS in China, we provide some suggestions for future work, including:

- The theoretical and practical research on the sovereignty, ownership and the right to use of genetic resources and intellectual property.
- Formulate a specific regulation on ABS based on the Nagoya Protocol, the ITPGRFA and Chinese status.
- Establish mechanisms to divide genetic resources into different owners. Except for those conserved in public agencies, other genetic resources could belong to the private sector or farmers.
- Apply and ratify the ITPGRFA.

3.10 Exchanges between public and private sectors

Marisé Borja
Syntech Research Group, Valencia, Spain

Since the inception of the Nagoya Protocol, the implementation of its access and benefit-sharing provisions has been uneven. While genebank repositories and multinationals are aware of the need for compliance, other public institutions and smaller companies have not been able to cope with, or implement, the protocol as efficiently and it is only when the patent, deposit or market is envisioned that the issue is addressed.

There are some success stories such as the breeding of the flowering annual plant *Impatiens hawkeri* by the Japanese company Sakata Seed Corporation who made an agreement with the Indonesian Government. However, there is still a need for global training on how and when to implement the Nagoya Protocol successfully, the further expansion to all geographies so there are no backdoors and the development of fair mechanisms so it would be easier for smaller companies to comply.

3.11 Access and benefit-sharing in an increasingly digitized future

David Ellis[1], Isabel Lopez Noriega[2] and Michael Halewood[2]
[1] *International Potato Center, Lima, Peru*
[2] *The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT), Rome, Italy*

Increasingly, we use and access digital information in our daily lives. However, there currently exists a lack of understanding, consensus and agreement regarding how access and benefit-sharing regimes can be applied to digital information. This has been highlighted by the current debate over digital sequence information (DSI). While there is basic agreement that the use of genetic resources collections increasingly relies on DSI and that open access to DSI databases is instrumental to the non-monetary benefits derived from its use, there is little agreement on if or how monetary benefits could result from use of DSI derived from genetic resources collections and if and how these monetary benefits should be shared.

It is extremely important that DSI databases remain open and inclusive to as many users as possible because the understanding and deciphering of these sequences relies on use of prior information and thereby building the data resource. One option that figured large in the suspended negotiations (2013–2019) to enhance the Plant Treaty's multilateral system of access and benefit-sharing was a subscription system for access to the physical genetic resources, which would also include all information associated with this genetic resource, including DSI. The Arabidopsis Information Resource (TAIR) is one example of a DSI database which is supported by a subscription system, although monetary benefit-sharing is not a component of the subscription. Nevertheless, this does provide evidence where the plant molecular community has moved successfully to a subscription system, thereby providing evidence that subscription systems for DSI databases do function.

3.12 Five ideas for optimizing access and benefit-sharing

Amber Scholz
Leibniz Institute DSMZ–German Collection of Microorganisms and Cell Cultures, Germany

Access and benefit-sharing (ABS) has a long tradition of being a noble goal with thorny real-life challenges. Five practical ideas for optimizing ABS are presented.

First, ABS across all sectors and instruments needs to be simplified and standardized.

Second, there are untapped opportunities to connect and digitize ABS processes and quantify and monitor (especially non-monetary) benefit- sharing.

Third, as we look towards new decisions on digital sequence information (DSI), we must ensure they are future-proof, that they account for technological revolutions such as protein folding, that are already upon us.

Fourth, for DSI, access does not need to be directly linked to benefit-sharing. This can and should be de-coupled into open access and benefit-sharing.

Finally, there are "leapfrog" opportunities for scientific capacity building around genetic resources and DSI that should come to the forefront of policy discussions.

For more information, see Scholz *et al.* (2022) and DSI Scientific Network (2022).

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3.13 Report of outcomes from the two parallel sessions dedicated to the theme of conservation of plant genetic resources for food and agriculture

Lamis Chalak[1], Charlotte Lusty[2] and Michael Halewood[3]
[1] *Plant Production Department, Faculty of Agronomy, The Lebanese University, Lebanon*
[2] *Global Crop Diversity Trust, Germany*
[3] *Policy Unit, Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT), Italy*

Two parallel sessions were dedicated to the theme of "Conservation of plant genetic resources for food and agriculture". The first session, entitled "The global conservation system", was chaired by Charlotte Lusty, co-chaired by Lamis Chalak and supported by the rapporteurs Tilabilenji Phiri and Thomas Payne. The first part of the session, dedicated to "The global conservation system – how it works", consisted of three presentations (by Nigel Maxted, Fiona R. Hay and Ahmed Amri) followed by a discussion moderated by the chair where the presenters responded to questions from participants posted in the chatbox. The second part of the session, dedicated to "The global conservation system – what impact has it had?", included a conversation between the chair and Pat Gwin, two presentations (by Karen Mapusua and Nelissa Jamora) and a discussion moderated by the chair where the presenters responded to questions from participants posted in the chatbox.

The second session, entitled "Access and benefit-sharing", was chaired by Lamis Chalak, co-chaired by Charlotte Lusty, and supported by the rapporteurs Isabel Lopez Noriega and Mariana Yazbek. The first part of the session consisted of five presentations (by Kent Nnadozie, Simone Nunes Ferreira, Qingwen Yang, Marisé Borja and David Ellis). The second part consisted of a panel discussion (with Szonja Csörgő, Yasmine Lara Beau, Tilabilenji Phiri, Ehsan Dulloo and Elzbieta Martyniuk) moderated by Michael Halewood, followed by a concluding presentation (by Amber Scholz).

The summary points from the parallel session on "The global conservation system" were as follows:

- Diversity underpins crop improvement and seed systems but has uncountable other values.
- Traditional crop landraces have multiple profound significances to Indigenous Peoples, as illustrated by the example from the Cherokee Nation.
- There are numerous examples of farmers seeing the benefit of adopting diversity on farms in the Pacific as part of a systems approach to pest management, improving nutrition, climate change adaptation, reducing the need for food imports.
- The economic impact of using crop wild relatives can be important. For example, traits from *Aegilops tauschii* conveyed resistance to hessian fly in wheat and a 10 percent increase in genetic contribution from materials received from the International Rice Research Institute (IRRI) genebank is associated with a 27 percent increase in rice yields in eastern India.
- Conservation of this diversity is the only way to prevent its loss.
- The only way to conserve is through complementary methods using *in situ*, on-farm and *ex situ* approaches.
- All governments should be urged to intensify their conservation efforts at the national level as well as continuing to support international efforts.
- More investment is needed in *in situ*/on-farm conservation, conservation of crop wild relatives and underutilized crops and in more efficient ways of managing seed quality (particularly drying), safety duplication and data management.

- A globally coordinated scientific review of PGRFA conservation and use is suggested to complement the State of the World's Biodiversity for Food and Agriculture report and to respond to SDG 2.5.

The major conclusions and recommendations from the parallel session on "Access and benefit-sharing" were as follows:

- The International Treaty on Plant Genetic Resources for Food and Agriculture (the Plant Treaty) multilateral system has demonstrated to be a functional system, particularly in terms of facilitating germplasm exchange for agricultural research and development. It does not yet have a demonstrated track record for monetary benefit-sharing from users of PGRFA. It is recommended to continue investigating options for increasing the flow of both monetary and non-monetary benefits derived from use of materials accessed under the multilateral system.

- Private sector actors continue to experience challenges in accessing materials for use in crop improvement, though they cite positive influence of the Plant Treaty. It is recommended that there be significant investments in capacity building for mutually supportive implementation of the Plant Treaty and the Nagoya Protocol, to ensure that both work together providing appropriate policy support for agricultural research and development, and for sharing related benefits.

- The generation and use of digital sequence information (DSI) is changing the nature of agricultural research and development, including conservation of PGRFA and plant breeding, and the kinds of benefits that can be generated and shared. Possible options for addressing benefit-sharing derived from the use of DSI should ensure continued access and interchange of data; it should also build on, and complement, the principles and architecture of the multilateral system.

- More generally, for moving forward over the next years, it is highly recommended that the international community works towards more harmonized access and benefit-sharing systems, reflecting the basic approaches of the multilateral system with standardized conditions, benefit-sharing organized through multilateral mechanisms, and substantial investments in scientific capacity building. This is to ensure that developing countries, Indigenous Peoples can benefit from the conservation and use of genetic resources, and from the ongoing and future breakthroughs in science and technology.

4. PARALLEL SESSIONS: CROP VARIETAL DEVELOPMENT AND ADOPTION


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Parallel session: Accelerating genetic gains in crops

4.1 Keynote: Accelerating genetic gains for sustainable development

Barbara H. Wells
Global Director, Genetic Innovations, CGIAR/Director-General, International Potato Center

New and improved crop varieties are strategic assets for sustainable development. They can generate sustainable livelihoods at the market, help farmers adapt food systems to climate change, protect biodiversity, bring inclusive growth and empowerment for women, youth and Indigenous Peoples, and put nutritious, affordable and tasty food on our plates. Successfully accelerating genetic gains means ensuring new and improved crop varieties meet the needs of farmers, markets, the environment and consumers, and are accessible and affordable to all. At the same time, successful crop breeding respects traditional food cultures and recognizes the role that farmers and other custodians have played over millennia to safeguard the genetic diversity upon which crop improvement programmes depend, including that found in the wild and on farmers' fields, as well as in genebanks.

Agriculture today contributes to large-scale land and water degradation, biodiversity losses and greenhouse gas emissions. It is no longer enough to feed the world, we need to nourish it too with a steady stream of diverse seeds that contribute to nutrition, health and food security; poverty reduction, livelihoods and jobs; gender equality, youth and social inclusion, climate adaptation and mitigation; and environmental health and biodiversity. But genetic gains on their own are not enough to achieve sustainable development. It is only when seeds are planted in farmer's fields, sold at the market, taken to large urban centres, or served on consumers' plates, that they can deliver their intended impact on the ground.

Despite great technical gains in breeding, many varieties are not adopted. All too often, breeding has overfocused on the improvement of single varieties rather than looking at the food system as a whole and on yield to the exclusion of nutrition and the characteristics demanded by farmers and consumers, such as taste and cooking time.

To achieve sustainable development outcomes, adoption rates need to increase. To this end, One CGIAR is launching a new research initiative that combines market intelligence and cutting-edge technologies. Cutting-edge tools can enable breeders to develop robust, resilient, productive, market-demanded varieties that farmers need and have great potential to accelerate the development of elite varieties with traits that would be unattainable using conventional breeding. This whole process will be underpinned by market intelligence ensuring that the needs of end-users come first, and that breeding targets specific needs of people in different parts of the world, different agroecological environments and different cultural contexts. In this way, market intelligence can inform the development of the right combinations of crops that are tailored to the needs and desires of both men and women farmers, processors, traders and urban consumers, increasing adoption rates and sustainable development outcomes.

One CGIAR has undergone a significant transformation to change the way it does breeding so that end-user needs drive breeding programmes, rather than the other way around. CGIAR has also integrated CGIAR centres' intellectual capital, infrastructure and capacities, creating shared services for partners and stakeholders. This transformation should substantially shorten the time needed to develop more resilient and nutritious varieties and will facilitate shaping policies to incentivize the turnover of older varieties; strengthen national and regional seed systems through capacity development and sustainable business models and promote public–private sector partnerships.

Public–private sector partnerships are particularly crucial to this effort, especially for delivering new varieties and other technologies to farmers and consumers. A new multistakeholder collaboration hub and investor dashboard will make it easier to monitor and guide new investments through evidence-based metrics that look at breeding in terms of sustainable development outcomes.

4.2 Climate-smart maize: Developing and deploying climate-smart DroughtTEGO and TELA maize for African farmers

Sylvester O. Oikeh[1], Yoseph Beyene[2], Mark Edge[3], Kingstone Mashingaidze[4], Emmanuel Okogbenin[1] and Stephen Mugo[5]

[1] *African Agricultural Technology Foundation, Nairobi, Kenya*
[2] *International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya*
[3] *Bayer, St. Louis, the United States of America*
[4] *Agricultural Research Council-Grain Crops Institute, Potchefstroom, South Africa*
[5] *Center for Resilient Agriculture in Africa (CRA-Africa), Kiserian, Kenya*

Frequent drought stress and insect pest damage (stem borers and fall armyworm) pose a significant threat to food security for over 300 million people in Africa who depend on maize as their main food source. Drought causes an annual average of 17 percent yield loss of maize in Africa. Stem borers are known to reduce maize production in Africa. For example, in Kenya, stem borers reduce maize production by an average of 13 percent or 400 000 tonnes of maize, which is equivalent to the annual Kenya maize imports, valued at more than USD 90 million. Fall armyworm is a new devastating, transboundary pest of maize that was first observed in Africa in 2016. If solutions are not put in place quickly, projections estimate that it could destroy up to 20 million tonnes of maize annually which is enough to feed 100 million people.

To address this threat to maize production, the Water Efficient Maize for Africa (WEMA) project was created in 2008 to develop and deploy new drought-tolerant and insect-resistant (climate-smart) maize hybrids for smallholder farmers through public–private partnership. The African Agricultural Technology Foundation, a technology transfer organization, leads the partnership that includes CIMMYT, Bayer and the national agricultural research systems of Kenya, Ethiopia, Mozambique, Nigeria, South Africa, the United Republic of Tanzania and Uganda. The partnership benefited from long-term investments by the Bill and Melinda Gates Foundation, the Howard G. Buffett Foundation and the United States Agency for International Development (USAID). The partnership believed that biotech crops (e.g. TELA maize) are safe and can contribute to African food and nutrition security.

The partnership used three approaches to develop climate-smart varieties: a) conventional breeding techniques including utilization of doubled haploids technology; b) molecular marker-assisted breeding including marker-assisted recurrent selection and genome-wide selection; and c) introduction of drought-tolerance and insect pest transgenes via genetic engineering into adapted conventionally bred drought-tolerant varieties to rapidly accelerate genetics for traits of interest.

The project first defined the product concept to guide product development with focus on white hybrids with 25 percent yield improvement over 2008 hybrids under moderate drought conditions. The target was first, to achieve 15 percent yield advantage from conventional breeding over ten years; and followed by an additional 8–10 percent yield advantage from drought tolerance transgene (*CspB*; MON87460; DroughtGard®) from *Bacillus subtilis*. To protect the yield gains obtained through drought tolerance, the project also explored insect-resistance (Bt) transgenes (MON810 and MON89034) from *Bacillus thuringiensis* to mitigate stem borer and fall armyworm damage.

In WEMA, the multiple breeding strategies that were explored for drought tolerance breeding, including marker-assisted recurrent selection, genome-wide selection and pedigree selection were compared for their efficiencies in accelerating genetic gain across eight to ten bi-parental populations from 2013–2014. Results showed that Cycle 3 marker-assisted recurrent selection gave yield advantage of 3–56 percent over the mean of the commercial checks, and 6–22 percent over the mean of hybrids developed through the traditional phenotypic pedigree selection.

Genetic gains study was carried out to compare gains from genome-wide selection, marker-assisted recurrent selection and pedigree breeding under drought stress. Results showed, on average, genetic gain of 70.5 kg/ha/year from genome-wide selection, which was two to four times higher than gains ever reported from conventional breeding in sub-Saharan Africa. Several new drought-tolerant lines and hybrids were developed by marker-assisted recurrent selection and genome-wide selection approaches and approved for commercialization.

The African Agricultural Technology Foundation used its robust business model for the commercialization of the climate-smart DroughtTEGO® hybrids in Kenya from 2013. Within five growing seasons, in less than three years, over 4800 demonstration plots were established with farmers across 17 counties. Results showed that the DroughtTEGO® hybrids gave yield advantage of 33–54 percent (5.5–6.3 t/ha) relative to the commercial check hybrids.

After a decade of excellent breeding in WEMA with over 120 DroughtTEGO® hybrids developed and approved for commercialization, the partnership was renamed TELA Maize Project to focus on accelerating further genetic gains through genetic engineering. The conventionally bred drought-tolerant inbred lines were traited with insect-resistant, Bt gene (MON810/MON89034) and drought-tolerant gene. TELA® hybrids were developed with stacked drought tolerance and Bt traits which were evaluated for efficacy of the traits in confined field trials in different countries.

On average, under natural fall armyworm and artificial stem borer infestation, hybrids with Bt MON810 trait gave 43 percent yield advantage compared to isogenic hybrids from 12 confined field trials across six locations in five countries from 2016–2020. Under moderate drought stress, on average, stacked genetically engineered hybrids with drought tolerance MON87460 trait gave about 17 percent yield advantage relative to non-genetically engineered isogenic hybrids from four confined field trials in three countries from 2016–2020. But under optimum moisture condition with chemical control of the target pests as required for regulatory trials, stacked genetically engineered hybrids gave similar yield as conventional isogenic hybrids, indicating that the inclusion of the traits did not alter non-target traits from 12 confined field trials conducted across six locations in five countries for five years. These results were used to support applications for environmental release of the traits in project countries, with Nigeria being the most recent to receive environmental release of the traits in 2021 to allow for multilocation advanced yield trials for variety certification, within three years of joining the partnership.

To develop transgenic seed systems for Africa, the partnership has engaged with 38 small and medium enterprise seed companies using humanitarian use licenses, the first of its kind in Africa, to facilitate the production of 29 206 tonnes of certified seeds of climate-smart DroughtTEGO® and TELA® hybrids. Enough seed to plant 1 168 240 hectares of maize.

The major challenge has been the heightened anti-GMO technology activism in Africa with efforts to stop African farmers from growing genetically engineered crops. This has also delayed getting environmental release and genetically engineered hybrids commercialization in some countries.

In conclusion, strategic combination of pedigree, marker-assisted breeding and genetic engineering technology has resulted in the highest genetic gain reported for maize improvement in Africa; with 128 high-yielding climate-smart DroughtTEGO® and TELA® hybrids now available for farmers. Greater support for genetic engineering technology is urgently needed by African governments to address food insecurity. There is a call to encourage African governments to embrace biotechnology, among other technologies to address chronic food insecurity; and for partners to stop funding those advocating for a blanket opposition to GMOs in Africa.

4.3 Bean improvement at Embrapa

Elcio Perpétuo Guimaraes and Thiago Livio Pessoa Oliveira de Souza
Embrapa Rice and Bean, Santo Antônio de Goiás, Brazil

The Brazilian Agricultural Research Corporation (Embrapa) bean improvement programme starts by making use of the genetic diversity available in its genebank, where there are around 19 000 accessions. Breeding objectives were set up years ago and are adjusted, when necessary, to ensure they represent farmers', markets' and consumers' demands. A team of scientists including breeders, pathologists, entomologists, agronomists and socioeconomists, carries on the breeding activities.

In order to accelerate genetic gain, bean breeders apply different breeding methods, including through using the support of biotechnological tools. The methodology used by Embrapa runs through traditional methods, such as pedigree and bulk, and it also includes recurrent selection. Biotechnological tools are used in backcross-assisted selection and transgenic cultivar development (genetically modified organism). It is worth mentioning that Embrapa is the first public sector institution ever to release a transgenic cultivar to the market (BRS FC401 RMD).

Looking ahead to potential problems, the programme also carries out preventive breeding activities, focusing on one disease with potential to threaten the country´s production. To ensure impact, the programme created a business technical committee to analyse and choose the breeding lines to be released as cultivars and also to design the most adequate business model for each cultivar to reach the market. The programme also forged a strong link between breeding activities and the seed-producing sector.

Recently, the breeding programme established a public–private partnership with 11 seed producers, where they support some of the breeding programme's activities and ensure seed production and distribution to farmers. As a result of these strategies, Embrapa released several cultivars, such as BRS Estilo, BRS FC104, BRS FC402, BRS FC406, among others, some of them yielding more than 5.0 tonnes/ha. These releases give to Embrapa over 60 percent of the Brazilian bean market share. In summary, Embrapa's bean breeding is a successful programme that uses different breeding strategies to accelerate genetic gains to impact Brazilian production in a sustainable manner.

4.4 Orange sweet potato: The model for biofortified crops with a visible trait

Maria Andrade
International Potato Center, Mozambique

More than 40 percent of children under five years of age suffer from vitamin A deficiency in sub-Saharan Africa. The dominant sweet potato varieties in sub-Saharan Africa are white- or yellow-fleshed, containing no or low levels of beta-carotene, respectively. Our initial sweet potato work in Africa began in the 1990s when support for agriculture was falling, so initial efforts to improve child nutrition relied on selection of "best-bet" varieties often bred in other parts of the world that had low adoption in the continent. Biofortification is breeding vitamin A into key staple crops and is one among several interventions in place to address vitamin A deficiency.

Staple crops biofortified with beta-carotene are orange in colour. Breeding progress for biofortified orange sweet potato has been much faster than for the other vitamin A enhanced staples, given the natural occurrence of high levels of beta-carotene in many sweet potato varieties. With the breeding effort and seed system, many varieties have been released and more than 6 million households/beneficiaries have been reached with orange sweet potato. Some varieties have been released in several countries.

This presentation reviews key factors influencing the uptake of orange sweet potato, the breeding investment, key delivery approaches that have been tested in the region and efforts to broaden government and other stakeholder engagement and later the modernization in breeding to improve genetic gain and the seed system.

4.5 Wheat quality improvement in China

Zhonghu He
Chinese Academy of Agricultural Sciences and International Maize and Wheat Improvement Center

Wheat is the third leading crop in China and over 85 percent of Chinese wheat is used to make steamed bread and noodles, although consumption of western bread is increasing significantly. Chinese wheat is characterized by weak dough and significant variation of end product colour. The objective of wheat quality breeding in China is to improve dough quality for pan bread and blending purpose and improve colour-related traits for traditional products, and significant progress has been made in research and breeding during the last 20 years.

Two constraints are limiting the use of molecular markers in wheat breeding. Gene-specific markers are ideal in breeding programmes. However, a very limited number of markers is available. There is a shortage of high-throughput platforms, making marker testing expensive and time consuming. This presentation will focus on gene-specific marker development and application, establishment of a high-throughput Kompetitive allele specific PCR (KASP) platform for breeding programme, and quality cultivar development.

Genomic information in rice, maize and wheat has been used to clone wheat genes and develop gene-specific markers during the last 20 years. Higher yellow pigment is desirable for yellow alkaline noodle and durum wheat pasta, but undesirable for Chinese noodles. Psy genes at chromosome 7A and 7B, responsible for yellow colour in wheat noodles, were cloned, allelic variation was identified, and gene-specific markers were developed and validated.

Gene characterization and gene-specific marker development in flour colour related traits include Pds, Lcye, 1BL.1RS, Ppo, Lox and Pod, by the same approaches. There are 63 gene-specific markers available in wheat quality traits including high molecular weight glutenin subunits (HMW-GS) and low molecular weight glutenin subunits (LMW-GS) for dough quality, colour-related traits and grain hardness.

90K and 660K SNP arrays are widely used to construct high-density linkage maps, and quantitative trait locus mapping and genome-wide association study based on SNP arrays are very powerful tools in locating candidate genes, and for marker-assisted selection. SNP arrays are used to understand colour-associated traits in our programme. Black point is characterized by dark discoloration at the embryo end of the kernel and we need to develop cultivars with less incidence of black point. However, no genetic information is available. Resistance to black point can be selected by the molecular markers of PPO genes on 2AL and 5B, and POD genes on 3AL, based on genome-wide association study.

All gene-specific markers in wheat are PCR-gel-based markers, and limitations in breeding application include higher cost in labour and chemistries, longer time, and less flexibility and accuracy. KASP is the most desirable technology for SNP genotyping with desirable flexibility, high-throughput and low cost. There are 142 KASP assays available for wheat and a central facility has been established where 1536 cultivars can be genotyped with 142 available markers in two to three days, with USD 0.09 per data point including DNA extraction, and are highly consistent with results from PCR markers.

About 100 markers are routinely used in parental characterization and advanced lines confirmation in our programme. Around 15 crosses are performed per year for the molecular marker-assisted programme, focused on quality improvement, and six cultivars such as Zhongmai 1062, Zhongmai 578 and Jimai 23, have been released in the last three years. The key points include that we needed excellent knowledge of breeding parents, both phenotype and genotype information, single cross or limited backcross, large population size of 500–600 plants for backcross. More importantly, it needs to be fully integrated with the conventional breeding programme with combination of field selection and quality evaluation.

Parallel session: Facilitated adoption of improved varieties by small-scale farmers

4.6 Keynote: Improving the low level and rates of adoption of improved varieties in the developing world

Ian Barker
International Potato Center, Lima, Peru

Smallholder farmers, especially women and disadvantaged groups, are particularly vulnerable to climate-related and other challenges, which compromises their ability to meet their own food, nutrition and income needs and much less to contribute to local and national food security. Due to inadequate seed supply and delivery systems, misaligned with user and market demand, smallholders use "old" varieties or recycle seed, and are thus not "reaping" the benefits from modern plant breeding and leaving them more vulnerable to a changing climate. Productivity varies by gender, with these challenges disproportionately affecting women. With increasing population and climate pressure, inclusive and climate-smart sustainable intensification of food production is urgently needed to deliver in key areas – nutrition, poverty, gender, climate and environment – and the second Sustainable Development Goal: Zero Hunger by 2030.

New improved varieties (alongside traditional varieties and underutilized crops), have the potential to transform agrifood systems and reduce yield gaps, "hunger months" and other disparities. However, a number of bottlenecks remain which limit access to and use of affordable, quality seed of well-adapted varieties with desired traits (Bänziger, Jones and Barker, 2021) and adoption remains low in many instances (Walker *et al.*, 2014). Achieving this requires an enabling policy environment to incentivize varietal turnover and quality seed use (Spielman and Smale, 2017) and integrating and leveraging formal and farmer-based seed delivery systems to the benefit of all.

The presentation featured four case studies, featuring women farmers, seed entrepreneurs and development practitioners, and highlighting some key aspects needed to improve varietal adoption, and which need to be addressed on a much wider scale and for a broader "basket" of crops.

In three drought-prone states in India, new drought-tolerant maize hybrids, originating from a public–private breeding programme, were very extensively tested ("on-farm") to gauge the acceptance of these new innovations amongst smallholder farmers, including women and other disadvantaged groups before deciding which hybrids to launch commercially through local seed companies. One women's farmer producer organization (FPO) in Madhya Pradesh, who had been part of this early testing, later became part of the seed production chain.

In eastern Africa, a number of, originally, maize seed companies and farmer producer organizations (including women headed businesses) took on the additional production and sale of improved varieties of common bean originating and licensed from public national breeding programmes. Production and sale of this seed was underpinned by demand from new regional bean markets and in some cases credit- and extension-linked supply of seed to smallholder farmers and thus "de-risking" these new enterprises.

Involving local legal practitioners in supporting seed companies to better understand and "navigate" new regional harmonized variety registration schemes (such as the Common Market for Eastern and Southern Africa [COMESA] scheme) resulted in the cross-border registration of 30 varieties of seven crops in east and southern Africa. This contributes to the lowering of the "cost of business", the implementation of appropriate seed policies and ultimately to increasing choice and access to seeds.

Lastly, the adoption of new seed multiplication technologies such as potato rooted-apical cuttings can lower the cost of seed production and make seed enterprises more profitable and attractive to new entrants including women entrepreneurs.

Functioning seed systems and new seed-embedded technology will help drive the adoption of improved varieties to build future resilience, improve nutrition and livelihoods for smallholder farmers.

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4.7 Development of nutrient-efficient rice varieties on small-scale farms in Madagascar

Matthias Wissuwa
Japan International Research Center for Agricultural Sciences (JIRCAS)

Most lowland rice in Madagascar is grown on highly weathered soils without any mineral fertilizer inputs and yields are consequently low at just below 3 t/ha for the national average. Deficiency of phosphate rather than nitrogen appears to be the main limiting factor under these conditions. We set out to develop rice varieties specifically adapted to such low-input lowland environments.

Our strategy relied on i) selecting donors with known tolerance to phosphate deficiency in crosses with the high-yielding modern rice variety IR64, and ii) conducting breeding operations in low-input farmers' fields instead of research stations. Selection in target environments of around 3 t/ha led to the recent release of two new varieties, FyVary 32 and FyVary 85, having yield increases of 16–21 percent over parent IR64, and of 12–16 percent over the local recommended variety. Remarkably, the yield advantage was not limited to low-input conditions, but varieties responded well to higher soil fertility and fertilizer application.

On-farm selection could potentially facilitate adoption of new varieties by small-scale farmers, as feedback by involved farmers was obtained regularly and considered in the selection process. Similarly, having conducted organoleptic tests in villages with grower-consumers avoided a possible divergence of grower and consumer preferences. Combining tolerance of low soil fertility with responsiveness to fertilizers would allow for intensification strategies without the need to change varieties. We are exploring options of bundling the new varieties with microdosing and more high-input intensification strategies with project partners to sustainably raise yield levels for smallholder farmers.

4.8 Facilitated adoption of improved varieties by small-scale farmers: Policy reforms to incentivize adoption

Peter Okoth Mbogo
Seedco Maize Breeding Station, Kitale, Kenya

Favourable policies and legal processes are critical in stimulating the creation of new improved crop varieties, as well as supporting an efficient seed supply chain that delivers high-quality seed which fulfils the needs of farmers and consumers.

The World Farmers' Organization (WFO) developed a farmers' consultation between February and April 2021 to explore and collect farmers' needs, constraints and expectations around new improved plant varieties and to promote a farmer-driven approach to innovation in this field. Results from a sample of 50 respondents in 30 countries in five continents showed that farmers look at new improved plant varieties with an innovation lens to ensure better yields, economic stability of the farms and resilience over shocks, making farming easier and less labour/input intensive. They also perceive the adoption of the new varieties as the key to tackling the challenges of climate change and the sustainability of food systems, ensuring drought tolerance, better pests and disease management. Furthermore, the adoption of improved varieties is vital to developing trust in farming activities with financial partners and insurance companies because of the assurance of excellent yields, nutrition and safety.

Policymakers including farmers, regulators, seed business actors, scientists, legislators have expectations on the adoption of new improved varieties, which include the following:

1. access to seeds in terms of availability and affordability;
2. access to training, information and knowledge on new improved plant varieties;
3. the need for an enabling and supportive regulatory environment in tandem with country legal requirements that support innovation and scientific framework in accessing new varieties;
4. consumers' education to build trust around new varieties;
5. partnership with stakeholders in the value chain to ensure farmers' expectations and needs are met; and
6. building a cooperation framework that benefits all the actors involved.

Policy issues that require intervention to incentivize the adoption of new improved varieties include:

1. Harmonization of seed laws and regulations. Accelerating the implementation of the seed harmonization regulations and implementation framework will minimize the time taken to test and release a variety. The absence of harmonization means that each time a variety is introduced in a new country, it must undergo three to four years of testing. This delays commercialization, is expensive for seed companies and is a bottleneck to variety adoption and turnover. The requirement of national performance trials, distinctness, uniformity and stability (DUS) and value for cultivation and use (VCU) is a challenge. VCU is a challenge because some traits are environment-dependent and therefore cannot be objectively assessed, they are labour-intensive, and sometimes fail to account for farmer-preferred traits, and this hampers adoption. Genetic fingerprinting and molecular markers, which are faster, more accurate and sometimes cheaper, can be used to minimize delays in achieving DUS standards. Integrating breeder's data and one year's national performance trials data could be used for decision-making to fast-track the release process.

2. It is critical to strengthen agribusiness sustainability by assisting in the unlocking

of private investment and applying evidence-based advocacy for government policies that can assist farmers in improving market access. Farmers will seek improved varieties with preferred traits and high yields resulting in higher earnings if they know they will be able to sell their produce and make a profit.

3. Many farmers will learn about the enhanced varieties and their benefits because of improved agricultural extension practices, training and innovative product promotion strategies, resulting in increased adoption.

4. Funding climate-resilient agriculture policy is critical in adoption. For example, in Kenya, Agricultural Finance Corporation (AFC) should be well funded and run professionally to be able to give loans to farmers to fund the farming activities of the new improved varieties with the hope of repayment upon harvest and sale of their produce.

5. Crop insurance firms should be encouraged to insure farmers who are testing out new products. The farmer would be compensated if the products fail. Farmers, on the other hand, will accept these new varieties if they are successful.

6. Affirmative action, gender transformative-responsive policies and programmes should be embraced. For example, a preferential award of a certain percentage of tenders in each government ministry to businesses owned by women, youth and persons with disabilities to take charge of their own destiny in addressing their food security needs and problems. Studies have shown that women play a key role in agriculture in Africa.

7. Enact consistent policies on new products developed through the latest plant breeding technologies to enable their use and seed production technologies targeting small-scale farmers. For example, Seed Production Technology for Africa (SPTA) is a CGIAR male sterility project that aims to strengthen the capacity of small and medium seed companies to produce high-quality hybrid maize more efficiently, in a timely manner, and at a reduced cost.

8. Adoption and implementation of business-friendly seed trade policies and regulations to accelerate seed movement. Multiple clearances required by and through government agencies cause delays across borders.

9. Strengthening national and regional frameworks on curbing the illicit seed trade, including tracking technologies and stiffer penalty and redress systems.

10. Policy reforms to allow for certification of private seed production inspectors to complement the role of regulatory staff who could be overwhelmed during crop inspection procedures. This complimentary arrangement ensures the new product pipeline connects with the farmer promptly.

In conclusion, good policy reforms accelerate the delivery of innovation and enable seed adoption to remain a contributor to solutions that address farmer and consumer needs; promote the benefits of quality seed as the foundation of sustainable agriculture value chains, since poor-quality seed discourages adoption; promote the efficient movement of quality seed to continue to deliver benefits to smallholder farmers; encourages and supports fair and sustainable business models; rewards plant breeders through demand-led breeding (breeding as a business) and mitigates climate change interventions by developing climate-smart varieties.

4.9 Role of cooperatives in adoption of new crop varieties

Rinaldo Gosparini
Santa Rosa Semillas Cooperative, Rosario, Argentina

The Cooperativa de Provisión de Servicios Agrícolas Criadero Santa Rosa Limitada began its activities in 1983 as the R&D department of the Federación Argentina de Cooperativas Agrarias, one of the two biggest second-degree cooperatives in Argentina at the time. Today, Santa Rosa is a second-degree cooperative that not only includes cooperatives but other private companies on its equity.

In the beginning it started working with maize but three years later it adopted soybean as the main crop in the breeding programme and has maintained its focus until now. Santa Rosa has been working since then with a couple of foreign introductions of parentals, but its work is mainly dominated by regional germplasm (and maturity groups) that nowadays offer soybean varieties that are perfectly adapted to the southern hemisphere in two continents, Africa and (Latin) America. The goal of this project was to provide farmers, owners of the first-degree cooperatives that make up Santa Rosa, with seeds, offering them adapted genetic, quality and friendly commercial conditions that allow them to protect the production, their farms, since the seed.

With the passing of time, the goals moved from a national to an international breeding programme, always focused on soybean but with high technology incorporated in its germplasm (traits). What has never changed was its philosophy – to provide farmers associated to the cooperatives with good genetic, seed quality, friendly commercial conditions and now, the latest technology available in the world into the germplasm, including new breeding techniques such as gene editing through its participation in the Bioheuris company (gene discovery and gene editing to decrease the use of herbicides) and its projects with the Agronomy Faculty, National University of Rosario.

To introduce the varieties to the farmers associated to the cooperative (or not) in all the territories, we have four different teams. One of these is in charge of statistical trials. Another is dedicated to the characterization of the products. The third one is the closer team to the farmers, using all the information generated in the other steps to show them how to use the varieties on their farms to increase yields into a sustainable production matrix. The last team working on the line is the marketing team, helping the others in showing the results of the trials and the opportunities the farmers have by using the varieties obtained from the germplasm of the cooperative.

4.10 Role of quality seed in improving rice yields: A case study

Rakesh Kumar Singh
International Center for Biosaline Agriculture, Dubai, the United Arab Emirates

Quality seed is the utmost important single factor amongst all to boost the crop yield by 15–20 percent. Other factors like crop management cannot be undermined to increase productivity but just absence of quality seed, despite good crop management, can make output significantly less viable. Therefore, the first emphasis should be given to the quality seeds to achieve higher yields in any crop. Major advantages of use of quality seed to the farmers are resource saving because less seed is needed per unit cropped area due to higher germination percentage and healthy seedlings; uniform plant stand throughout cropping season hence uniform maturity; good market price due to genetic purity because of minimum or no-mixture; less numbers of off-types, and better plant stand due to no-missing hills.

The major issue is: How often do farmers replace the saved seed by the good quality seed? The sooner the old-saved seed is replaced by the certified quality seed, the better is the productivity in the farmers' field. Seed replacement rate is directly proportionate to the yield improvement in the farmers' field. Invariably, seed replacement rate is much higher for cross-pollinated crops or hybrid crops comparing to self-pollinated crops like rice and wheat due to obvious reasons. Seed replacement rate is also much lower in Africa than major rice growing countries in Asia. Low seed replacement rate is not always linked with affordability or lack of knowledge but also due to availability and accessibility in many cases. It is imperative to increase the seed replacement rate through congenial policy intervention at the government policy level through increased availability, affordability and accessibility of quality seeds to boost crop productivity that can contribute significantly to the country's food security.

Every single good quality seed is a "pack of technology" that signifies the contribution of different ancestral landraces in the genetic background for the important trait-combinations. A good example of quality seed is an IRRI line IR72046-B-R-3-3-3-1 that was released as 'CR405' rice variety by the Central Rice Research Institute (CRRI) in Cuttack, Odisha, India. This variety had built-in tolerance to salinity stress along with good yielding ability. The quality seed of this variety was made available to the farmers of Ersama Block in Jagatsinghpur district of Odisha, which was a very poor district and mostly monocropped with rice in the wet season.

Before the joint IRRI–CRRI project intervention, farmers of the area were unable to grow any crop during the dry season due to high salinity. Unfortunately, there was no good quality seed of any salinity tolerant variety in the area. The existing local varieties and landraces were very poor yielders as they did not have enough tolerance to withstand salinity stress and most were poor quality seed from the farmer's own saved seed stock or from neighbouring farmers.

Once the project started in Ersama block, the foremost critical intervention in the block was the introduction of quality rice seed of variety CR405. This proved to be a turning point and the rice cropping in the whole block in the dry season started increasing drastically. By 2009, the rice area during the dry season increased by more than 450 percent compared to 2003–2004 (the time of project inception). The improved variety not only increased the average yield from 2.0–2.5 t/ha (local variety Khandagiri) to over 5.5 t/ha (CR405), but also improved the social status of the small and marginal resource poor farmers.

Once farmers of the Ersama block got the confidence in good quality seed of the rice variety, they started applying inputs in the fields as per the recommended agronomical practices. Otherwise, there were hardly any farmers who used to apply inputs in the fields because of "no guarantee" of crop survival during the dry season.

Quality seeds alone gave enough confidence to the farmers to apply inputs in the fields for better and ensured returns. Governments should promote policies which are conducive to promote high seed replacement rate, as quality seed is one of the catalysts of higher productivity and ultimately to sustain food security (SDG2, SDG1).

4.11 Report of outcomes from the two parallel sessions dedicated to the theme of crop varietal development and adoption

Emmanuel Okogbenin
African Agricultural Technology Foundation, Nairobi, Kenya

Two parallel sessions were dedicated to the theme of "Crop varietal development and adoption". The first session, entitled "Accelerating genetic gains in crops", was co-chaired by Emmanuel Okogbenin and Idah Sithole Niang and supported by the rapporteurs Ikhide Imumorin and Oluwole Fatunbi. There were five presentations (by Barbara Wells, Sylvester Oikeh, Elcio Perpetuo Guimaraes, Maria Andrade and Zhonghu He) and a panel discussion (with Seungho Cho, Vivienne Anthony, Mark Laing, Lorena Basso and Gigi Manicad) moderated by Humberto Gómez Paniagua.

The second session, entitled "Facilitated adoption of improved varieties by small-scale farmers", was co-chaired by Maryke Labuschagne and Maria Andrade and supported by the rapporteurs Daniel Kyalo Willy and Julius Pyton Sserumaga. It included five presentations (by Ian Barker, Matthias Wissuwa, Peter Okoth Mbogo, Rinaldo Gosparini and Rakesh Kumar Singh) and concluded with a panel discussion (comprising Tania López Lee, Peter Button, Rasheed Sulaiman V, Dominic Glover, Ousmane Ndiaye and Stella Salvo) facilitated by Martin Ekvad.

The key messages from the parallel session on "Accelerating genetic gain in crops" were:

- Agriculture keeps facing new and complex challenges, but breeding pace is slower than required to make desirable rapid progress.
- Genetic gain must align with other enabling factors to meet the needs of farmers in producing crops that best meets the demands of the market.
- Successful cases of breeding must essentially incorporate farmers' desired traits and that success must be evidence-based and verifiably measured by indicators that ensure farmers' needs are being met.
- The opposition against genetic modification is affecting the dissemination of genetic modification technologies that offer great potential in mitigating limitations not adequately addressed by conventional breeding approaches.
- The combined exploration of different breeding techniques, including both conventional technologies and biotechnology, can deliver useful products to different users to meet diversified needs in the marketplace.
- Strong public–private partnerships are needed to stimulate private sector actors' engagement in seed production and marketing for good impact of seed on end users.
- Support for small and medium scale enterprises through partnerships with the public sector is fundamental to building strong capacity for breeding and seed systems development.
- There is a need to integrate and factor useful data from small and medium scale enterprises and Indigenous Peoples in the decision-making system at national, regional and global levels to efficiently address SDG challenges.
- The central question is: What should be the trait content of the variety that will address the multidimensional challenges facing the end users?
- Transformation is not taking place fast enough to guarantee and ensure that the impact of genetic gain gets down to farmers/end users who need it.

Key messages from the parallel session on "Facilitated adoption of improved varieties by small-scale farmers" were anchored on three fundamental questions which were critical to comprehensively understand the full dimensions of the issues involved and proffering well-analysed and informed actions to address the issues. The questions and the accompanying key messages that emanated from the session are as follows:

1. What do farmers look for while evaluating new innovations before adoption?

- Prioritize innovations that can deliver better yields, economic stability and resilience over climatic and biotic shocks while making farming easier and less labour/input intensive.
- In addition to excellent yields, innovations should also address nutrition and safety needs to build trust of financial partners and insurance companies in commercial agriculture.
- Innovations should strengthen confidence in seed quality and catalyse the application of other inputs and complementary management practices to boost and maximize productivity, yields and farmers livelihoods.

2. What are the critical drivers in the successful deployment and adoption of new varieties to farmers?

- Breeding programmes should be supported by comprehensive market intelligence to identify farmer- and consumer-preferred attributes.
- The use of quality seeds helps to boost yields with the following added advantages:
    - less seed quantity is needed for planting arising from high seed germination percentage with good establishment of healthy seedlings;
    - uniform plant stand and development throughout the cropping season hence uniform maturity;
    - good market price due to less admixture; and
    - low level of off-types.
- The farmer cooperative model should be adopted and promoted as had been successfully applied in Argentina for 38 years to consistently offer farmers quality seeds (including those for products emanating from new plant breeding techniques, such as gene editing) that possess genetic improvement and better local adaptation that suits friendly commercial production system.
- Stakeholders in the seed sector are demanding improved policies and regulations that could help boost availability and affordability of seeds, catalyse innovation and research towards the development, testing and release of new varieties, promote capacity building in breeding programmes and seed industry, and to create increased end user/consumer education/awareness on improved seeds and products.

3. What are the priority policy interventions that are needed to boost the adoption of new seed varieties?

- Congenial policy and regulatory interventions that boost availability and affordability of quality seed that can drastically reduce or eliminate the use of farmer-saved seeds.
- Accelerate the implementation of seed harmonization regulations and implementation framework.
- Make agricultural markets operationally efficient and more accessible to eliminate market failures and guarantee substantial return on investment for farmers.
- Facilitate growth of agricultural finance and insurance to boost farmers resilience and their engagement in testing and adoption of new varieties.
- Boost quality control in seed production through policy reforms to allow for certification of private seed production inspectors to complement public sector personnel.
- Policies to improve variety turnover to rapidly respond to emerging market needs and new opportunities.
- Stimulate the public sector to take up investments in areas the private sector considers very risky.

Conclusion

The intensification of crop varietal improvement for genetic gain is a fundamental pillar to the attainment of greener, sustainable agricultural development and global food security especially in the context of rapid climate change. Collaboration between players from the private and public sectors in the seed value chain, and between nations through multilateral cooperation via international treaties, agreements and instruments was deemed integral to resilient food systems.

5. PARALLEL SESSIONS: SEED SYSTEMS

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Parallel session: System innovations in the seed value chain

5.1 Keynote: Seed systems: Their importance and policy challenges

Niels Louwaars
Plantum, the Netherlands

Seed is a critical input for all crop production. The qualities of seeds such as germination capacity and seed health determine a good start of a crop. The genetics embedded in the seed are critical for both yield and yield stability, and for consumption and market values of the produce. This also makes seed an agent for innovation which is a key target of this conference. Having seed, including both true seeds and vegetative planting materials, available at the right time, quantity, quality and price is a concern for all farmers. Breeding is an essential tool for innovations towards changing environments and market demands, and thus for food security and rural livelihoods. Genetic resources and technologies, discussed in themes 1 and 2 of this conference, provide important inputs to the breeder's work. Seed is then the agent to transfer such innovations (new varieties) to the farmer.

A reliable farmers' access to seed is an important challenge. Traditionally, farm-saved and locally shared seed have been, and for several crops still are, the most important source of seed in practice. However, climate change and demographic developments put pressure on the sustainability of such informal systems. Farmer-focused formal seed systems can be much more resilient and thus have a better capacity to respond in such quickly changing conditions. Supporting the emergence and further development of such "green seed industry" options is therefore the theme of this conference.

Different operators have different opportunities to serve farmers well. The strategy of developing large-scale public seed enterprises, for which FAO gave a major thrust in the 1960s and 1970s, has been left in most countries in favour of a more diverse private sector. Private seed supply is by definition farmer/customer-focused as adoption by farmers drives the chain from sales, through production and quality controls to investments in breeding and technology development.

When the public seed enterprises were dissolved, in some countries, multinational companies took over; in others, investments in companies at the national level were stimulated, and more recently an additional focus developed to also support farmer groups and cooperatives to specialize in the production and sales of quality seeds locally. Depending on the country and the capacity of these different enterprises, some of these will naturally focus on hybrid maize or vegetables, and others on other commercial and local crop seeds. Some will focus on reproducing varieties from public breeding; others will have their own national or international breeding programmes. Together with the local seed systems that will continue to be relevant for several crop seeds, the creation of a diversified market-oriented and thus farmer-focused seed sector is a major step towards enhancing seed choice and securing availability of good seed for farmers, too many of whom still use food grain to plant their crops. The use of such formal seed systems will also maximize the roles of seeds in innovating agricultural systems for food security and improving rural livelihoods.

Such an approach of diversified seed systems that best serve the needs of farmers for their different crops and farming systems does however create challenges for policymakers. A one-size-fits-all approach will not do the job. Policies to stimulate different types of enterprises have to be carefully designed to support the diversity of actors in the seed value chains. One may think of appropriate institutions and rules to secure seed quality (full certification next to quality declared or other), to streamline the roles of public and private breeding so that they do not unnecessarily compete with each other, of variety registration systems and the protection of plant varieties serving a broad choice for farmers, and also fiscal and credit stimuli for start-up enterprises. In addition, seed choice of farmers can also be supported by effective international seed trade, which requires regional or global alignment of seed rules and standards and well-designed phytosanitary systems. International institutions such as the OECD Seed Schemes, ISTA and UPOV provide important tools for this. Designing such diverse policy components for integrated seed sector development with different private sectors side by side, including local cooperatives next to nationally and internationally operating companies, is more complex than for the blueprint solutions that have been designed in the past, and that some countries have found difficult to implement.

The current "Seed Systems" theme brings together a diversity of speakers that will discuss this. The theme concentrates on the two key elements: seed quality management and their institutions, and on ways to stimulate seed enterprise development across the globe.

All farmers need good seed, irrespective of their farming systems and the markets that they focus on. The private seed sectors have an increasingly important role to play.

5.2 A success story of India: Telangana State as global seed hub

Keshavulu Kunusoth
Telangana State Seed and Organic Certification Authority, Hyderabad, India

Achieving food sufficiency has long been an Indian concern. From the late 1940s to the 1960s, India faced challenges for increasing food production. These challenges were addressed mainly with the Green Revolution which brought systematic initiatives for breeding productive high yielding varieties of staple crops. However, this necessitated the availability of improved varieties within well-established seed systems.

Further, the national agricultural research systems that started breeding improved cultivars necessitated institutional support with establishment of the National Seeds Corporation (public company) to provide for seed multiplication and certification, established the State Farms Corporation of India, seeds development corporations (public companies), seed certification agencies, seed testing laboratories, and seed production units for seed multiplication and distribution. These organizations were growth drivers for the promotion of public and private seed sectors where growers could introduce improved varieties and provide farmers access to quality seed.

In parallel, the government framed seed policies, laws and regulations through the seeds act, seed (control) order and national seed policies amongst others to regulate varietal development, seed multiplication, and marketing including mandatory labelling/volunteer certification. These aimed to provide access to best quality seed and strengthen the seed sector. Further, to encourage seed companies in the seed market, the industrial policies permitted foreign investors and liberalized seed trade. Consequently, food production increased from 82.02 million tonnes in 1960–61 to 308.65 million tonnes in 2020–21.

Seed production systems

The Indian seed production system comprises breeder, foundation and certified/labelled seed. This provides adequate safeguards for quality assurance and maintenance of varietal purity as seed flows from breeding institutes to farmers.

The Indian seed industry has grown immensely during the last three decades. Formal seed production systems, consisting of the public and private sectors, have evolved from a predominantly public sector into a multifaceted industry with a large involvement of private firms to meet both domestic and international needs. However, informal systems, which are broadly farm-saved seed and farmer-to-farmer exchange, community groups, seed growers, NGOs etc, continue to operate at the community level and provide a significant percentage of overall seed requirements. Ultimately, mixed seed systems that include both formal and informal sectors assist access to improved seed.

The Government of India has been supporting seed sector development including strengthening of quality assurance laboratories and their capacities and capabilities. The regulatory frameworks implemented for seed systems have resulted in strengthening of the formal, informal and integrated seed sectors, resulting in expanded access to quality seed and increased food security. Combined, the public sector and private industry have together laid the strong foundations for the Indian seed sector.

Telangana State towards global seed hub

Telangana is India's youngest state, with an agriculture-based economy where agricultural crop production has grown hugely from 20.7 million tonnes in 2014–15 to 38.3 million tonnes in 2020–21. A key mandate is to promote comprehensive seed systems to accelerate agricultural productivity growth, promote transformative structural changes and create an enabling environment to ensure farmers' access to quality seed. The state has adopted proactive seed policies, regulations, capacities, integration of seed systems, investment support for farmers, so as to ensure that farmers benefited from improved seeds and also to provide new emerging seed markets. At the same time, improved cooperation with OECD and ISTA to verify seed purity and quality has enhanced international trade.

Telangana has a congenial semi-arid climate that provides a cool and dry weather all year round with three cropping seasons, a professional industry with skilled human resources, strong research, expanding infrastructure and advanced logistical facilities for quality seed multiplication and storage. Farmers have transitioned to seed growers, seed entrepreneurs and communities transformed to "seed villages".

The Telangana seed industry also combines both public and private seed companies. The public sector contributes to plant breeding, early and later generation seed multiplication. To provide quality seed to rural farmers, the provincial department of agriculture has undertaken seed supply system and business skills development through seed villages. The private sector includes more than 400 companies of varying size that are involved in plant breeding, seed multiplication and marketing within stringent regulations. Farmers' cooperative societies are also taking on seed multiplication and increasing farmers' income and quality seed supply. The seed industry is supported by a digitized State Seed Certification Authority for domestic and international certification and ISTA laboratories to verify seed quality.

The Telangana seed sector combines critical strengths with better logistical connectivity and contributes more than 50 percent of India's seed requirements and seed exports. Transformations have taken place by creating an organized seed sector enabling the introduction of improved seeds and advanced technologies including genetically modified crops.

Hyderabad, Telangana has become the seed capital of India by adopting diverse seed systems with continuous innovations within the regulatory frameworks enabling movement of seeds, creating enduring partnerships across the seed value chain and promoting seed exports. Together, these activities are moving Telangana State towards becoming a global seed hub that plays a pivotal role in sustainable agriculture.

Conclusions

Seed sector development in Telangana has identified potential actions and strategies that enable farmers in food-insecure regions increased access to quality seeds:

- Adoption of flexible approaches and effective seed systems including formal, informal and mixed sectors, translated into food productivity enhancements in farmers' fields with adoption of improved seeds.
- Seed production systems, within an enabling environment of effective seed policies, laws and regulations throughout the value chain have enhanced access for small-scale farmers to quality seeds of food security crops.
- An objective of this Conference on Green Development of Seed Industries is to promote cooperation between sectors. The example from India is that supporting infrastructure, partnerships and education and the participation of both public and private seed actors through enabling policies and flexible seed systems can strengthen the seed value chain.

5.3 Seed quality for sustainability in Latin America

Enriqueta Molina
Santamarina and Steta Law Firm, Mexico

Agriculture faces different challenges: ensuring food and goods that are sufficient, healthy, nutritious and affordable for a growing population. According to FAO, it will be necessary to increase our food production by 70 percent to meet the needs of the global population, expected to be 9 billion in 2050. Agricultural production includes food, ornamental crops, fibres, biofuels, medicinal and other bioproducts, which satisfy market demands and represent important opportunities for development.

Growing more food with less land, water and resources, with an ageing crisis in farming and enabling improvement of the livelihood of the rural sector, requires innovation, efficiency and sustainability. To achieve these goals, seed is a key factor, as the origin of production and a means of technology.

Seed is essential for sustainability, in particular for small farmers and family farming. Seed encloses identity, quality, health and productivity. Seed is the source of genes and diversity for selection and breeding, for competitiveness, adaptation to climate change, and crop resilience. At least 50 percent of the agricultural production depends on the seed (in addition to agricultural practices and environmental conditions).

But that is not all. Seed is a cultural heritage and it is essential to achieve resilient and sustainable communities. For this reason, public policies should recognize the value of seeds, and encompass the different seed systems.

Considering the different elements and kinds of agriculture, including the seed value chain, there is an interaction and coexistence between the conservation and sustainable use of plant genetic resources, new plant varieties as a result of selection and breeding, and seed production and their corresponding regulations and international agreements (Convention on Biological Diversity, International Treaty on Plant Genetic Resources for Food and Agriculture, Nagoya Protocol, and the International Union for the Protection of New Varieties of Plants).

The potential of plant genetic resources for food and agriculture in Latin America is huge. It contains 50 percent of the world's biological diversity and some of the megadiverse countries, like Brazil, Colombia, Ecuador, Mexico and Peru. There is also an important cultural diversity, with more than 800 Indigenous Peoples' communities. Local seeds selected by farmers and adapted by the response to the growing conditions are an important mechanism to preserve diversity and face the climate change.

Usually, farmers select their own seed according to health and productive characteristics in the field, in addition to cultural criteria. Sometimes their surplus seeds are sold locally or exchanged in regional fairs or networks. However, these seeds are rarely tested to identify their quality, and it may not always be possible to have good storage conditions.

Operation of community seed banks is an appreciated strategy to enhance diversity, assure seed conservation, and promote collaboration and regional organization. Furthermore, it is more likely to have minimal quality analysis.

On the other hand, plant breeding is an important approach to achieve better productivity, as well as other valuable features, such as yields, resistance to drought, pests or diseases, nutritional value, earliness, among other agronomic characteristics.

One important strategy is participatory plant breeding, which allows a close link and cooperation between researchers and farmers, taking advantage of the knowledge and experience of each of them to resolve particular issues, preserving diversity and local adaptation.

In general, breeding results are transferred through certified seeds. The purpose of seed certification is to guarantee the identity of plant varieties, as well as the quality of seed: genetic (purity, identity), physical (free of damages, inert matter), physiological (viability) and phytosanitary (absence of pest or disease agents). This procedure requires the description of plant varieties to get their registration, as well as the verification of specific standards across field inspection, conditioning and cleaning practices, laboratory testing and labelling.

Seed certification scheme requires uniformity, and local seeds of traditional varieties or landraces are often heterogeneous, because of their high genetic diversity. For this reason, some countries are assessing ad hoc approaches for more flexibility in the registration process, in order to incorporate "formal" systems.

Local seeds usually are not forbidden, but neither mentioned in seed laws. For this reason, it is important to integrate both systems, as complementary, in regulations and public policies, with a comprehensive and strategic vision to recognize their relevance and provide proper schemes and support programmes for both, to overcome inequalities.

In Mexico, around 30 percent of maize was sowed with certified seeds. Landraces are very important for biodiversity and according to local uses and customs. There are some issues with ´traditional' seeds, such as conservation in suitable conditions, collection, movement, storage, testing, marketing, among others. However, the particular characteristics of this kind of maize add value and imply the development of niche markets.

Whether seeds are selected or exchanged by farmers, or acquired through a producer, distributor or marketer of seeds, both spheres are part of the seed system, and must be analysed in a comprehensive manner with differentiated policies and not isolated, and much less opposed.

Ultimately, the most important point is to ensure that farmers have access, according to their socioeconomic, agroecological, technological and productive conditions, to quality seeds in order to achieve more resilience of crops and communities.

5.4 Different quality control systems in one regulatory frame

Bellah Mpofu
Feed the Future Southern Africa Seed Trade Project, Zambia

The basic purpose of seed legislation and its subsequent enforcement is to regulate the quality of seed sold to farmers. Seed certification is a quality control process that ensures genetic purity and identity of certified seed sold, through generation control, inspection and labelling. It is designed to protect farmers from poor quality seed. However, it raises the cost of seed to farmers as it can keep small operators out which often reduces access to seed. In addition, it is also costly for governments to manage.

Consequently, some African countries also allow the sale of seed that is produced less rigorously and is relatively cheaper such as quality declared seed (QDS) or standard grade seed, in their legislation. This may assist emerging seed companies to establish their businesses and serve niche markets which may not require certified seed.

The QDS system is based on four principal points:

a) A list of varieties eligible to be produced as QDS is established.

b) Seed producers must register with the national seed authority.

c) The national seed authority will check at least 10 percent of the seed crops.

d) The national seed authority will check at least 10 percent of the QDS seed offered for sale.

QDS facilitates local seed production initiatives, which have advantages for many of the staple small grain crops. These crops often present problems for seed supply because the premium, which can be charged for seed over the grain price, is limited by the option of farm-saved seed.

QDS provides an opportunity to accommodate the diversity of farming systems, particularly in the more marginal areas where highly organized seed systems do not function well. Countries that recognize QDS include Zambia and Uganda.

Instead of QDS, Zimbabwe has standard grade seed. This is a class of seed that only meets the minimum germination and purity requirements stipulated in the seed regulations, thus its genetic purity cannot be guaranteed. Seed certification is mandatory for crops of commercial importance (maize, soybean, tobacco, cotton, wheat, barley, oats and potatoes). For these crops, it is illegal to sell standard grade seed.

Although seed certification is the most common system in Africa, it is expensive for small producers unless subsidized. Challenges include inadequacy of early generation seed, prevalence of fake seed in the market and use of retained seed by farmers in self-pollinating varieties is common. A further challenge is the inadequacy of technical capacity, infrastructure, equipment and mobility within the regulatory authorities.

In addition, many African countries have incorporated regional harmonized seed regulatory systems in their regulatory frameworks to facilitate seed trade within regional blocs. A handful of countries are affiliated to international seed bodies such as the Seed Schemes of the OECD and ISTA and produce and test seed destined for export according to the rules. However, it is important in such cases to allow the use of local protocols and seed certificates by seed companies whose niche markets end within the national boundaries.

It is important for seed regulatory frameworks to provide options in terms of quality assurance mechanisms that protect consumers in cost-effective ways. Permitting the production of quality declared or standard grade seed may assist emerging seed companies to establish their seed businesses and serve niche markets (e.g. pulses and local vegetables) which may not require certified seed. Decentralized certification with accreditation and private licensing arrangement for inspections, sampling and testing should be encouraged. Even in countries that have affiliation to regional and international seed bodies, it is important to make provision for local certification. This is mostly because local certification is a less costly option.

5.5 Quality seed production systems

Ali Üstün
Economic Cooperation Organization Seed Association (ECOSA), Ankara, Türkiye

For quality and standard plant production, one of the essential prerequisites is the supply of high-quality seeds to producers. One of the most important barriers to getting quality seeds is the lack of, or insufficient, quality seed systems. The importance of high-quality systems was recognized about 100 years ago and some institutions or organizations such as UPOV, ISTA and ISF were set up at the international level. Currently, any country which seeks to have a quality seed production system can work with these institutions. In other words, a quality seed system means having international standards of seed production, marketing and trade within the country and between countries. Another way to put this into words, these standards for quality seed production systems guarantee seed quality. When seed quality is ensured, then seed trade within the country or between countries becomes easy.

The issues related to quality of seeds start from plant breeding activities up to growers or producers. However, the base or core of seed quality lies in registration of varieties and seed certification in any country. Registration and certification protects breeders, farmers and consumers, and also contributes to food safety. The duration of all activities from germplasm to planting by farmers in crops and vegetables might need 16 to 18 generations. In other words, if only a normal growing season was utilized, it means that 16 to 18 years are needed. In this long process, inspection, measurements and observations must be performed to verify the seed quality officially in registration and certification phases but unofficially in the breeding stage. Quality considerations in plant breeding are not the focus of this brief presentation. We assume that genotypic and physical quality was assured in the plant breeding stage. I will focus on registration and its relation to seed certification for quality seed production systems.

After a candidate variety is obtained, the next step is the official registration of the variety/hybrid. When registration was suggested, its aims were to protect farmers from low-quality seeds in order to avoid yield and quality losses, maintain production levels in the country, and assign an identity to genotypes to be used in plant production. After the 1970s, another aim was added related to new varieties/hybrids which is to protect new varieties from illegal use.

The registration process may differ from country to country. Thus, there is no one identical registration system in all countries. However, countries who follow UPOV guidelines have almost the same system in basic principles. Registration for all plants needs a proper distinctness, uniformity and stability (DUS) system. Distinctness is the core of plant breeders' rights. In legal disagreements on application of plant breeders' rights, the DUS test, in general, and distinctness, in particular, are main tools to solve cases.

Based on crops and vegetables, there are two main registration systems. Only DUS tests are needed for vegetables. DUS and value for cultivation and use (VCU) evaluations are the basis of registration in crops. There might be two reasons for this difference: variety life in vegetables and ornamentals is very short and varieties for these plants are preferred not for their VCU but appearance, shape, colour, smell, and so on. Crops have a high economic and social impact on society and, for this reason, VCU is the official and essential part of registration.

Updates and improvement of registration and DUS tests are prepared and published by UPOV. It is very useful for any country to be a member of UPOV to make use of varieties/hybrids in other countries. However, in order to complete UPOV membership, ISTA accreditation and membership to the OECD Seed Schemes can be very beneficial for any country due to meeting some standards required for UPOV and OECD membership and ISTA accreditation. All the requirements or standards are intended to have high quality in seeds.

The EU Common Catalogue of varieties of agricultural plant species was set up using UPOV guidelines, ISTA rules and OECD standards in seed production. When seed production is done under the OECD Seed Schemes and gets the OECD certificate, it is guaranteed that accuracy of the name of the variety/hybrid, genetic and physical properties of the variety/hybrid is assured. International trade of seeds can be facilitated very quickly and easily, and safe marketing can be accomplished.

The number of countries involved with UPOV, ISTA and the OECD Seed Schemes is not very high. There are countries which do not know how to get membership to UPOV and the OECD Seed Schemes and ISTA accreditation, although they would like to have these features. There are also countries that are lacking educated and experienced staff to set up the systems. There are countries where they need not only educated and experienced staff but also infrastructure such as necessary laboratories. FAO, ISF and Regional Seed Unions can have undeniable roles to help, advize and supervize these countries. When we reach this target, we are much more safe for the quality of seeds. When we consider the dates of UPOV, ISTA and OECD Seed Schemes, we realize that governments or states had much more involvement in seed business in the past compared to today. In the last 50 to 60 years, the private sector has been more involved in the seed business with every passing year. For this reason, representatives of the private seed sector such as ISF and regional seed associations should have more official voice in decision-making bodies of these organizations.

5.6 Seed authenticity: Consequences of counterfeit seed in the market and innovative remedies

Duncan Ochieng' Onduu
Seed Trade Association of Kenya, Nairobi, Kenya

Counterfeit seed is seed which has not gone through the certification process by the Kenya Plant Health Inspectorate Service (KEPHIS), the regulatory body in Kenya also known as the "Service" as per the Seeds and Plant Varieties Act cap 326. The certification process ensures that seed has met quality standards after undergoing field inspections and laboratory tests. The drivers of counterfeit seed include inadequate integrity and innovation of the packaging materials and difficulty in identification of counterfeit seed. It is a lucrative business where unscrupulous persons take advantage of shortage of supply of desired seed, popular brands and subsidy programmes sometimes implemented by governments and NGOs.

Consequences of counterfeit seed

Counterfeit seed has adverse effects in the country, the major effect being loss of productivity. Planting counterfeit seeds can lead to poor or lack of germination. Uncertified seed has not undergone germination tests by KEPHIS to assure the seed of good germination coupled with good agronomic practice. It can also lead to reduced yield because uncertified seed is not high yielding and has more insect and disease problems. Farmers lose their investment when they lose the crop due to poor performance on account of the counterfeit seed. This would subsequently affect their ability to plough money back into their business. Planting counterfeit seed makes it difficult to track the source of seed especially if seed was not bought at an agrodealer shop.

The Seed Trade Association of Kenya is an association of Kenyan seed companies and organizations registered to produce, process and/or distribute seed as well as play other supportive roles to agriculture. It aims to promote the interests of seed enterprises through the use of quality seed and it works in partnership with KEPHIS. To avert the use of counterfeit seed, the Seed Trade Association of Kenya in partnership with the Ministry of Agriculture and KEPHIS collaborated to come up with the seed sticker label. This label was introduced in 2017 as an anti-counterfeit measure and the law makes it compulsory for all certified seed sold in packets of 2 kg and below to have the label affixed on the packet.

How the seed sticker label works

A farmer scratches a 12-digit series code and sends it to 1393 at no cost. This can be done through a smartphone or a basic phone. If seed is certified, the farmer will receive the following feedback on variety name, weight, species, lot number, class and testing date. If not, the farmer will receive feedback that the seed may not be genuine. There is a toll-free number where farmers can call to make such a report and it is recorded for action.

Seed labels performance

According to a study commissioned by The African Seed Access Index (TASAI) in 2017, the seed sticker labels have increased seed companies' confidence in the fight against counterfeit seed, from 39 percent in 2013 to 72 percent in 2017 as a direct result of the seed labels. As at 2020, 50 million labels have been sold to seed companies. A study commissioned by the Seed Trade Association of Kenya across eight counties showed that the level of awareness of the labels ranged from 65 percent to 100 percent with an average of 85 percent. However, the level of utilization of the seed label was significantly lower at an average of 35 percent. The study recommended increasing awareness of the use of the seed sticker labels through agrodealers and use of the media to convey the message to farmers on the benefits on the use of seed sticker labels.

Challenges

Farmers have become familiar with the labels thus they do not scratch. They are also loyal to the brands they are used to, thus they see no need in scratching. Another challenge is the non-deterrent penalties to offenders found counterfeiting seed. KEPHIS has joined forces with the Anti-Counterfeit Authority to punish offenders. The ability to jointly prosecute offenders means those found guilty may be charged with additional violations of the Anti-Counterfeiting Act, which increases total fines from the current maximum of USD 10 000 to about USD 30 000.

Way forward

The Seed Trade Association of Kenya is playing a lead role in partnership with other actors like KEPHIS, the Anti-Counterfeit Authority, the Judicial Service and the Kenya Police in the fight to eradicate counterfeit seed. There is need for continuous sensitization of farmers on the value of scratching. There is also need to lobby for stiffer penalties for offenders to act as a deterrent.

5.7 The contribution of seed treatment to green innovation of plant production

Tim Loeffler
Seed Vigor Consulting LLC, the United States of America

Seed treatments continue to provide significant contributions to plant production with recent innovations focused on green agriculture plant production strategies. Seed treatment refers to the exposure of seeds to physical, chemical or biological agents to control or reduce the influence of diseases, insects, nematodes and/or stresses during germination and stand establishment.

The goals of seed treatments include increasing plant production and crop yield, improving land use and carbon sequestration, and reducing impact on environment. Some recent innovations involve advancements in seed sanitation to disinfect seeds, introduction of microplastic-free polymers, biostimulants to reduce plant stress, organic seed priming and many others. New innovations related to seed treatments will continue to be a major contributor toward meeting green initiatives and will involve large growers to small landholders. There is a clear commitment among seed industry partners (seed and crop protection companies, regulatory agencies and universities) to deliver green development initiatives.

Parallel session: Seed enterprise development and international trade

5.8 Government incentives for seed business development – Nigeria

Okelola Folarin Sunday
National Agricultural Seeds Council, Abuja, Nigeria

The main objective of any dynamic and responsive seed system is to deliver quality seed of high-yielding varieties to farmers at the right time, place, quantity and an affordable price for increased productivity. This task requires adequate and strategic steps that will strengthen the seed system. However, government efforts to increase farmers' accessibility to quality seed have not yielded the expected results, as farmers are still producing below expected productivity due to utilization of seeds of low quality or farmer saved seed.

This situation has attracted many efforts from the Nigerian Government to create a domestic policy, legal and institutional environment that will increase the crop yield per hectare which will match the yields found in other developed nations. This paper, therefore, attempts to review the evolution of the Nigerian seed industry and efforts embarked upon by government to develop the industry, with a view of assessing the progress of the industry associated to the incentives.

Available records revealed that the first attempt of seed business development in Nigeria dated back to 1975 with the establishment of the National Seeds Service as a unit under the Federal Ministry of Agriculture and Rural Development. Although several actions and transformations were reported during this period, the seed business development situation still needed more interventions.

The current dispensation of the industry was traced to 2007 when full implementation of Act 72 of 1992 led to the creation of the National Agricultural Seeds Council as a full parastatal of the Federal Ministry of Agriculture that was saddled, amongst others, with the responsibility of coordinating all seed-related matters in the country. The review of the impediments to the growth of the industry during this period led the government to introduce additional initiatives aimed at incentivizing the seed business development of the nation and trigger the recent growth experienced in the seed industry of the country.

The strategies identified and discussed include creation of an enabling seed business environment through introduction of right policies, laws and regulations; unbundling access to financial services for seed system development; provision of support to ensure access to quality early generation seed through accreditation and encouragement of private players; decentralization of the seed quality assurance system; massive educational enlightenment, sensitization and conduct of market raids to curb seed faking and deployment of modern molecular tools for diagnostic certification and DNA fingerprinting.

A game changer was the introduction of the electronic seed quality assurance and tracking tool called SEEDCODEX which complements the statutory seed certification tags to give farmers more confidence in the seeds they buy from seed dealer shops and choke out unscrupulous seed merchants from further exploiting farmers by sale of poor-quality seeds. In addition, the signing into law of the Plant Variety Protection Act in 2021 is creating a new courage for private investment into the Nigerian seed business space.

Each strategy was discussed before it was concluded that, although the Nigerian seed industry has recorded tremendous growth in the recent time, it has not reached the peak of the destination in terms of seed business development. It was then recommended that more investment by the public and private sector will help the seed industry to get to the desired destination.

5.9 Government incentives for seed business development in China

Jikun Huang
China Center for Agricultural Policy, Peking University, China

China's seed industry has significantly contributed to agricultural productivity growth and food security. For example, the yields of newly released crop varieties such as rice, wheat and maize have steadily increased since the early 1980s. For three major cereals, the current adoption rates of modern varieties all exceed 96 percent, which is largely due to its own strong seed R&D system. Meantime, the improved lines and other genetic resources from international sources, particularly CIMMYT and IRRI, have also contributed to the breeding programme and yield frontier of major cereals in China. The public R&D system has played an important role in generating new varieties for hundreds of millions of small farms in the past, but private sector has been rising rapidly. For example, the number of seed companies with more than RMB 100 million (or about USD 15 million) asset increased from 243 in 2013 to 386 in 2019.

The rapid seed sector expansion has been closely associated with the evolution of seed development policies in China in the past. The public sector, the government research institutes and universities, were nearly the only source of seed varieties released to farmers by the late 1990s. In order to develop a modern seed sector to promote private sector to engage in seed business, China decreed its first Seed Law in 2010, right after it joined UPOV (1978) in 1999. Seed varieties with higher yields generated by both public and private sectors increased rapidly in the 2010s. To facilitate seed market development and modernize seed industry, China implemented several major policies in 2011–2013, including the efforts to move commercial breeding programmes from public to seed companies, focus the public sector on basic and applied basic R&D, and integrate the public and private sectors through market. Meantime, China has also tried to consolidate seed companies by raising the entry threshold. While these policies have important implications for the seed industry, the implementation is partially successful.

With the experience of seed policy reform in the 2000s and early 2010s, China made a big effort to relax variety approval requirement and meantime to enhance plant variety protection in the middle 2010s. Major policies include the green channel for big companies for obtaining their plant variety protection and relaxing the variety approval procedure for all seed companies in the end of 2014 and modifying the Seed Law in 2016. The modified Seed Law enhances plant variety protection for all crops despite the coverage of crops required for variety approval procedure being reduced from 28 crops to 5 crops. In sum, the policy changes have two major impacts: improving plant variety protection for all crops and increasing the number of newly released varieties.

Despite the rapid development of China's seed industry in the past, China now is also facing several challenges. The rapid rising number of seed varieties and huge number of seed companies have pros and cons. While competition has been rising as indicated by the falling profit of seed business and huge number of seed companies, R&D expenditure by the major seed companies stagnated recently. The impact of increasing efforts to protect intellectual property rights is evidenced, but it is still a challenge to have significant change under UPOV 1978. In addition, despite great efforts that have been made to integrate public and private sectors, the actual progress is not very encouraging.

In dealing with the above challenges, China's Government has initiated its National Seed Industry Revitalization Initiative since 2020. Major efforts include reinforcing intellectual property rights in general and plant variety protection in particular, investing in the innovations of seed industry from the conservation and utilization of germplasm resources all the way to downstream breeding and seed production, expanding supports from mainly cereals in the past to horticulture, livestock and fishery, and enhancing policy supports for integrating public and private sectors. The above effects are expected to have significant impacts on moderating China's seed industry in the coming decade. In addition, more efforts to make clear division of public and private roles in seed R&D and business, further enhancing international exchange of seed and genetic resources, and joining UPOV 1991 may further contribute to China's National Seed Industry Revitalization in the future.

5.10 Seed sector development for resilience: Finding formal seed solutions in an informal world

Shaun Ferris
Catholic Relief Services, East Africa Regional Office, Nairobi, Kenya

This presentation draws on a study in Uganda that reviewed the main seed sectors including formal, semi-formal, informal and emergency-based seed systems (Longley *et al.*, 2021). The findings showed that most farmers in Uganda continue to access seeds through a combination of these seed channels.

Whilst hybrid seeds for maize and vegetables varieties are accessed through formal seed systems, most smallholder farmers access non-hybrid seeds, for self-pollinating and vegetatively propagated crops, through home saved seeds and local informal markets. Whilst most countries aim to develop robust formal seed systems to provide farmers with quality seed, in many cases, governments, humanitarian and development agencies buy or procure certified seed and provide this to vulnerable farmers through various free seed channels. Although seed subsidy programmes may be successful in the short run, in enabling farmers to access seed, there is little evidence to show that free seed programmes, such as direct distributions or seed fairs, lead to long-term business relations between seed input suppliers and farmers when the free seed programme ends.

This talk will review the effects of recurrent subsidized seed delivery on the formal commercial seed sector in Uganda, where decades of free seed disbursements have led to a situation where it is thought that 30–50 percent of the commercially available seed is of low quality, expired or counterfeit seed. To address the degradation of free seed on the formal seed markets and associated early generation seed systems, agencies such as Catholic Relief Services are developing more sustainable and resilient ways of enabling farmers to access quality seed of non-hybrid seeds at affordable prices by establishing improved business links between seed companies and farmers. These methods are supported by innovative financing systems, and last-mile delivery agents. These methods aim to support both sustainable and scalable business models.

There is increasing evidence that countries with high levels of free seed in their seed supply systems are struggling to improve their commercial seed markets. The policy environment is not always supportive of innovation in seed systems, and procurement systems used by humanitarian agencies may be contributing to poor performance in the commercial seed markets. More needs to be done to develop seed systems that enable more farmers to access quality seed, and this requires better coordination and use of best practices by humanitarian and development agencies alongside new approaches with the government and private sector.

Reference

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5.11 Plant variety protection: A sustainable policy for the development of seed business

Nguyen Thanh Minh
Vietnam Seed Support Service Center, Hanoi, Viet Nam

Viet Nam is an agricultural country within which the crop production sector contributes from 64 to 68 percent of the total value of agricultural output. Recently, Viet Nam has become a big food and agriculture exporter. Of the top ten agriproducts exported, seven are crop products. Good-quality seed plays an indispensable role in crop production. Without sufficiently high quantities of quality seeds, food security cannot be assured.

Agriculture is a key economic sector in Viet Nam. Aware of the importance of seed to the development of the agricultural sector, Viet Nam has established many policies in relation to all aspects of seed production and trading.

Prior to 1986, seed production and distribution was subsidized by the government. All seed companies were state organizations. At that time, three grades of seed – foundation seed, basic seed and certified seed – were produced at different levels: nationally, at provincial and at district levels. The state provided certified seed free of charge to all agriculture cooperatives in the country. However, seed production was only sufficient to meet the needs of some provinces, and mainly for rice, not for other crops.

Due to national economic difficulties, such subsidies were no longer made available and in 1986, the Vietnamese Government decided to transform the economy from a subsidy-based model to a market economy, including various economic sectors. Hence, the private sector emerged in Viet Nam as some small companies were established.

In this new context, the development of the seed business sector required a legal framework, and appropriate government policies. We subsequently implemented many policies related to such matters as seed price support, land use, tax, credit supply and so forth. But today I want to mention in particular the plant variety protection (PVP) policy that promoted the development of the seed business sector in a sustainable and stable manner in Vietnam.

Plant variety protection encourages the breeding and introduction of new plant varieties. The PVP system was established in Viet Nam in 2004. In 2006, Viet Nam joined the UPOV Convention. I will now present evidence of the impact of PVP on the development of the seed business sector in Viet Nam. The number of applications for PVP in Viet Nam has been increasing since the PVP system was established. Especially after we became an UPOV member in 2006, applications rapidly increased. In recent years, we received around 250 applications per annum, many for new plant species. Thus, an exciting seed market, not only relating mainly to rice and maize as previously, but also including a great variety of vegetables, flowers, fruit crops and medicinal plants, is now actively trading in Viet Nam.

The private sector is developing new varieties and growing the size of their R&D facilities since the PVP system was established. Before 2006, almost all seed companies were traders only. Since the PVP policy was enacted, they were licensed to exploit plant breeders' rights and, more recently, they are developing their breeding facilities through their own investment, with many becoming big corporations with excellent breeding capacity. Those designated techno-scientific enterprises are recognized by the Ministry of Science and Technology as companies with good breeding facilities. The process from plant breeding to the production of a new variety is highly specialized. The PVP policy is also supporting the effective marketing of seed in the country. The private sector has grown in strength and now contributes vitally to the realization of government policies. The sector plays an important role in the linkage of "farmer, manager, scientist & entrepreneur", facilitating implementation of the major agriculture policies of the government.

The role of PVP in the development of the seed business sector encourages mobilization of human resources to engage in the breeding and introduction of the new varieties. Nowadays, plant breeders in Viet Nam include farmers and other individuals. In recent years, many companies from sectors other than agriculture have invested in R&D to produce new varieties, including companies in the pharmacy, finance, construction and property sectors. The number of significant new varieties emerging from the private sector is often higher than from the public sector, enabling the government to divert its finances to serve alternate vital purposes.

Many new plant varieties are bred and discovered from wild species, in the process not only developing valuable products for the consumer, but also contributing to the conservation of plant genetic resources in the country. This is significant in the context of the decline of genetic resources through the impact of factors such as climate change, urbanization and industrialization in Viet Nam.

In order to enhance the seed business sector's capacity to promote the development of the agriculture sector, the Vietnamese Government has issued policies related to incentivizing seed business development, in particular two key policies:

- Seed Program (2020–2030): this mainly aims to increase the percentage of those using certified seed in crop production areas for the main crops, to strengthen R&D capacity, as well as improving the seed trading system.
- IP Strategy (2020–2030): this aims to increase PVP applications in Viet Nam by 12–14 percent per annum. In addition, government incentives for seed business development are not limited to the country but also extend to the global market through encouraging 10–12 percent of Viet Nam's applications to be filed in other countries. To encourage Vietnamese applicants to file overseas – as well as facilitating foreigners' applications in Viet Nam – joining the PVP region of Viet Nam is mentioned in the IP Strategy.

5.12 Embracing market-based approaches to development: The East-West Seed Story

Lysette T. Lacambra
East-West Seed Knowledge Transfer Foundation, Chiang Mai, Thailand

Farmers are powerful market actors, but they are often neglected in the agricultural value chain. East-West Seed is bringing them into the value chain, spurring the creation and development of sustainable markets. For almost 40 years, the company has lived by its mission to provide seed and service innovations. Seeing the vast potential in smallholder farmers – and recognizing their need for quality seeds and enhanced agronomic knowledge in order to gain a competitive position in the markets – East-West Seed has supported intensive training programs as an essential core of its business model for many years. To move these precommercial activities beyond the company and to ensure that they are most effectively geared towards benefitting smallholder farmers, the company created East-West Seed Knowledge Transfer Foundation (EWS-KT). It is an independently funded and managed non-profit initiative that currently operates in nine countries in Asia and Africa.

EWS-KT collaborates with like-minded organizations through public–private partnerships. These collaborations catalyse and foster market creation and local economic development. Not only do the additional financial resources from these partnerships enable EWS-KT to scale its outreach, but synergies with these partners deepen the impact of EWS-KT's work by bringing skills and experience in such areas as health and nutrition, financial literacy, microfinance, post-harvest handling, information technology applications and platforms, and connections to downstream buyers and consumers.

EWS-KT's knowledge transfer approaches are mainly field-based and face-to-face activities, including setting up strategic demonstration fields to showcase simple but effective agronomic practices, conducting practical training of farmers, and providing farmers with technical support and monitoring during the whole cropping season. Through this intensive training, EWS-KT aims to reach 100 000 farmers per year. To aid in the training, EWS-KT has produced a series of training modules and extension materials with Wageningen University and Research. These aids were tested with local communities before being released and are currently available in up to 36 local languages. They are distributed as printed handouts or can be accessed through EWS-KT's online learning platform, GrowHow.

GrowHow is just one of EWS-KT's digital initiatives, which also include social media, radio programmes, and SMS texting. Through these platforms, EWS-KT was able to reach more than 1.3 million farmers in 2020. EWS-KT also trains farmer advisors and agricultural-input dealers as a strategy to reach more farmers in the community and assist in training mobilization. Farmer advisors serve as liaisons between farmers and the technical field staff and are especially vital for increasing women farmers' engagement. Partnership with, and capacity building of, agro-input dealers ensures availability of quality farm inputs and more accurate technical support to farmers on fertilization and crop protection.

Knowledge is a valuable tool to initiate market creation. High-quality seeds must be coupled with excellent and reliable advice to enable farmers to achieve the maximum benefit from the genetic gains of improved vegetable varieties. When equipped with more effective agricultural practices, the growers produce bigger yields and earn higher profits, which sets the stage for long-term market development. Successful and profitable crop cycles serve to position vegetable production as an attractive and viable livelihood, which also creates an opportunity for youth engagement and the reduction of urban migration. As more growers adopt improved practices, they catalyse the development of competitive input markets and build a fertile environment for businesses to grow. It is in this environment that East-West Seed and other private actors can be more effective in developing new markets and supporting rural economic development.

5.13 Phyto-sanitary: New approaches on phytosanitary controls to support cross-border seed trade

Rose Souza Richards
International Seed Federation, Switzerland

Seed is often seen as an important risk factor for the introduction and spread of pests. It is important to take into consideration that only for a limited number of pests, seed is a pathway for transmission of a pest. However, many countries regulate several pests without conclusive scientific evidence of seed to seedling transmission in natural conditions.

Breeding, production, processing and sale of seeds occurs all over the world, driven by factors such as climate conditions, logistics, processing location and sales country. Seed lots may be stored for several years and repeatedly re-exported to multiple destination countries. Each time the seeds move from one country to another, phytosanitary documents are needed and today, this has become very challenging. Different countries have different import requirements which are not harmonized and can even be conflicting. Already at the time of seed production, companies must know to which countries the seed will eventually be sold (possibly via re-export) so that the field inspections required by the countries of sales can be compiled and included in the phytosanitary documents. This makes planning in a seed company very complex as it is not always known beforehand where a seed lot may be sold.

Seed trade is growing rapidly. At the same time, many countries are defining new, not harmonized and more specific phytosanitary requirements for seeds. Risk avoidance is an important factor driving new regulations. The increase in trade as well as in phytosanitary requirements results in a high degree of complexity to move seed around the globe. Further, it increasingly strains the limited National Plant Protection Organization (NPPO) resources. In the long run, the seed industry foresees that the current phytosanitary system is not sustainable. There is a need for simplification and harmonization of the current system to ship seed internationally. The international seed industry proposes an alternative solution in which seeds produced in a NPPO-approved production system can be imported and (re-)exported with a phytosanitary certificate, without the specification of individual pests.

The international seed industry and NPPOs have a shared need for a good phytosanitary system that prevents the introduction and spread of plant pests and at the same time enables global trade in a fast business model. The seed industry strives for recognition of the practices that are currently used to ensure the production of healthy seeds. Seed companies already have many procedures in place to prevent infection/infestation of seeds with known seed-transmitted pests.

In the current phytosanitary system, phytosanitary measures are always targeted in a taxonomically unequivocal way to specific harmful organisms. This results from the fact that their evaluation needs to be based on a time-consuming pest risk assessment. As the number of pests and the number of risk assessments are very large, the number and variation in phytosanitary measures is also very large which hampers global trade of seeds. The international seed industry proposes that in the systems approach, measures are not to be based on individual pests but on the pathways of introduction and spread of pests into a seed production site. Although there may be many different pests, there are relatively few pathways of introduction. Mitigation measures for a particular target pest also effectively protect against similar pests in each pathway category.

The multilateral systems approach framework for seed that is envisioned is based on an evaluation of the risk posed by relevant pests to enter a seed production. The evaluation is based on an analysis of the pathway of entry of pests into a seed production system. Relevant pests are those pests where seed has been identified to be a pathway for introduction and spread of the pest under natural field conditions.

The international seed industry strives for global harmonization via implementation of a multilateral agreement based on a sufficiently clear systems approach for seeds. These systems can be built up gradually and evolve from only a few participating countries in the beginning to global acceptance in time.

5.14 Seed policy and regional harmonization

Justin Rakotoarisaona
African Seed Trade Association, Nairobi, Kenya

Seed is a major technology transfer in agriculture and it links conservation, cultivation, production, consumption, trade of agricultural inputs and produce. Building an effective seed system is essential to successful agricultural transformation, diversification, intensification and inclusive market growth. Many factors contribute to how seed systems function and create opportunities. Seed policy guides government action and define roles of seed stakeholders in a seed system in order to elaborate priority interventions to address challenges in a seed sector and exploit opportunities for improved performance with a view to ensuring availability and access to safe and high-quality seed to all stakeholders for increased food security and economic growth.

The ability of a regulatory framework to facilitate delivery of high-quality seeds to farmers depend upon both legal and institutional factors and how gaps in these systems are identified and addressed. While having good laws and solid regulations is a critical step in developing a seeds system, these measures are only as effective as their implementation on the ground.

The liberalization of the seed sector in Africa paved the way for the involvement of the private sector in the seed activities (research, production and marketing) with a view to improving seed supply to farmers and allow them to access good germplasm and new seed technologies. To do so, the private sector requires an enabling environment such as appropriate seed legislation both at national and regional levels.

Often accessing the right seeds depends upon crossing a national border as borders physically cut across agroecological zones within a region, but fragmentation of markets deters investment in seed multiplication and supply. Movement of seeds, germplasm and data across borders has been a complicated process due to the complexity of requirements by countries.

In some African countries, it can take several years to register new seed varieties in a particular country. This is often true even when the varieties are already available in neighbouring countries. Slow registration contributes to restricting farmers' access to improved seeds, and therefore further limits their ability to increase yields.

Regional harmonization of seed laws and regulations holds potential to streamline and shorten procedures for evaluating and releasing new varieties, simplify requirements and procedures for importing or exporting seeds and establish regional efforts on plant variety protection to encourage breeders to develop new crop varieties. It promotes cross-border seed trade i.e. increased seed market size justifying a significant investment in the seed sector.

The regional economic communities in Africa, such as the Economic Community of West African States (ECOWAS), the Common Market for Eastern and Southern Africa (COMESA), the East African Community (EAC) and the Southern African Development Community (SADC) regions, have all adopted harmonized seed regulations to promote cross-border seed trade and recently the Commission of the African Union adopted the African Continental Free Trade Area (AfCFTA) of which seed regulations are an integrated part.

Numerous efforts have been made to implement harmonized regional seed regulations in Africa to increase agricultural productivity and regional economies. However, efforts of all seed stakeholders are required to overcome various challenges such as lack of capacity of the member states and the absence of vibrant private seed sector in some countries in Africa. Indeed, although regional harmonization efforts endeavour to unify national seed legal and regulatory regimes, the actual process of changing national systems to reflect regional rules takes a significant amount of time, and a number of discrepancies between regional and national systems still exist. Further, while national governments are increasingly seeking to take the interests of seed growers and companies into account and engage them in putting in place systems that can both ensure quality of seeds, further change in national level legal and regulatory systems will be required to bring the private sector into the process as regional harmonization efforts move forward. However, when seed markets cut across a greater number of countries, the enabling environment tends to become more complex.

In conclusion, seed policy and harmonization are a long process that requires the cooperation of all the seed stakeholders in order to create and/or maintain a conducive environment for seed activities with a view to appropriately serving the farming community that is responsible for producing food for the fast-growing population in Africa.

5.15 Report of outcomes from the two parallel sessions dedicated to the theme of seed systems

Keshavulu Kunusoth[1] and Niels Louwaars[2]
[1] *Telangana State Seed and Organic Certification Authority, India*
[2] *Plantum, the Netherlands*

Two parallel sessions were dedicated to the theme of "Seed systems". The first session, entitled "System innovations in the seed value chain", was co-chaired by Martin Ekvad and Alison Powell and supported by the rapporteurs Csaba Gaspar and Andreas Wais. There were seven presentations (by Niels Louwaars, Keshavulu Kunusoth, Enriqueta Molina, Bellah Mpofu, Ali Üstün, Duncan Ochieng' Onduu and Tim Loeffler) followed by a discussion moderated by the co-chairs where the presenters responded to questions from participants posted in the chatbox.

The second session, entitled "Seed enterprise development and international trade", was co-chaired by Keshavulu Kunusoth and Shaun Ferris and supported by the rapporteurs Catherine Langat and Hélène Khan Niazi. It included seven presentations (by Okelola Folarin Sunday, Jikun Huang, Shaun Ferris, Nguyen Thanh Minh, Lysette T. Lacambra, Rose Souza Richards and Justin Rakotoarisaona) and concluded with a panel discussion (with Kristiina Digryte, Francois Burgaud, Kanokwan Chodchoey and Tsungai Bwerazuva) facilitated by Niels Louwaars.

The overall summary report for the theme of seed systems is as follows:

Any adoption of effective seed systems must respond to country needs and include formal, informal and integrated approaches. This must translate into resilience and productivity of crops in farmers' fields with high adoption of improved seed. Improved seed includes seed of high-quality varieties adapted to climate change and productivity and consumption quality for a growing population. Improvements may also be achieved by selective seed treatments.

Seed systems, within an enabling environment of effective seed policies, laws and regulations throughout the value chain, have to enable (small-scale) farmers the access to quality seeds for food security and farmers to secure and develop their families and their communities.

In order to transform seed systems into effective, responsive and dynamic suppliers of seed for farming systems, appropriate solutions that provide choices for farmers to enable them to respond to changing farming conditions and market requirements, a diverse seed sector, with multiple players that multiply and distribute quality seed, bred locally or internationally, underpinned by explicit seed-focused economic policies, is required. The system will need innovations in seed production and certification, processing, storage and post-harvest quality assurance combined with appropriate policy support through the seed value chain to guarantee a sustainable seed sector.

International seed trade is critical to providing farmers with choice of seeds with some of the best genetics and should be enabled by regionally and globally aligned policies that promote access to quality seed options by farmers through resilient and diversified seed systems. Such policies should include measures to stimulate seed business development and to guarantee the long-term funding for public breeding and human resource development. Regulatory measures that provide the necessary services to the seed sector should guarantee seed health and quality, varietal identity, access to technology and well-balanced rights of farmers, breeders and nations in relation to seeds and genetic resources. Functional and efficient institutional measures to make sure that rules are implemented in impartial and cost-effective ways adapted to the needs of the operators in the seed chains should underpin the system.

No matter which seed systems are in place, knowledge of seed quality components such as purity, other seeds, moisture, seed health and germination are eminent for the farmer. To obtain reliable information on seed quality, correct methods for sampling seed and for analysis have to be followed. The International Seed Testing Association delivers those methods within a system of accredited laboratories and sampling entities where competence is verified.

Outside the area of farm saved and locally exchanged seed, national control of seed production is important to ensure that the seed bags contain the seed of the variety which the farmer intended to buy and there are no mix-ups or contaminations during seed multiplication. Thus, farmers will receive genuine seed and can fully benefit from the characteristics of the variety during crop production. The OECD Seed Schemes provide widely adopted, internationally harmonized procedures that are designed to ensure traceability through different breeding generations and the seed supply chain and ensures that both the varietal identity and the varietal purity of varieties are maintained and safeguarded.

6. HIGH-LEVEL MINISTERIAL SEGMENT AND CLOSING PLENARY SESSION

*Participants at the High-level Ministerial Segment and Closing Plenary Session.
From left to right, top row: Beth Bechdol, Thomas Vilsack, Zhang Taolin and Marije Beens;
bottom row: Jorge Solmi, Julian Jaftha, Mohamed Ali Fahim and Jingyuan Xia.*

6.1 Statement by Thomas Vilsack

Secretary of Agriculture, United States Department of Agriculture (USDA), the United States of America

- I would like to thank FAO for hosting this event on such an important topic.

- People deserve access to a variety of high-quality foods that they trust, and which also meet their nutritional, health and cultural needs. Plants are an essential component of our diets and our food systems.

- And that is why investments in plant breeding are critical to USDA's efforts. We know that plant breeding is one of agriculture's most effective tools for adapting to new circumstances, including ever-increasing challenges of droughts and floods, temperature increases, pest and disease pressure, just to name a few. Plant breeding is also needed to improve nutritional value.

- USDA recognizes that breeding investments need to be complemented by research in agronomy, economics and social science. Breeding is only one component of a system. For new varieties to contribute to sustainable agriculture, their use needs to be informed by other research, such as research on soil management practices, market information and appropriate storage. Complementary technologies, practices and data are needed for benefits of breeding to be realized by growers, consumers and the environment.

- USDA also invests in new genetic tools and methods to increase the efficiency of breeding and to support faster and more precise development of new varieties that can address food system challenges. Genome editing is a great example of this.

- Genome editing offers great potential for helping to meet our shared goals of building resilient food systems while reducing the environmental impacts of agriculture. It will be an essential tool for both adapting to and mitigating climate change.

- Researchers are developing seeds that increase carbon sequestration in agricultural systems, seeds that lower the need for inputs that contribute to climate change, seeds that improve shelf life of products to reduce food waste, and seeds that are adapted to changing environmental conditions.

- With new breeding technologies, like genome editing, new traits can be developed more easily, with greater precision, more quickly and at a lower cost. These efficiencies have enabled small companies to carve out new areas for innovation. They're developing niche traits in agricultural sectors that have not been able to benefit from genetic engineering to date, such as specialty crops, locally adapted cultivars, underutilized crops, and forestry.

- These innovative technologies, when combined with three decades of experience, allow us to develop new solutions, promote safety across our food systems, and increase the options available for our consumers.

- However, innovation depends on more than research and science, it also depends on investments and good regulatory frameworks. In particular, we must recognize the importance of intellectual property rights for spurring innovation, including the development of new seeds.

- For this, reason I encourage countries around the world to join the International Union for the Protection of New Plant Varieties 1991 agreement.

- I also encourage countries to join the International Treaty on Plant Genetic Resources for Food and Agriculture. USDA continues to work with other countries to seek improvements to the Treaty such as expanding the list of crops covered to promote further conservation and sustainable use of diverse plant genetics. This is critical for food security and mitigating climate change.

- Access to genetic resources and new tools allows us to move forward, and we need to move forward if we seek to attain greater sustainability and resiliency with the limited natural resources available.

- We know there is huge demand for climate adaption in agriculture, but also enormous opportunities for mitigation – through scaling of practices that sequester carbon, and through adoption of new technologies and tools.

- That's why, the United States and the United Arab Emirates began the Agriculture Innovation Mission for Climate, or AIM for Climate, which will be launched at the 2021 UN Climate Change Conference (COP26) in November.

- This is a landmark initiative to accelerate global agricultural innovation through increased investment in research and development, leading to innovative, science-based solutions to help agriculture mitigate and adapt to climate change.

- Investments in climate-smart agriculture and food systems innovation can enhance existing approaches and deliver new ways to sustainably increase agricultural productivity, improve livelihoods, conserve nature and biodiversity, and adapt and build resilience to climate change, to reducing greenhouse gas emissions, and sequestering carbon.

- Our hope is that, together, AIM for Climate partners will mobilize new investment – targeted in the billions of dollars – in climate-smart agriculture and food systems innovation, and create incentives and mechanisms for maximizing impact for positive outcomes amid a changing climate.

- I am also urging interested parties to join the Coalition of Action for Sustainable Productivity Growth for Food Security and Resource Conservation.

- Announced at the UN Food Systems Summit, the Coalition will accelerate the transition to more sustainable food systems through productivity growth that optimizes agricultural sustainability across social, economic and environmental dimensions.

- So, I want to thank you again for the opportunity to join you today and wish you the best of luck in the conference.

6.2 Statement by Zhang Taolin

Vice Minister, Ministry of Agriculture and Rural Affairs, the People's Republic of China

Distinguished delegates,

It's a great pleasure to join you at today's conference thanks to the invitation of Director-General Qu Dongyu. With green development of seed industries as its theme, the conference will help mobilize greater support for the seed sector worldwide and substantially contribute to global sustainable agricultural development and food security.

A small seed can change the world. As a major player in agriculture, China has a huge demand for seeds. The Chinese Government has set a priority on promotion of seed industries, which is an important approach to ensure the supply of food and other major agriproducts and drive the greening of agriculture. Through comprehensive policy measures in the past few years, China has enhanced agricultural germplasm conservation, intensified efforts on variety improvement, improved breeding systems and strengthened the rule of law in the seed market, with a view to modernizing the seed sector and ensuring farmers' access to quality seeds.

First, China has strengthened the survey and conservation of germplasm resources. Germplasm resources are the shared treasures for mankind. From 1950 to 2010, China completed two national surveys of germplasm resources, by which large quantities of germplasms were collected and preserved. In 2015, along with the publication of the National Plan for Medium and Long-term Conservation and Utilization of Agricultural Germplasms (2015–2030), the Chinese Government launched the third national survey of crop germplasms. Over the years, China's conservation system and preservation capacity for crop and livestock germplasms has undergone significant improvement.

Second, China has stepped up efforts on variety improvement. The government has strengthened the role of enterprises as main players in innovating the seed sector, facilitated joint efforts of enterprises, universities and research institutes, organized multi-institutional research programmes, and established a sound plant variety protection system. These efforts have injected a great impetus to breeders and considerably accelerated the development of new varieties. To date, six to eight generations of new varieties have been wildly adopted in China's crop farming, with 96 percent of the crop area covered by improved varieties.

Third, China has improved its seed production systems. Through the establishment of national hybrid rice and corn seed production zones and crop breeding bases, seed production in China has become more mechanized and standardized. Average production scale has expanded with an over 10 percent increase in yield. Such a notable growth in seed production capacity has ensured sufficient supply of quality seeds for food and agricultural production.

Fourth, China has strengthened the rule of law in the seed market. China has made continuous efforts to enhance plant variety protection and advance law-based governance of the seed sector, including promulgating the Regulations on the Protection of New Plant Varieties in 1997 and the Seed Law in 2000, and a subsequent amendment to the latter in 2016. The stronger regulation and law enforcement have resulted in better seed quality and greater protection for farmers' access to good seeds.

Fifth, China has deepened international cooperation and exchange. China embraces openness in developing its seed sector, and therefore has been committed to deepening cooperation and exchange and boosting trade with other countries. Through South–South cooperation and multilateral and bilateral assistance programs, China has provided superior varieties such as hybrid rice and millet for developing countries, contributing to the significant growth of their food productivity. Meanwhile, China has maintained close communication and collaboration with FAO, the International Union for the Protection of New Varieties of Plants (UPOV), the International Seed Federation (ISF) and other international organizations. For instance, the World Seed Congress 2014 was successfully held in Beijing, which greatly promoted international cooperation and exchange in the seed sector.

Over the years, many high-yield and quality varieties with multistress tolerance and good suitability for mechanization have been widely used in agricultural production. Such notable progress has significantly contributed to China's food security and supply of major agricultural products as well as to global food security. Moreover, green agricultural development has made headway in China, as evidenced by rapid transformation of production modes and the decline of agrochemical use for four consecutive years.

Ladies and gentlemen,

Climate change, natural disasters, animal and plant diseases as well as resource constraints are threatening agricultural development around the world. Projections on food security are bleak with rising world hunger in 2020. The international community should remain united in combatting these common challenges. China firmly supports FAO's initiative to strengthen international cooperation in seed industries and stands ready to work with all parties to foster green development of the sector. I hereby would like to make three proposals:

First, we need to increase institutional support to the international cooperation in the seed sector. China encourages FAO to deepen cooperation with UPOV, ISF and other international organizations, and lead the efforts on institutional building to enhance global governance of seeds and actively contribute to the development of international standards and cooperation rules in the seed sector for better conservation and utilization of global germplasm.

Second, we need to strengthen collaborative breeding at the field level. China advocates the establishment of joint labs and agricultural demonstration centres, and supports fully leveraging CGIAR and FAO Reference Centres for joint development of new varieties between member states. China is willing to highlight collaborative breeding in the South–North, South–South and Triangular Cooperation, to boost germplasm exchanges and help developing countries build technological competence in the seed sector.

Third, we need to stimulate collaboration among enterprises. One of the conference's objectives is to catalyse the growth of seed enterprises. We should fully leverage the role of seed enterprises in promoting the development of global seed industries and encourage business investment in modern breeding systems. At the same time, smallholder farmers' rights and interests should be adequately protected.

Ladies and gentlemen,

Modern seed industries are critical to food security and green agriculture. China is spurring the seed sector's growth at full steam, and keen to work with all parties to breed superior varieties, promote good practices, create sound mechanisms, develop well-facilitated farmland as well as to drive mechanization for enhanced productivity. With that, we can make a greater contribution to global food security and the 2030 Agenda for Sustainable Development.

Thank you.

6.3 Statement by Marije Beens

Director-General for Agriculture, Ministry of Agriculture, Nature and Food Quality, the Netherlands

Some years ago I met Simon Groot, who would go on to win the World Food Prize in 2019.

An experienced seedsman, Simon had noticed that smallholder farmers in the tropics were trapped in a system ruled by big money and dependencies. So, they continued using inferior seed. Simon thought of a practical – typically Dutch – solution: he distributed sample packets of tropical vegetable seeds. And then he let the seeds work their magic. The farmers who had taken the packets harvested many more courgettes and beans than their more conservative neighbours.

And this set off a small revolution, in which conservative farmers learned to expect a good crop. Now, these better seeds are embraced by farmers worldwide. Giving more people access to nutritious food. What I especially like about this company – East-West Seed – is that it has always continued to invest locally. Employees taught farmers better growing methods and ways to combat pests and diseases.

There are more Dutch companies that work like this. That want to exercise social responsibility, and team up with local people to find out what works best. Combining local knowledge and experience with the latest scientific insights.

As we all know, broad access to good-quality seed opens the way to higher yields and more stable and sustainable food production systems. Improving the lives of farming families and strengthening communities.

- This requires, first, that we have an active seed sector in which big international companies work together with small ones.
- We also need countries at the front of the pack to take responsibility, so that others can transition to more sustainable methods, too.
- And it is important to put new insights to the test right away. Preferably at local level, starting with farmers themselves. Because let us not forget that it is farmers who can help us tackle the challenges facing our food systems. They are the first to feel the lash of climate change. They know what the earth needs. And integrating their activities with the cycles of nature is part and parcel of what they do.

The Netherlands facilitates public–private partnerships in which companies – big and small – share their knowledge and technologies with the rest of the world.

We're keen to contribute to initiatives focused on sharing practical and sustainable agricultural knowledge. And we also support farmers' participation in decision-making.

We're involved in work on seed legislation, variety release, plant variety protection, phytosanitary regulations, seed import, agricultural finance, and agricultural advisory and extension services. As part of the global community we started the Inclusive Seed Systems initiative, around the time of the UN Food Systems Summit. Coincidence or not, it's very much in the spirit of East-West Seed. This initiative is aimed at exchanging knowledge, investing in education and training, creating more opportunities for farmers to obtain good-quality seed, and developing sustainable seed systems.

I hope you'll join us. Because we'll be able to achieve the UN Sustainable Development Goals faster and more efficiently if we work together.

6.4 Statement by Jorge Solmi

Secretary of Agriculture, Livestock and Fisheries, Argentina

First of all, I would like to register my gratitude for the invitation to participate in this event, which brings together actors from the governmental, private, science and civil society sectors. We are honoured to participate, given the importance of the topic on the international agrifood agenda. Unfortunately, Minister Domínguez is unable to attend this event himself, owing to pre-existing commitments; he asked me to convey his greetings and to share the following thoughts with you.

Argentina is firmly committed to promoting efficient seed production and marketing activity, with a view to assuring farmers of the identity and quality of the seeds they buy; to provide adequate protection for plant genetic creations; and to guarantee the accessibility and use of the seeds by farmers, under the balanced system of rights currently in force.

We have a national certification system that consists of an official control process carried out by inspectors from the National Seed Institute (INASE) in conjunction with accredited technical inspectors.

The National Institute of Agricultural Technology (INTA) has produced a catalogue of the varieties obtained by us and listed both in INASE and in its specific registers – the National Register of Cultivars (RNC) and the National Register of Cultivar Property (RNPC). The varieties in question are the outcome of various institutional programmes and research projects, or joint activities with businesses or other institutions through technological linkage agreements.

We align with FAO in recognizing the decisive role played by the seed industry in fulfilling the desire to improve production. In this regard, I should note that Argentina sees technology and innovation, biotechnology and the digitalization of agriculture as key to achieving sustainable productivity growth.

I cannot omit to mention the high technical standards achieved by our farmers, and their proactive incorporation of innovations and commitment to the stewardship of natural resources.

Argentina has a vigorous scientific and technical system based on the work of INTA and the National Science and Technology Council (CONICET). On the topic to be addressed at this conference, it has made important contributions in the domain of green innovation in plant production. These include developments in biotechnology for the efficient use of nutrients that make it possible to control weeds with less reliance on external inputs; and the drought resistance measures that are currently being applied in wheat and soybean cultivation, a tool specifically suited to countering climate change. I would also note here that, in the context of emerging climate change and in keeping with the commitments made in the Paris Agreement, the Argentine Republic is making steadfast progress towards carbon neutrality by 2050, in line with the commitments being made by other countries. It is now imperative that the international community (led by developed countries) take urgent steps to adopt the relevant commitments, to provide effective and appropriate means of implementation and thus enable developing countries to progress their climate actions. Our agriculture sector has also definitively adopted soil conservation techniques involving direct sowing practices, which are also linked to the incorporation of biotechnological innovations in the plant varieties of national origin that are being used.

Collaboration between the public sector and private companies, especially small and medium-sized national enterprises, is essential in this regard. The basic idea is to adapt and/or integrate both classical and modern biotechnology to confront climate challenges and use resources effectively, in the framework of food security, understood as guaranteed access to food and health care. Argentina assumes this responsibility as one of the world's leading food producers; and it puts itself forward as a major supplier of biotechnological innovations for green development.

As part of the sectoral policy that we have been developing, I would draw attention to the recent draft law on the regime for promoting federal, inclusive, sustainable and exporting agricultural bioindustry development. This legislation aims to foster increased investment and employment; boost the production and competitiveness of the various sectors that make up agricultural bioindustry chains; improve productivity and quality through greater industrialization; pursue the comprehensive use of biomass and its transformation into high value-added bioproducts; and foster the production of processed foods, agroforestry, technologies and services for agriculture, taking into account the heterogeneity that exists in the productivity and competitiveness of the different value chains and among their constituent producers.

In relation to the issue at hand, the draft law establishes the Agricultural Bioindustry Promotion System for Sustainable Production, which aims to increase agricultural production and exports and preserve the natural capital of soils, within a framework of good practices and climate change adaptation measures.

I should also mention the Law on Historical Reparation of Family Farming for the Construction of a New Rurality in Argentina. This creates the Native Seeds Production Centre (CEPROSENA), which, in collaboration with INTA and INASE, has a mission to help guarantee food security. Its objective is to register, produce and supply both native and creole seeds, in which the roles assigned reveal a commitment to strengthening green agriculture. The processes required to create the system for registration and identification of creole seeds, and implementation of the resolution on the production and commercialization of native species, are both at an advanced stage. Together with local regulations, these constitute the instrument for the defence and sustainable use of our genetic resources, in the framework of the Convention on Biological Diversity, to which Argentina is a party.

Lastly, I would point out that the Argentine National Constitution enshrines the principle of sustainable development as a criterion of harmony between production, technology and the environment; and that the doctrine of the government of which I am a member recognizes the timely defence of natural resources, the environment and human health; and it considers stewardship of our common home as the pillar of its public policies.

In a world in which alarming rates of hunger and malnutrition still persist, it is essential that we try to move forward together, to strengthen international cooperation endeavours as an indispensable tool for achieving food security and zero hunger. In this domain, I believe that FAO, as the United Nations specialized agency on food and agriculture, is called upon to make a substantial contribution and showcase its leadership role.

6.5 Statement by Julian Jaftha

Chief Director, Plant Production and Health, Department of Agriculture, Land Reform and Rural Development, South Africa

On behalf of the Honourable Thoko Didiza, Minister of Agriculture, Land Reform and Rural Development, South Africa

Programme Director,
Director-General of FAO, Dr Qu Dongyu,
Chairperson,
Honourable Ministers, Deputy Ministers,
Excellencies,
Distinguished delegates and representatives of international organizations, including the representatives from UN agencies,
Researchers, scientists and other experts in the seed industry present,
Ladies and Gentlemen.

It is indeed a pleasure to participate in this Global Conference on Green Development of Seed Industries of the FAO. We appreciate the efforts of the FAO in providing this platform for the relevant role players to engage in focused dialogues on how best to make quality seeds of preferred productive, nutritious and resilient crop varieties available to farmers.

This current event is extremely timeous as it follows the recent Food Systems Summit of the United Nations. As you are aware, the Food Systems Summit was focused on how we can leverage the power of food systems to drive the global recovery from the COVID-19 pandemic towards the attainment of all 17 Sustainable Development Goals by 2030.

The ability of our food systems to provide nutritious food in an environmentally sustainable manner is challenged by rapid population growth, increased urbanization and changes in consumption patterns. On the other hand, the current food system contributes to land degradation, loss of biodiversity (of up to 80 percent) and climate change since it contributes to one-third of greenhouse gas emissions. Thus, a system-wide approach is necessary to ensure that food production takes place in a sustainable manner. A system-wide approach requires the involvement of a range of stakeholders including governments, private sector and civil society working collaboratively across multiple sectors, different scientific and social disciplines and different knowledge systems (in particular traditional knowledge systems).

South Africa has already expressed its support for the outcome of the UN Food Systems Summit. At country level, an assessment has been undertaken to determine whether the country's food system is positioned to fulfil the 2030 Agenda for Sustainable Development and further consultations are ongoing.

South Africa has identified four strategic actions to drive our pathway towards food systems transformation. These are:

- enhancement of sustainable local production for local consumption of safe, nutritious and native foods;
- promotion of social, economic and environmental resilience;
- facilitation of inclusive, sustainable and competitive value chains; and
- promotion of integrated food systems policies, legislation, planning and governance.

Seed, as a key agricultural input, performs an important role in contributing to improved food security and nutrition, supporting the livelihoods of producers, contributing to sustainable resource use and mitigating and adapting to climate change. Access to new and improved varieties is important for improved productivity, sustainability and resilience of agricultural production.

It is encouraging that this conference considers a wide range of issues relevant to seed and seed systems, including:

- new technological developments;
- conservation and sustainable use;
- seed systems; and
- policies and governance which underpin and support the aforementioned points.

I will attempt to briefly share some experiences in some of these areas starting with a brief introduction of the seed sector in South Africa.

South Africa has a relatively well-developed seed industry, valued at approximately R 10 billion. The country exports seeds to many countries on the African continent and other parts of the world. The agronomic crop seeds account for about 73 percent of the total South African industry while horticultural crops and forage and pasture crop seed account for 18.5 percent and 7.5 percent respectively.

South Africa's seed industry was established in the 1940s. Consolidation started in 1980 with the establishment of the Association of National Seed Organisations (ANSO). However, as government decided to transfer some of its functions to the private trade, specifically seed certification, the South African National Seed Organisation (SANSOR) was formed in June 1989. Currently, some 115 seed companies are members of SANSOR.

The seed industry is regulated under the Plant Improvement Act, to ensure orderly trade in seed, focusing on registration of premises, sale, cleaning and packing of seed.

Seed certification schemes, which have the objective of making seed of superior quality available, are also provided for under the Plant Improvement Act. However, participation in seed certification is voluntary.

Seed testing started in South Africa in the late 1940s and South Africa has an Official Seed Testing Station (OSTS). The OSTS aims to ensure the physical and physiological quality of seed.

South Africa is also a member of the International Seed Testing Association as well as OECD Seed Schemes. Membership of these organizations enables South Africa to trade with many other countries in the world in terms of seed.

The country had also played a leading role in the development of the SADC Seed Regulations Harmonisation Programme. In addition to facilitating seed trade among the member countries, the Programme can also facilitate access to more productive seeds in the region.

A further development in the African Region is the African Seed and Biotechnology Programme (ASBP) which was endorsed by the African Union Assembly in 2007 as a strategic framework for the development of the seed sector in Africa. This Programme aims to provide a platform for facilitating discussion, advocacy for resource mobilization, advancing policy advice and accessing global knowledge for stakeholders in the African seed systems.

It is also known that access to new varieties is closely linked to the intellectual property rights regime in a particular territory. Breeders are likely to release their varieties into territories where there is adequate protection for such varieties. Plant variety protection in South Africa is provided for under the Plant Breeders' Rights Act which aligned to the International Union for the Protection of New Varieties of Plants. This Act has recently been amended and implementation thereof will soon proceed; the major amendment affected includes extending protection to all plant genera.

At this point, I also wish to briefly touch on the Intellectual Property Rights from Publicly Financed Research & Development Act. The object of the Act is to make provision that intellectual property emanating from publicly financed research and development is identified, protected, utilized and commercialized. The Agricultural Research Council (ARC), an entity of the Department of Agriculture, Land Reform and Rural Development, South Africa is applying this Act and the Plant Breeders' Rights Act to ensure that seed is available to farmers, while at the same time protecting their intellectual property. More specifically the Agricultural Research Council:

- sells reproductive material directly to farmers; and
- licenses private companies to multiply its seed for sales. A major focus is also on licensing smaller companies and new entrants in this space to address the dominance of major companies which often leads to concerns of monopolization of the seed system.

The Agricultural Research Council also works in partnership with Provincial Departments of Agriculture, by providing basic seed (of maize and sorghum) to **community-based seed producers**, these producers then produce and market certified seed to other community members.

As we all know, conservation and sustainable use of crop diversity is the basis of food security. With respect to global efforts to strengthen conservation and sustainable use of crop diversity, I acknowledge the recommendations from the recent eighteenth session of the Commission on Genetic Resources for Food and Agriculture (CGRFA) and, relevant to this meeting, those recommendations pertaining to capacity building on strengthening national seed systems, including plant breeding, for the delivery of diverse and high-quality seeds and planting materials, in particular to meet the needs and priorities of smallholder farmers as well as on efforts to maintain genebanks, including community seed banks, for the continued collection, conservation, characterization, evaluation and distribution of crop germplasm and associated information.

I recognize that one of the Key Actions in the 2021–23 Action Plan for the Implementation of the FAO Strategy on Mainstreaming Biodiversity across Agricultural Sectors is to facilitate policy dialogue at country or regional levels for the ratification and implementation of FAO biodiversity-related conventions, for example, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). I am pleased to announce that South Africa, as one of the few African countries who have not yet acceded to the Treaty, is in advanced stages in national processes towards obtaining necessary parliamentary approval for accession to this important instrument.

South Africa is committed to supporting its National Programme on Conservation & Sustainable Use of Plant Genetic Resources for Food & Agriculture. Through this programme, South Africa also reports on implementation of SDG Target 2.5 through the FAO World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture. This programme also extends to participatory plant breeding efforts and conservation of crop wild relatives in partnership with international institutions such as Bioversity International. Recently, the SADC Ministers responsible for Agriculture and Food Security and Fisheries and Aquaculture approved the White paper on the establishment of the SADC Crop Wild Relatives Conservation Network making this the first regional network for the *in situ* conservation of crop wild relatives in the world.

As debates continue under the Convention on Biological Diversity and its related treaties in support of biological diversity which ultimately supports food security; we maintain a key interest on developments around access and benefit-sharing (ABS) and digital sequence information (DSI). It is Africa's view that ABS and DSI are interlinked, and it is of outmost importance that processes and negotiations taking place in different national, regional and international fora, including the Post 2020 Biodiversity Framework, should prioritize coming up with solutions on benefit-sharing for the use of DSI.

Lastly, I will briefly touch on research and innovation, without which new, improved and appropriate seed varieties will not reach the farmers. South Africa is currently finalizing its Science, Technology and Innovation Decadal Plan. It aims to drive the implementation of initiatives that will see the National Science Innovation system contribute to:

- economic growth and inclusivity;
- social development and environmental sustainability; and
- the development of strong institutions.

The decadal plan includes an Agriculture Research Development & Innovation Roadmap which prioritises programmes in both crop and animal improvement to revitalize the economy, to provide technologies for large and small-scale farmers to increase competitiveness and improve livelihoods, and support GDP growth in the country. And as this plan is being finalized, it will address the important efforts in transforming the food systems, of which seeds are an important component.

Chairperson, within this short space of time, I wish to thank you for this opportunity and trust that even the outcome of this conference will contribute to the global efforts and dialogues on food systems as we recognize its power to drive the global recovery from the COVID-19 pandemic towards attaining the SDGs by 2030.

6.6 Statement by Mohamed Ali Fahim

Director, Climate Change Information Center, Egypt

On behalf of His Excellency Al Sayed Mohammed Marzouk El-Qosair, Minister for Agriculture and Land Reclamation, Egypt.

The world has witnessed a boom in the field of agricultural research leading to the achievements of production and productivity leaps. The production of selected seeds became an industry and joined patents field, they also became technological secrets for producing countries.

Development of high-production quality strains, compatible with the environment and climatic conditions, with less water requirements are features of the modern era.

Research does not stop there. Green innovations are continuing and it is no longer acceptable that the productivity of the planted unit of vegetables and fruits in Arab or African countries represents only 50 percent of those in the developed countries.

On the national level, plant varieties of strategic crops, in particular, have achieved notable successes, especially in the field of seed production. Indeed, these achievements are not comparable to those achieved globally. Accordingly there is, still, an existing technical varietal gap between both sides.

The real truth is "improved seeds are the basis of good production", regardless of how much attention we give to agricultural processes and production requirements with all its elements, still, we cannot expect abundant production to occur unless we start with suitable selected and improved seeds.

Ladies and gentlemen

This conference constitutes a neutral forum for members, partners, seed industry leaders, opinion leaders and other stakeholders to engage in focused dialogues on best ways to provide high-quality seeds for preferred and resilient crops with the aim of shifting to more efficient, comprehensive and sustainable agricultural systems, which contribute to achieving the Sustainable Development Goals. This is what the objectives of this conference are interested in, in terms of enhancing cooperation between sectors, especially between the public and private sectors. And discuss the latest knowledge and technologies on the green development of the seed production sector.

Ladies and gentlemen

The main objectives of the seed production sector of the Ministry of Agriculture aim to increase the production and productivity of strategic crops and some vegetable crops, raising improved seeds coverage percentage and reducing production costs, establishing a national industry for the production of genetically pure seeds of field crops, hybrid seeds and some vegetables' varieties, instead of importing them, aiming to reach self-sufficiency which will contribute, to a high extent, to achieving stability and breaking the monopoly of foreign companies, taking into consideration the climate changes and its effects that need the breeding programmes to concentrate on developing varieties that can face these challenges.

Ladies and gentlemen

The justifications for adopting seed industry on the national level is to build on what has been achieved in relation to developing certain plant varieties with high productivity, especially in the field of cereals, such as wheat, rice and maize. But these successes are still related to climatic conditions of breeding and propagation areas, as well as to soil nature, the extent of water availability and the differences in temperatures and relative humidity and, consequently, diversity in variety development and breeding is needed to suit the climatic, terrestrial and water conditions, in addition to the reduction in many imported varieties productivity than those of the origin country, and also the continuous rise in the prices of imported seeds, which increases cost elements and weakens competition.

Ladies and gentlemen

The Egyptian Ministry of Agriculture has followed some procedures that led to improving the hosting environment of seed industry on the national level, such as:

- Continuous support of national programmes for "strategic crop seed production" (wheat, maize, rice, cotton, legumes and others) to develop several varieties and improve early-maturing hybrids that are resistant to environmental and biological stresses.
- The Agricultural Research Center of the Ministry of Agriculture was able to develop many crop varieties, such as wheat, which is characterized by high yield potential, as one of the most important factors in increasing wheat crop productivity. Those efforts were intensified in the early 1980s where wheat productivity was only 1.4 tonnes/acre and the total production in 1981 had registered 1.94 million tonnes.

Efforts continued in developing new varieties that caused the yield to increase up to 2.8 tonnes/acre, in 2014 and beyond, in addition to increasing total production to reach 9 million tonnes.

- The Ministry of Agriculture adopted the national extension campaigns that led to increasing the cultivated areas with the improved seed varieties.
- Launching the national programme for vegetable seeds production and the axes of implementation of this programme include: developing new hybrids and varieties of vegetables, increasing the coverage rate of seeds for vegetable crops, holding partnerships with foreign companies to produce seeds, in addition to assisting the state to import seeds to respond to market requirements.
- As ten basic vegetable crops were selected to implement the programme (tomato, cucumber, eggplant, pepper, squash, cantaloupe, watermelon, peas, cowpeas and green beans). Varieties and hybrids for selected crops have been developed. A number of (25) hybrids and new varieties have been registered for (9) vegetable crops.

6.7 Closing remarks

Beth Bechdol
FAO Deputy Director-General

On behalf of the Director-General, I would like to make some observations and remarks, before bringing this conference to a close.

Honourable Ministers,
Excellencies,
Distinguished Guests and Participants,
Ladies and Gentlemen,

We have reached the end of this milestone event and I would like to thank the distinguished speakers we had the pleasure to listen to yesterday and today, as well as everyone in the audience who participated in the discussions. My sincere appreciation to all participants of today's high-level segment for their excellent interventions that have greatly enriched this conference.

And a special thanks goes to our organizing team from the Plant Production and Protection Division for preparing the sessions and facilitating the dialogue. Thank you to Dr Xia and all my colleagues for their valuable contributions and active engagement over the past two days – but also over the past weeks and months.

We heard inspiring messages from many different actors working across the agricultural value chain, as they discussed the future of the seed industry in a climate-changing world. These voices included farmers and scientists, policymakers and researchers. We participated in rich discussions illustrating the essential role of seeds in agriculture and food production, and we heard about concrete examples and solutions for farmers.

I will share that this is a deeply personal topic for me. As the daughter of a farmer, the seventh generation of our family farm in rural Indiana, I do understand the power of an individual seed – what that seed means to a farmer, to her or his families and their livelihoods, and what it ultimately delivers to our planet, especially to our soil and water, and to the people of the world.

Over these generations, my family has been fortunate – and even blessed – to have a high degree of certainty as to when, where, how and at what cost the next year's supply of seeds would be sourced. This is the certainty that every farmer in every part of the world deserves. I am glad to note that this conference is a step in the right direction for FAO to achieve this aim for all.

The conference has brought together participants from different segments of the sector, with very different backgrounds. But, they all had something in common – their willingness to work together, and to find solutions. These two days have demonstrated that we have the making of something very great here. A new way of working. I am convinced that we are moving beyond some of the traditional and even "entrenched" approaches that have prevailed due to different interests.

As many speakers mentioned, this conference has come at a very opportune time. As we begin to implement our FAO Strategic Framework 2022-31, its theme of seeds could not be more appropriate. They are the foundation of our agrifood systems.

The positive impacts of this conference are truly encouraging. The keynote addresses were informative and visionary. The parallel sessions showcased the latest achievements gained and the best lessons learned. And, our work on seeds received political endorsement in the high-level ministerial segment. The ten conference recommendations will sharpen our focus as we strive to promote the green development of global seed industries moving towards the 2030 Agenda.

So, what did we hear during these two days? This conference delivered reasons for optimism and concrete solutions for farmers on ways to address the numerous challenges that were presented. Let me share a few of my thoughts.

First, Scientific Innovation. It has been repeatedly demonstrated that research and development is a key driver to deliver improved crop varieties. It is evident that seeds, particularly quality ones, do not just happen. They are made, developed and strengthened through a process of several distinct, yet interwoven steps.

I urge all development partners to support research and development in plant breeding and genetics, as well as the conservation of plant genetic resources for food and agriculture, especially through strengthened institutional and human capacities.

Second, Farmers' Capacity. Farmers, especially small-scale farmers in remote parts of low- and middle-income countries, cannot produce essential food because they lack access to the most critical input – seeds. I call upon governments and development partners to remove these constraints and strengthen the capacities for farmers to have this access to quality seeds.

Third, Seed Industries. The private sector is a key partner and a most formidable ally in promoting agriculture development. This is one of the reasons that FAO has developed a new Strategy for Private Sector Engagement. I challenge industry and private sector colleagues to adopt a vastly different business model to the norm – and to be co-creators of solutions that ensure **everyone** is well-fed and guaranteed a respectable livelihood.

Fourth, Government Policy. The role of governments, who are in the driver's seat to eradicate hunger, cannot be overemphasized. I suggest that governments launch national seed actions as a means to strengthen the entire seed value chain.

And, fifth, International Cooperation. As an African proverb tells us, 'if you want to go fast, go alone; but if you want to go far, go together'. International cooperation, at global and regional levels, enables greater access to resources and permits the sharing of knowledge and information.

As I close, let me convey to you the commitment from everyone at FAO to leverage the momentum generated by this conference and to translate the evidence provided into action on the ground. More specifically:

We will continue to provide technical support through our usual mechanisms, including from our regular budget and extra-budgetary resources.

We will share information and support the exchange of genetic resources. FAO will drive information dissemination on enhanced access to quality seeds, and continuously advocate for, and support access to, plant genetic resources for food and agriculture.

We will encourage and convene policy dialogues. Taking advantage of our longstanding normative processes, FAO will remain at the forefront of standard setting and building international consensus, including through international seed trade.

And, we will support countries and national governments to develop and implement national policies, regulations and laws to create predictability and ultimately foster confidence in seed systems.

I believe that civil society, research and academia, governments, development agencies and the private sector agree that farmers deserve the seeds that they trust will deliver solutions.

Yes, there are different opinions as to how best to arrive at this goal. But, I am confident that even these differences can be bridged. They pale in comparison to the benefits that can be achieved by working together.

It is for this reason that FAO commits to bringing all of us together to translate the evidence provided through this conference into action on the ground, which will ensure that farmers have access to the full benefits of quality seeds. And this will require cooperation… from all of us!

With this, I declare the 2021 Global Conference on Green Development of Seed Industries officially closed. I wish everyone a good day and a good evening and look forward to working more closely together in the future.

7. CONFERENCE RECOMMENDATIONS

Proceedings of the Global Conference on Green Development of Seed Industries
4–5 November 2021

Recommendations from the Global Conference on Green Development of Seed Industries held at FAO headquarters on 4 and 5 November 2021

FAO hosted the Global Conference on Green Development of Seed Industries virtually on 4 and 5 November 2021, which was attended by over 2200 participants from 126 FAO Members. The overall objective of the Conference was to provide a neutral forum for FAO Members and all key stakeholders to discuss evidence-based solutions to the problems that constrain farmers' access to quality seeds and planting materials of preferred productive, nutritious and resilient crop varieties. Strategically, the event was a means to identify priority interventions for the implementation of relevant aspects of FAO's Strategic Framework 2022–31 aimed at the transformation to more efficient, inclusive, resilient and sustainable agrifood systems for better production, better nutrition, a better environment and a better life, thus contributing to the achievement of the United Nations' Sustainable Development Goals (SDGs), especially SDGs 2 and 1.

The two-day event had an opening plenary session, which was headlined by the Director-General of FAO, Dr Qu Dongyu, and featured six keynote addresses. The closing plenary session included a high-level ministerial segment. In between, there were eight parallel sessions – two for each of the four themes, advanced technologies; conservation of plant genetic resources for food and agriculture; crop varietal development and adoption; and seed systems. A fifth theme, policy and governance, was crosscutting.

Stakeholders adjudged the event as timely, informative, inclusive and inspiring. Based on the inspiring outcomes, the Steering Committee of the Conference identified the following ten recommendations on Strategic Actions for the Green Development of Global Seed Industries:

1. *Adopt* innovations that harness appropriate scientific and technological advancements, in particular through the convergence of institutions, infrastructures, policies and regulatory frameworks and partnerships along the seed value chain – from the conservation of plant genetic resources for food and agriculture, through their use in breeding progressively superior crop varieties, to the availability and use of affordable quality seeds – as means to develop and deliver context-specific solutions to farmers.

2. *Strengthen* institutional and human capacities for the judicious use of the advances in agricultural biotechnologies – in particular genetic modification, genome editing, induced mutagenesis, high-throughput screening, genomics-assisted breeding, systems biology, synthetic biology, next-generation sequencing and cell biology – and informatics and data analytics to enhance plant breeding and the conservation of crop diversity.

3. *Create* the enabling environment at national, regional and global levels, through appropriate national policies, laws and regulations and regional and international agreements, for enhanced capacities to access and use advanced technologies safely for generating improved crop varieties and safeguarding crop diversity.

4. *Safeguard* crop genetic resources in their natural habitats, in genebanks and through enhanced on-farm diversity; characterize their heritable variations; evaluate them for agronomic performance; and improve associated documentation and data management systems.

5. *Enhance* access to, including through exchanges across national boundaries in keeping with appropriate phytosanitary measures, and use of, crop diversity, especially for research and for breeding progressively superior crop varieties, while enabling the fair and equitable sharing of their benefits.

6. *Breed* a diverse portfolio of well-adapted progressively superior crop varieties, which are more nutritious, produce higher yields with fewer external inputs, are resistant to biotic and abiotic stresses, fit the farming systems and satisfy the needs of consumers and end-users under worsening climate change scenarios.

7. *Disseminate* information on improved crop varieties, create the enabling environment for effective information sharing – through effective policies, laws, regulations and incentives – and strengthen institutional and farmers' capacities for the widespread adoption and use of these elite materials in cropping systems.

8. *Develop* capacities along the seed value chain – from production, through quality assurance, to marketing via diversified seed enterprises and related service providers – so that farmers have timely access to enough quantities of affordable quality seeds and planting materials of the improved crop varieties that are most suited to their production systems and end use.

9. *Enforce* effective national policies, laws and regulatory frameworks and regional and international agreements, and support effective institutions, including in collaboration with relevant international organizations, to incentivize innovations along the seed value chain, in order to enhance the demand for, and supply of, quality seeds and planting materials of preferred crop varieties, including through regional and international trade.

10. *Accord* high priority to the development and strengthening of the seed value chain, especially through the inclusion of sector-specific provisions, for instance 'seed action' – which outlines strategic interventions – in overarching national plans and policies and associated budgetary support and encourage private sector investment across multiple sectors for the development of sustainable agricultural and food systems.

Governments, development partners and all stakeholders along the seed value chain are called upon to implement these strategic actions, publicize them widely through appropriate electronic and print media, incorporate them into advocacy materials and provide feedback to FAO.

For further information and engagement, please contact the Director of FAO's Plant Production and Protection Division: NSP-Director@fao.org

ANNEX 1.
CONFERENCE ORGANIZATIONAL BODIES

Proceedings of the Global Conference
on Green Development of Seed Industries
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The Global Conference on Green Development of Seed Industries was organized by FAO with the support of a Steering Committee, a Scientific Advisory Panel, and a Secretariat.

STEERING COMMITTEE

The Steering Committee had the following responsibilities: provide advice on all aspects of the conference, provide advice to the Scientific Advisory Panel regarding the programme, act as the event's ambassador among the respective organizations/networks/countries of the Steering Committee members, encourage people to attend the conference, and provide advice on potential follow-up to the conference.

Composition

Chair:

- **Beth Bechdol**, Deputy Director-General, FAO

Vice-Chairs:

- **Yemi Akinbamijo**, Executive Director, Forum for Agricultural Research in Africa, Ghana
- **Marco Ferroni**, Chair, CGIAR System Board
- **Hanzhong Wang**, Vice President, Chinese Academy of Agricultural Sciences

Members:

- **Lorena Basso**, President, Argentinian Seed Association and President, Seed Association of the Americas
- **Robert Bertram**, Chief Scientist, Bureau for Resilience and Food Security, United States Agency for International Development
- **Robert Delve**, Lead Global Technical Advisor (Agronomy), Sustainable Production, Markets and Institutions Division, International Fund for Agricultural Development
- **Ismahane Elouafi**, Chief Scientist, FAO
- **Michael Keller**, Secretary General, International Seed Federation
- **Alberto Lipparini**, Secretary General, Italian Seed Association (Assosementi)
- **Mauricio Lopes**, Research Scientist, Embrapa Agroenergy, Embrapa
- **Kent Nnadozie**, Secretary, International Treaty on Plant Genetic Resources for Food and Agriculture, FAO
- **Fatma Ben Rejeb**, Chief Executive Officer, Pan-African Farmers' Organization
- **Rakesh K. Singh**, Program Leader and Principal Scientist (Plant Breeding), Crop Diversification and Genetics, International Center for Biosaline Agriculture
- **Jingyuan Xia**, Director, FAO Plant Production and Protection Division

SCIENTIFIC ADVISORY PANEL

The Scientific Advisory Panel had the specific role of developing a draft programme covering the main conference themes. In doing so, the panel provided proposals for the names of potential keynote speakers, presenters, panellists and chairs for the different sessions, ensuring gender and geographical balance in the proposals. For each of the five conference themes, working groups were established, with two co-leads for each working group.

Composition

Chair:

- **Ismahane Elouafi**, Chief Scientist, FAO

Vice-Chairs:

- **Rachel Chikwamba**, Group Executive: Chemicals, Agriculture, Food and Health, Council for Scientific and Industrial Research (CSIR), South Africa (Co-lead conference theme 5: Policy and governance)
- **Niels Louwaars**, Director of Plantum, the Netherlands Seed Association, the Netherlands (Co-lead conference theme 4: Seed systems)

Members:

- **Maria Andrade**, Sweet potato breeder and 2016 World Food Prize winner, International Potato Centre
- **Vivienne Anthony**, Senior Scientific Advisor, Syngenta Foundation for Sustainable Agriculture.
- **Peter Button**, Vice Secretary-General, UPOV
- **Lamis Chalak**, Professor, Head of Plant Production Department, Faculty of Agronomy, The Lebanese University (Co-lead conference theme 2: Conservation of plant genetic resources for food and agriculture)
- **Martin Ekvad**, Former President, Community Plant Variety Office
- **Shaun Ferris**, Senior Technical Advisor, Agriculture/Livelihoods and Markets, Catholic Relief Services
- **Csaba Gaspar**, Programme Manager, OECD Seed Schemes
- **Keshavulu Kunusoth**, Director, Telangana State Seed and Organic Certification Authority, India (Co-lead conference theme 4: Seed systems)
- **Charlotte Lusty**, Head of Programs and Genebank Platform Coordinator, Global Crop Diversity Trust (Co-lead conference theme 2: Conservation of plant genetic resources for food and agriculture)
- **Long Mao**, Head, Research Group of Wheat Complex Traits Dissection, Institute of Crop Sciences, Chinese Academy of Agricultural Sciences (Co-lead conference theme 5: Policy and governance)
- **Cathie Martin**, Professor, Department of Metabolic Biology, John Innes Centre, the United Kingdom
- **Nigel Maxted**, Professor of Plant Genetic Conservation, School of Biosciences, University of Birmingham, the United Kingdom
- **Chikelu Mba**, Team Leader, Seeds and Plant Genetic Resources, FAO
- **Peter Okoth Mbogo**, Senior Maize Breeder, Seed Co, Kenya
- **John McMurdy**, Vice-President of Innovation and Development, CropLife International
- **Emmanuel Okogbenin**, Director, Programme Development and Commercialization, African Agricultural Technology Foundation (Lead conference theme 3: Crop varietal development and adoption)
- **Tilabilenji Phiri**, Senior Programmes Officer, In-Situ Conservation and SADC Seed Centre Coordinator, SADC Plant Genetic Resource Centre

- **Alison Powell**, Chair of the ISTA Seed Science Advisory Group to the ISTA Executive Committee and Chair of the ISTA Vigour Technical Committee
- **Sobhana Sivasankar**, Section Head, Plant Breeding and Genetics, Joint FAO-IAEA Centre for Nuclear Techniques in Food and Agriculture
- **Rajeev Varshney**, Research Program Director, International Crops Research Institute for the SemiArid Tropics & Adjunct Professor, Food Futures Institute, Murdoch University (Co-lead conference theme 1: Advanced technologies)
- **Vittorio Venturi**, ICGEB Scientific Coordinator and Group Leader, Bacteriology and Strains4Plants, International Centre for Genetic Engineering and Biotechnology (Co-lead conference theme 1: Advanced technologies)

SECRETARIAT

The FAO Secretariat was in charge of the organization of the conference, including its programme, logistics and communication.

Composition

Executive Secretary:
- **Jingyuan Xia**, Director, Plant Production and Protection Division

Deputy Executive Secretary:
- **Rémi Nono Womdim**, Deputy Director, Plant Production and Protection Division

General Coordinator:
- **Chikelu Mba**, Team Leader, Seeds and Plant Genetic Resources

Coordination:

- **Ndeye Ndack Diop**, Agricultural Officer
- **Stefano Diulgheroff**, Information Management Officer
- **Bonnie Furman**, Agricultural Officer
- **Wilson Hugo**, Agricultural Officer
- **Haekoo Kim**, Technical Adviser
- **Preetmoninder Lidder**, Technical Adviser
- **Shawn McGuire**, Agricultural Officer
- **Arshiya Noorani**, Agricultural Officer
- **Lucio Olivero**, Seed Specialist
- **John Ruane**, Senior Agricultural Innovation Specialist
- **Alexandra Sokolova**, Programme Officer

Communication:

- **Maria Soledad Fernández González**, Digital Communication Specialist
- **Mirko Montuori**, Communication Officer
- **Ginevra Virgili**, Graphic Designer

Operations:

- **Alessia Laurenza**, Clerk Typist
- **Elena Rotondo**, Office Assistant
- **Sara Tripodi**, Office Assistant
- **Juliet Upton**, Office Assistant
- **Chantal Wedge**, Intern

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ANNEX 2.
CONFERENCE PROGRAMME

Thursday, 4 November 2021

09.30-10.00

PLENARY SESSION 1: OPENING

Moderator: ***Beth Bechdol,** Deputy Director-General, FAO*

Opening remarks

QU Dongyu, Director-General, FAO

10.00-12.30

PLENARY SESSION 2: KEYNOTE ADDRESSES

Moderator: ***Ismahane Elouafi,** Chief Scientist, FAO*

Section A: Developing solutions for farmers

- *Solutions for small-scale farmers*
  Fatma Ben Rejeb, Chief Executive Officer, Pan-African Farmers' Organization (PAFO)
- *Advanced technologies impacting the green development of seed industries*
  Mauricio Lopes, Research Scientist, Embrapa Agroenergy, Brazilian Agricultural Research Corporation (Embrapa), Brazil
- *Crop improvement, better seed – From conservation of crop biodiversity to impactful use*
  Marco Ferroni, Chair, CGIAR System Board
- Discussion

Section B: Delivering solutions to farmers

- *Seed systems as enablers to seed choice*
  Michael Keller, Secretary General, International Seed Federation (ISF)
- *The green development of China's seed industry*
  Hanzhong Wang, Vice President, Chinese Academy of Agricultural Sciences (CAAS), China
- *Policies and governance: Providing clarity and coherence to shape a robust and inclusive seed industry*
  Rachel Chikwamba, Group Executive for Chemicals, Agriculture, Food and Health,
  Council for Scientific and Industrial Research, South Africa
- Discussion

Break **12.30-13.30**

Thursday, 4 November 2021

PARALLEL SESSIONS: THEME 1 AND 2

Theme 1: ADVANCED TECHNOLOGIES

13.30-15.30

Session 1.1 Modern plant breeding technologies

Co-Chairs:

- ***Rajeev K Varshney***, *Research Program Director, Accelerated Crop Improvement, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Professor, Murdoch University, Australia*
- ***Cathrine Ziyomo***, *Senior Scientist, BECA-ILRI Hub, International Livestock Research Institute (ILRI)*

Break **15.30-16.00**

16.00-18.00

Session 1.2 Emerging biotechnologies and informatics technologies

Co-Chairs:

- ***Vittorio Venturi***, *Scientific Coordinator and Group Leader, Bacteriology and Strains4Plants, International Centre for Genetic Engineering and Biotechnology (ICGEB)*
- ***Sobhana Sivasankar***, *Section Head, Plant Breeding and Genetics, Joint FAO-IAEA Centre for Nuclear Techniques in Food and Agriculture*

Theme 2: CONSERVATION OF PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE

13.30-15.30

Session 2.1 The global conservation system

Co-Chairs:

- ***Charlotte Lusty***, *Head of Programs and Genebank Platform Coordinator, Global Crop Diversity Trust*
- ***Lamis Chalak***, *Professor, Head of Plant Production Department, Faculty of Agronomy, The Lebanese University, Lebanon*

Break **15.30-16.00**

16.00-18.00

Session 2.2 Access and benefit-sharing

Co-Chairs:

- ***Lamis Chalak***, *Professor, Head of Plant Production Department, Faculty of Agronomy, The Lebanese University, Lebanon.*
- ***Charlotte Lusty***, *Head of Programs and Genebank Platform Coordinator, Global Crop Diversity Trust*

Friday, 5 November 2021

PARALLEL SESSIONS: THEME 3 AND 4

Theme 3:
CROP VARIETAL DEVELOPMENT AND ADOPTION

9.00-11.00

Session 3.1 Accelerating genetic gains in crops

Co-Chairs:

- ***Emmanuel Okogbenin**, Director, Programme Development and Commercialization, African Agricultural Technology Foundation (AATF)*
- ***Idah Sithole Niang**, Professor, Department of Biotechnology and Biochemistry, University of Zimbabwe, Zimbabwe*

11.30-13.30

Session 3.2 Facilitated adoption of improved varieties by small-scale farmers

Co-Chairs:

- ***Maryke Labuschagne**, Professor in Plant Breeding, University of the Free State, South Africa*
- ***Maria Andrade**, Sweet Potato Breeder, International Potato Centre (CIP)*

PARALLEL SESSIONS: THEME 3 AND 4

Theme 4:
SEED SYSTEMS

9.00-11.00

Session 4.1 System innovations in the seed value chain

Co-Chairs:

- ***Martin Ekvad**, Former President, Community Plant Variety Office (CPVO)*
- ***Alison Powell**, Chair, International Seed Testing Association (ISTA) Seed Science Advisory Group to the ISTA Executive Committee and Chair, ISTA Vigour Technical Committee*

11.30-13.30

Session 4.2: Seed enterprise development and international trade

Co-Chairs:

- ***Keshavulu Kunusoth**, Director, Telangana State Seed & Organic Certification Authority, India and Vice President, International Seed Testing Association (ISTA)*
- ***Shaun Ferris**, Senior Technical Advisor, Agriculture/Livelihoods and Markets, Catholic Relief Services*

Break **13.30-14.30**

Friday, 5 November 2021

14.30-16.00

PLENARY SESSION 3: REPORTS ON CONFERENCE THEMES AND RECOMMENDATIONS

Moderator*: **Jingyuan Xia**, Director, FAO Plant Production and Protection Division*

Reports on conference themes

- Theme 1: Advanced technologies
  Rajeev K. Varshney, Research Program Director, Accelerated Crop Improvement, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Professor, Murdoch University, Australia
- Theme 2: Conservation of plant genetic resources for food and agriculture
  Charlotte Lusty, Head of Programs and Genebank Platform Coordinator, Global Crop Diversity Trust
  Lamis Chalak, Professor, Head of Plant Production Department, Faculty of Agronomy, The Lebanese University, Lebanon
- Theme 3: Crop varietal development and adoption
  Emmanuel Okogbenin, Director, Programme Development and Commercialization, African Agricultural Technology Foundation (AATF)
- Theme 4: Seed systems
  Keshavulu Kunusoth, Director, Telangana State Seed & Organic Certification Authority (TSSOCA), India and Vice President, International Seed Testing Association (ISTA)

Report on conference recommendations

- Recommendations
  Long Mao, Chinese Academy of Agricultural Sciences

16.00-17.30

PLENARY SESSION 4: HIGH-LEVEL MINISTERIAL SEGMENT AND CLOSING

Moderator*: **Beth Bechdol,** Deputy Director-General, FAO*

High-level ministerial segment

- **Thomas Vilsack,** Secretary of Agriculture, United States of America
- **Zhang Taolin,** Vice Minister for Agriculture and Rural Affairs, the People's Republic of China
- **Marije Beens,** Director-General for Agriculture, Ministry of Agriculture, Nature and Food Quality, the Kingdom of the Netherlands
- **Jorge Solmi,** Secretary of Agriculture, Ministry of Agriculture, Livestock and Fisheries, Argentina
- **Julian Jaftha,** Chief Director, Plant Production and Health, Department of Agriculture, Land Reform and Rural Development, South Africa
- **Mohamed Ali Fahim,** Director, Climate Change Information Center, Egypt

Concluding remarks

Beth Bechdol, Deputy Director-General, FAO

This book represents the proceedings of the Global Conference on Green Development of Seed Industries which FAO organized in a virtual format on 4 and 5 November 2021. Coming 12 years after the previous World Seed Conference, FAO convened the conference to provide a neutral forum for its Members, partners, industry leaders, opinion leaders and other stakeholders to engage in focused dialogues on how best to make quality seeds and planting materials of preferred productive, nutritious and resilient crop varieties available to farmers, especially in food insecure parts of the world.

The proceedings provide a record of the main highlights of the conference, including the opening and keynote address plenary session, a high-level ministerial segment and eight parallel sessions dedicated to the four conference themes of advanced technologies, conservation of plant genetic resources for food and agriculture, crop varietal development and adoption, and seed systems. The fifth conference theme, policy and governance, was crosscutting.

The conference was timely, informative, inclusive and inspiring and its successful convening creates an important momentum to facilitate the development and delivery of the solutions that enable farmers to have access to quality seeds and planting materials of improved crop varieties.

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