

CGIAR System 3-Year Business Plan (2019-2021) Companion Document

Initiative on “Crops to End Hunger” Strategy and Options for CGIAR Support to Plant Breeding

Business Plan Action: 1.3 - Deepen the portfolio through new thematic strategies and initiatives

Purpose: This document presents, in the following three annexes, a comprehensive modernization agenda for crop breeding in the CGIAR, the Funder-led *Initiative on “Crops to End Hunger”*. *Strategy and Options for CGIAR Support to Plant Breeding*.

- **Annex 1:** Executive Summary
- **Annex 2:** Initiative on “Crops to End Hunger”, Strategy and Options for CGIAR Support to Plant Breeding
- **Annex 3:** ‘Draft 0’ Implementation Plan developed at the request of the System Management Board

Action Requested: The System Council is requested to provide strategic guidance and inputs on the Draft Implementation Plan set out in **Annex 3**, informed by the Initiative on “Crops to End Hunger”; Strategy and Options for CGIAR Support to Plant Breeding set out in **Annexes 1 and 2**.

Document category: Working document of the System Council

There is no restriction on the circulation of this document

Prepared by: **Annexes 1 and 2:** multi-Funder group led by USAID and including the Gates Foundation, DFID, UK; GiZ Germany and ACIAR, Australia;
Annex 3: CGIAR System Management Office

Annex 1: Executive Summary (Revised October 10 2018 -final)

Initiative on “Crops to End Hunger” Strategy and Options for CGIAR Support to Plant Breeding

Executive Summary

Purpose

The challenge to the CGIAR system is to apply modern scientific advances towards achieving the sustainable development goals (SDGs) of reducing poverty, hunger and malnutrition. A cornerstone of this vision is for the CGIAR system to contribute to the Sustainable Development Goals (SDGs), especially SDG 2 to “*End hunger, achieve food security and improved nutrition, and promote sustainable agriculture*”.

The purpose of the initiative on “*Crops to End Hunger*” is to increase the effectiveness of the CGIAR in crop breeding programs, in partnership with national agricultural research systems (NARS), in developing and delivering more productive, resilient, and nutritious varieties of staple crops in demand by smallholder farmers and consumers in various geographic regions of the developing world. The initiative aims to support more focussed, science-based, well-resourced and long term CGIAR R&D programs and investments by the CGIAR system in modern plant breeding on priority crops, which build on: (1) The CGIAR’s demonstrated impact on food security and poverty reduction through plant breeding; (2) its comparative advantages in global public goods research on crop breeding and genetics; and (3) its central role and responsibility for the conservation and characterisation of the world’s crop biodiversity, which is held in trust by the CGIAR centres for the world community.

The intention of strengthening the CGIAR’s crop improvement programs is to accelerate the development, delivery and widescale use of a steady stream of new crop varieties that meet the food, nutrition and income needs of both producers and consumers, respond to market demands and provide resilience to new environmental challenges arising from climate change.

Scope

The initiative recognises that accelerating the development and delivery of new plant varieties requires a spectrum of activities, including market research to help define the characteristics/traits of new varieties preferred by farmers, consumers and others along the value chain (formalised as a “product profile”); population development; extensive, field based evaluation programs to identify the most promising lines suited to various agro-ecological environments and farming systems; and linkages to seed systems in-country, in which national regulatory agencies take responsibility for the registration of new varieties, while various public agencies, community organizations and private seed companies undertake the multiplication, distribution, promotion and sale of varieties to farmers.

Discovery research to identify the genetic sources of traits for use in plant breeding and the development of new methods and tools to accelerate and improve efficiency and precision in breeding programs are also critical inputs to effective, modernized breeding programs oriented to continuous improvement. However, these efforts are not within the scope of the focused investments proposed here. High performing breeding programs will be better positioned to take advantage of collaboration with universities and other advanced research institutes to undertake such discovery research.

While recognising the importance of seed systems in ensuring new varieties reach farmers in developing countries, there are a range of national governments, international development agencies and philanthropic foundations addressing the importance of strengthening seed systems and with whom CGIAR breeding programs cooperate. This initiative focuses on the role of the CGIAR system in plant breeding *per se* including the hand-off of finished products to the seed system. It will not focus

on last-mile product delivery, but rather on ensuring that new products are truly superior to what farmers currently grow. Its aim is to improve the speed and efficiency with which CGIAR plant breeding programs and partnerships with NARS develop and deliver new varieties that respond both to farmers' needs and consumer preferences, are demanded by the market, are widely adopted, and lead to increased productivity in farmers' fields.

Rationale

Productivity and profitability in crop agriculture are driven by the continual introduction of new, higher yielding, more pest and disease resistant and more climate resilient crop varieties that meet both farmers' needs and consumer preferences. These new varieties replace older varieties, on a continuous cycle of varietal improvement, use and replacement, thus continually delivering genetic gain. The key high-level metrics for the effectiveness of plant breeding and dissemination programs are:

- i) *The rate of genetic gain in productivity, on an annual basis, delivered in farmers' fields in the form of producible, resilient, farmer- and consumer-preferred varieties.* This metric characterizes the success over time of the program in producing a steady stream of improved varieties. This metric should also take into account the cost per unit of gain.
- ii) *The average area-weighted age of varieties in farmers' fields (AAWAV).* This is a measure of the effectiveness of the breeding and dissemination system in driving the adoption of new varieties and replacement of obsolete ones.

These metrics shift the focus from measures only indirectly linked to impact, like the number of varieties released, or backward-looking metrics like total area planted to a program's varieties (even very old ones) towards the measurement of current, ongoing effectiveness and impact. The purpose of this initiative is to increase the rate of genetic gain generated by CGIAR-linked breeding programs, and to accelerate the delivery of this gain in farmers' fields in the form of farmer-, consumer-, and market-preferred varieties. One of its key benefits will be the alignment of CGIAR centers, CRPs, and the donor community around a common set of metrics for guiding and evaluating investments in crop improvement. This will provide research managers with clear guidance, and unambiguous performance measures.

Accelerating the development and wide-scale adoption of new varieties of crops important in the various regions of the developing world will deliver several benefits, including: Increased incomes for farmers and others along the crop value chain; more nutritious and affordable food that meet consumer preferences and market demand; more diverse diets, as farmers and consumers devote less land and income to staple crops and more to nutrient-dense fruits, vegetables, and animal-sourced foods, and more resilient crops, better able to cope with climate shocks such as drought as well as new pest and disease outbreaks. Modernising the global and regional crop improvement programs supported by the CGIAR is urgently required to achieve these benefits. Accelerating new variety development and enabling the more widespread adoption and use of new varieties is one of the components of agricultural transformation, enabling small-scale farmers to move from subsistence production to farming as a profitable business.

Modern plant breeding is driven by new scientific and technical advances and improved processes, including automation and mechanization, faster turnover of generations, and more accurate selection methods, including marker assisted selection. Such advances are now used routinely in modern plant breeding programs in both the public and private sectors. These new approaches have led to substantial increases in the efficiency and effectiveness of plant breeding programs and are driving continual genetic gains in commercial agriculture.

Modern approaches to plant breeding are equally applicable to the breeding of crops important throughout the developing world. The use of new breeding technologies in global, regional and

national breeding programs supported by the CGIAR would accelerate new variety development and enable a continuous supply of improved varieties, as indicated by more rapid turnover and replacement of older varieties.

Measures of success

Success of CGIAR supported breeding programs will be measured by their achievements in accelerating the rate of genetic gain delivered by CGIAR-supported breeding programs, and by reducing the area-weighted age of varieties in farmers' fields. In practice, these metrics take years to influence, so in the medium term (five years), the CGIAR supported breeding programs will be evaluated using intermediate measures of breeding program effectiveness that are widely applied in the private sector, including breeding cycle length, heritability in yield trials, and the year-on-year performance of new cohorts relative to currently-grown varieties.

Prioritization and implications for future funding

IFPRI and USDA were commissioned to undertake foresight modelling for 20 crops on which the CGIAR conducts breeding programs. The models presented a range of options on relative priority of crops, depending on the approach and the criteria used. The relative ranking of crops by their share of expected benefits provides a menu of choices for investments in crop improvement on one crop or groups of crops, globally or in different regions and the share of benefits to be derived from these investments.

The donor group over the course of the next year--while modernization proceeds--will agree on a core set of crops x geographies that will have priority for funding. The donors will commit to having that core financed for a specific number of years at specific dollar amount. Other crops and geographies will also be supported under the Initiative but will not be included in this prioritized shared agenda.

However, IFPRI notes that these modelling studies are only one of the inputs to inform decisions on future investments by the CGIAR system in plant breeding. Other factors also need to be considered in reaching decisions on future investments, including new scientific opportunities; the technical feasibility of achieving increased productivity through genetics and breeding; the comparative advantage of the CGIAR Centres and breeding programs; availability of other providers, including the role of the private sector; and the likelihood of high rates of adoption of new varieties with product profiles that respond to farmers' requirements and consumer preferences.

What the prioritization studies means for future funding of CGIAR breeding programs

The modelling analysis has confirmed that the 20 CGIAR crops considered in the analysis have either global and/or regional importance in meeting the SDG2 goals in the future. Given segmentation of public and private sector efforts, and the relatively short time frame to convert approaches into impact before 2030, there is no crop amongst this 20 that merits elimination, rather the future focus will be shifting breeding emphasis to specific geographies where there is greater strategic importance of specific crops for reducing poverty and strengthening food security. Further, the priority is to focus each of the CGIAR's crop breeding programs within specific geographic areas on developing a series of ***priority product profiles***, developed in partnerships with NARS and others along the value chain, which will contribute maximum impact from delivering these improved varieties/product profiles to deliver genetic gains in farmer's fields as rapidly as possible and to make the programs agile enough to respond to the exigencies of climate change.

It should be noted that, to be eligible for continued support, all CGIAR breeding programs, regardless of their inclusion in the prioritized core set, should have in place a continuous improvement plan to increase breeding program effectiveness. These plans will be developed and implemented with the technical support of the EIB.

Implementation

The implementation of the initiative will build on existing CGIAR programs and expertise, while seeking additional advice and support for these programs from the world's strongest public and private sector breeding organizations. It aims to strengthen current CGIAR plant breeding programs and enable CGIAR Centres to expand their partnerships with national plant breeding programs, including by creating regional plant breeding networks that focus on accelerating genetic gains for improving agricultural productivity and profitability in the crops most important in the developing world.

These international plant breeding partnerships/networks will link international agricultural research centres, national agricultural research systems (NARS), private sector companies, and advanced research institutes (ARIs), around the common purpose of developing and delivering new crop varieties that increase productivity, and/or have other attributes that lead to increased productivity, profitability and/or sustainability (such as consumer preferences in taste, colour or quality).

A modernization agenda for CGIAR plant breeding programs

A series of independent assessments of the CGIAR breeding programs were commissioned by the Bill & Melinda Gates Foundation (BMGF) during 2016-18, using the Breeding Program Assessment Tool (BPAT), and led by the University of Queensland, Australia. Approximately 20 BPAT assessments, have identified areas of strength and weakness in crop breeding programs common across a range of CGIAR programs and areas of opportunities where the current breeding programs urgently need to be strengthened to improve their efficiency and effectiveness.

The key components of a modernization agenda and best practises recommended for CGIAR plant breeding programs are:

1. More systematic use of ***Product profiles***, based on continually updated market intelligence and stakeholder consultations, to ensure that new varieties are designed to meet the requirements and preferences of women and men farmers, consumers, traders, processors and others along the crop value chain.
2. ***Institutional accountability*** of the CGIAR Centres to be responsible for the delivery of genetic gains in farmers' fields, through institutional ownership of product profiles, and institutionally managed product advancement systems.
3. ***Continually optimized breeding pipelines*** that maximize genetic gains vs the time and cost of plant breeding programs through the use of rapid breeding cycles that accurately integrate genotypic and phenotypic information in selection decisions.
4. ***Mechanized and digitized phenotyping and data collection systems*** that increase accuracy and throughput while reducing costs
5. ***Breeding information management systems*** that support the integration of genotypic, pedigree, and phenotypic information in selection decisions.
6. ***Variety testing (on-station and on-farm) and advancement systems*** that clearly identify new products (new varieties) that are demonstrably superior to the varieties that farmers currently grow.
7. ***Demand creation and dissemination*** of new varieties through strong linkages with seed systems, and clear messaging on the need to replace obsolete varieties with proven new products.
8. ***Stronger partnerships with NARS*** that involve co-design of product profiles, joint testing from Stage 1 (the initial yield testing phase), joint selection of parents, and joint advancement and dissemination decisions.

All breeding programs operated by CGIAR Centres and their NARS partners should develop and implement a modernization program based on current best practices, commensurate with their resources. Modernising all CGIAR plant breeding programs will require strengthening capacity within

individual breeding programs as well as enabling access to new technologies applicable across a range of crops (e.g. high-throughput genotyping) via services that are efficiently shared; as well as greater sharing of new technologies and research facilities amongst CGIAR Centres, NARS partners and universities. The newly formed CGIAR Excellence in Breeding platform (EiB) is charged with the responsibility of working with the CGIAR Centres and their NARS partners to help all Centre-led breeding programs achieve these aims.

Modernization at the breeding program level

The modernization process should include three basic steps:

- i) A baseline assessment using the BPAT, highlighting key opportunities for improvement;
- ii) The development of a breeding program modernization plan, with the technical support of the EiB.
- iii) The implementation of the modernization plan, with technical support of the EiB and periodic re-assessment via the BPAT.

Future Challenges to the CGIAR System and Actions Required

The CGIAR's crop breeding programs and their extensive breeding networks with national partners are well positioned to take advantage of new technologies and best practices for plant breeding and apply these technologies more widely to crops in various regions of the developing world. However, the modernization of CGIAR supported plant breeding programs to better deliver genetic gains in farmers' fields will require actions by all levels of the CGIAR system and with their partners.

The priority actions are:

- **Stronger research culture, leadership and accountability by both the CGIAR System and CGIAR Centres for the delivery of genetic gains from new crop varieties**

More strategic leadership, direction and accountability is needed from the CGIAR System's leadership (System Council and System Management Board) and by Centres' and CRP leadership. This will require leadership by people knowledgeable about modern plant breeding and able to ensure accountability by the CGIAR Centres that CGIAR-supported plant breeding programs (including regional breeding networks and partnerships with national plant breeding programs) efficiently deliver products that lead to new varieties and result in genetic gains in farmers' fields. CGIAR leaders need to effectively support their breeding teams and hold them accountable for the delivery of genetic gains in farmers' fields. This will require sharing services (such as high-throughput genotyping and breeding information management system development) that are more efficiently provided across the entire system than by individual centers.

- **Continuous professional development of plant breeders and new recruitment to strengthen CGIAR crop improvement teams:**

Modernising CGIAR plant breeding programs will require continuing professional development of the cadre of approximately 150 plant breeders currently working in the CGIAR system. The newly formed Excellence in Breeding Platform (EiB) will play an important role in this regard. The CGIAR Centres responsible for the implementation of modern breeding programs also require new recruitments of scientists with additional skills in modern plant breeding and related disciplines (including the engineering skills needed to mechanize and digitize experiment stations). In addition to strategically hiring new CGIAR staff, the breeding programs will need access to skills in complementary areas, such as market analysis, to enable CGIAR crop improvement teams to address current gaps, such as developing product profiles for new varieties that better reflect farmer and consumer preferences; and to enable better interaction of plant breeding programs with seed system participants to ensure the delivery and wider adoption of new varieties.

➤ **Financial resources: More efficient use of current resources and mobilising new investments in plant breeding**

The CGIAR system currently invests about USD 120m per year in plant breeding (2017\$), the majority of which (about 80%) comes through (Window 3) bilateral funding to CGIAR centres for plant breeding projects. Modernizing CGIAR plant breeding programs will require making the most efficient use of current resources as well as mobilizing additional financial resources to drive substantial investments in modern plant breeding to underpin agricultural transformation in the developing world. Because of the continuous and long-term nature of plant breeding, sustained and predictable funding will be needed.

A balanced portfolio of future investments by the CGIAR in crop improvement would include a selection of priority crops, targeted to geographic and agri-ecological environments where increasing crop productivity, profitability and/or sustainability will contribute to: agricultural transformation; nutritional security; and enabling agricultural systems to be more resilient to climate change. All three targets are part of the CGIAR's strategy whereby food and agriculture will contribute towards achieving the Sustainable Development Goals.

Annex 2: Strategy and Options for CGIAR Support to Plant Breeding
Revised October 10 2018 final

**Initiative on “Crops to End Hunger”
Strategy and Options for CGIAR Support to Plant Breeding:**

October 2018



Revised October 10 2018

**Initiative on “Crops to End Hunger”
Strategy and Options for CGIAR Support to Plant Breeding**

Annotated Table of Contents

PART A – CONTEXT, FINDINGS AND RECOMMENDATIONS

This section describes the context of the “Crops to End Hunger” initiative, and its key findings

1. Context	3
➤ Purpose, scope and rationale for the initiative	
2. Summary of Key Findings and Recommendations	6
➤ Prioritization and implications for future funding	
➤ A modernization agenda for CGIAR Breeding Programs	
➤ Future challenges to the CGIAR System and actions required	

PART B: PRIORITIZATION ANALYSIS AND IMPLICATIONS FOR FUTURE SUPPORT

This section contains a summary of the prioritization analysis conducted by IFPRI and USDA, on 20 crops, in various geographic regions, and their implications for future support for plant breeding

3. Prioritization	10
3.1 Prioritization studies: IFPRI approach to modelling and analysis	
3.2 Summary of prioritization studies and their implications for future support of CGIAR/NARS breeding programs	

PART C: DETAILS OF CGIAR CROP BREEDING PROGRAMS AND AREAS FOR IMPROVEMENT

This section focuses on the current CGIAR breeding programs, the results of the breeding program assessments and the constraints and areas of improvement identified, where action is required, at the CGIAR System level and by individual Centres and CRPs and by cross system entities

4. Current CGIAR Crop Breeding Programs	15
4.1 What do current CGIAR breeding programs produce?	
4.2 Overview of current CGIAR plant breeding programs	
5. Breeding Programs Assessments: Constraints and Areas for Improvement and Action	17
5.1 Breeding Programs Assessment (BPAT): Methodology	
5.2 Constraints and Areas for Improvement and Action, at the CGIAR system level and by CGIAR Centres/programs and cross-system entities	

PART D: DETAILED IMPLEMENTATION PLAN FOR MODERNIZATION OF CGIAR BREEDING PROGRAMS

This section proposes a seven-step, detailed implementation plan for the modernization of CGIAR breeding programs and stronger partnerships with national plant breeding programs for the delivery of genetic gains, and areas where future funder support is required.

6. Initial Implementation Plan for Modernization of CGIAR breeding programs: 7 steps	21
ANNEX A: Crop Prioritization: IFPRI Modelling and Analysis for 20 crops	26
Summary of IFPRI prioritization studies, with data Tables from IFPRI report.	

Revised October 10 2018

**Initiative on “Crops to End Hunger”
Strategy and Options for CGIAR Support to Plant Breeding**

PART A – CONTEXT, FINDINGS AND RECOMMENDATIONS

The section describes the context of the “Crops to End Hunger” initiative, and its key findings

1. CONTEXT

Purpose

The challenge to the CGIAR system is to apply modern scientific advances towards achieving the sustainable development goals (SDGs) of reducing poverty, hunger and malnutrition. A cornerstone of this vision is for the CGIAR system to contribute to the Sustainable Development Goals (SDGs), especially SDG 2 to “*End hunger, achieve food security and improved nutrition, and promote sustainable agriculture*”.

The purpose of the initiative on “*Crops to End Hunger*” is to increase the effectiveness of the CGIAR in crop breeding programs, in partnership with national agricultural research systems (NARS), in developing and delivering more productive, resilient, and nutritious varieties of staple crops in demand by smallholder farmers and consumers in various geographic regions of the developing world. The initiative aims to support more focussed, science-based, well-resourced and long term CGIAR R&D programs and investments by the CGIAR system in modern plant breeding on priority crops, which build on: (1) The CGIAR’s demonstrated impact on food security and poverty reduction through plant breeding; (2) its comparative advantages in global public goods research on crop breeding and genetics; and (3) its central role and responsibility for the conservation and characterisation of the world’s crop biodiversity, which is held in trust by the CGIAR centres for the world community.

The intention of strengthening the CGIAR’s crop improvement programs is to accelerate the development, delivery and widescale use of a steady stream of new crop varieties that meet the food, nutrition and income needs of both producers and consumers, respond to market demands and provide resilience to new environmental challenges arising from climate change.

CGIAR supported plant breeding has made major contributions to global food security since the mid-1960s, but there is evidence that the rate of adoption of its products slowed after the 1980s. Recent expert evaluations of CGIAR programs via the Breeding Program Assessment Tool (BPAT) have shown that, overall, they have been slow to adopt state-of-the-art breeding methods, are not managed, funded, and supported appropriately for their product development function, and are not optimized to deliver high rates of genetic gain per unit of time or investment. Few CGIAR programs have reported the rate of genetic gain they deliver; those that have (CIMMYT wheat and maize, IITA maize, IRRI irrigated rice) generally report rates of gain below 1% annually over the last 20 years. Gains are likely much lower, or even stagnant, in most NARES breeding programs. Great potential exists to at least double the rate of genetic gain delivered by CGIAR breeding networks through the adoption of improved approaches to product design, breeding pipeline optimization, and dissemination. It is urgent that this be done across the system to allow it to deliver the steady stream of improved varieties needed to increase productivity and income of smallholder farmers (SHF), make available affordable and nutritious food to rural and urban consumers, permit adaptation of farming systems to a changing climate, and support rapidly commercializing agricultural systems in the developing world.

In 2017-18, a multi donor group led by USAID and including the Gates Foundation, DFID, UK; GiZ Germany and ACIAR, Australia agreed to launch a “Crops to End Hunger” initiative , with the view to reinvigorating plant breeding for the staple crops important in the developing world, and for this, a modernization and prioritization program for public plant breeding in the developing world is urgently required.

Scope

The initiative recognises that accelerating the development and delivery of new plant varieties requires a spectrum of activities, including market research to help define the characteristics/traits of new varieties preferred by farmers, consumers and others along the value chain (formalised as a “product profile”); population development; extensive, field based evaluation programs to identify the most promising lines suited to various agro-ecological environments and farming systems; and linkages to seed systems in-country, in which national regulatory agencies take responsibility for the registration of new varieties, while various public agencies, community organizations and private seed companies undertake the multiplication, distribution, promotion and sale of varieties to farmers.

Discovery research to identify the genetic sources of traits for use in plant breeding and the development of new methods and tools to accelerate and improve efficiency and precision in breeding programs are also critical inputs to effective, modernized breeding programs oriented to continuous improvement. However, these efforts are not within the scope of the focused investments proposed here. High performing breeding programs will be better positioned to take advantage of collaboration with universities and other advanced research institutes to undertake such discovery research.

While recognising the importance of seed systems in ensuring new varieties reach farmers in developing countries, there are a range of national governments, international development agencies and philanthropic foundations addressing the importance of strengthening seed systems and with whom CGIAR breeding programs cooperate. This initiative focuses on the role of the CGIAR system in plant breeding *per se* including the hand-off of finished products to the seed system. It will not focus on last-mile product delivery, but rather on ensuring that new products are truly superior to what farmers currently grow. Its aim is to improve the speed and efficiency with which CGIAR plant breeding programs and partnerships with NARS develop and deliver new varieties that respond both to farmers’ needs and consumer preferences, are demanded by the market, are widely adopted, and lead to increased productivity in farmers’ fields.

The scope of the initiative envisages:

- (1) **Prioritization**: Defining the selection criteria and developing the evidence base by which to identify options for a portfolio of **priority crops and their target geographies**, with potential to contribute to reducing hunger, poverty and malnutrition in various geographic regions;
- (2) Determining the future role of **global public goods research** in modern crop breeding and genetics;
- (3) Identifying the **comparative advantages** of the CGIAR system in breeding and genetics, relative to other public and private sector providers; and
- (4) Identifying the options and scope for **future investments** that will increase the rate of genetic gain delivered to smallholder farmers in the developing world, and that will have most impact on increasing income and reducing hunger and poverty in targeted crops, geographical regions and agro-ecological systems.

Rationale

Productivity and profitability in crop agriculture are driven by the continual introduction of new, higher yielding, more pest and disease resistant and more climate resilient crop varieties that meet both farmers' needs and consumer preferences. These new varieties replace older varieties, on a continuous cycle of varietal improvement, use and replacement, thus continually delivering genetic gain. The 2 high-level metrics for the effectiveness of plant breeding and dissemination programs are:

- i) *The rate of genetic gain in productivity, on an annual basis, delivered in farmers' fields in the form of producible, resilient, farmer- and consumer-preferred varieties.* This metric characterizes the success over time of the program in producing a steady stream of improved varieties. This metric should also take into account the *cost* per unit of gain.
- ii) *The average area-weighted age of varieties in farmers' fields (AAWAV).* This is a measure of the effectiveness of the breeding and dissemination system in driving the adoption of new varieties and replacement of obsolete ones.

These metrics shift the focus from measures only indirectly linked to impact, like the number of varieties released, or backward-looking metrics like total area planted to a program's varieties (even very old ones) towards the measurement of current, ongoing effectiveness and impact. The purpose of this initiative is to increase the rate of genetic gain generated by CGIAR-linked breeding programs, and to accelerate the delivery of this gain in farmers' fields in the form of farmer-, consumer-, and market-preferred varieties. One of its key benefits will be the alignment of CGIAR centers, CRPs, and the donor community around a common set of metrics for guiding and evaluating investments in crop improvement. This will provide research managers with clear guidance, and unambiguous performance measures.

Accelerating the development and wide-scale adoption of new varieties of crops important in the various regions of the developing world will deliver several benefits, including: Increased incomes for farmers and others along the crop value chain; more nutritious and affordable food that meet consumer preferences and market demand; more diverse diets, as farmers and consumers devote less land and income to staple crops and more to nutrient-dense fruits, vegetables, and animal-sourced foods, and more resilient crops, better able to cope with climate shocks such as drought as well as new pest and disease outbreaks. Modernising the global and regional crop improvement programs supported by the CGIAR is urgently required to achieve these benefits. Accelerating new variety development and enabling the more widespread adoption and use of new varieties is one of the components of agricultural transformation, enabling small-scale farmers to move from subsistence production to farming as a profitable business.

Modern plant breeding is driven by new scientific and technical advances and improved processes, including automation and mechanization, faster turnover of generations, and more accurate selection methods, including marker assisted selection. Such advances are now used routinely in modern plant breeding programs in both the public and private sectors. These new approaches have led to substantial increases in the efficiency and effectiveness of plant breeding programs and are driving continual genetic gains in commercial agriculture.

Modern approaches to plant breeding are equally applicable to the breeding of crops important throughout the developing world. The use of new breeding technologies in global, regional and national breeding programs supported by the CGIAR would accelerate new variety development and enable a continuous supply of improved varieties, as indicated by more rapid turnover and replacement of older varieties.

Measures of success

Success of CGIAR supported breeding programs will be measured by their achievements in accelerating the rate of genetic gain delivered by CGIAR-supported breeding programs, and by reducing the area-weighted age of varieties in farmers' fields. In practice, these metrics take years to influence, so in the medium term (five years), the CGIAR supported breeding programs will be evaluated using intermediate measures of breeding program effectiveness that are widely applied in the private sector, including breeding cycle length, heritability in yield trials, and the year-on-year performance of new cohorts relative to currently-grown varieties.

2. SUMMARY OF KEY FINDINGS AND RECOMMENDATION

Prioritization and implications for future funding

IFPRI and USDA were commissioned to undertake foresight modelling for 20 crops on which the CGIAR conducts breeding programs. The models presented a range of options on relative priority of crops, depending on the approach and the criteria used. The relative ranking of crops by their share of expected benefits provides a menu of choices for investments in crop improvement on one crop or groups of crops, globally or in different regions and the share of benefits to be derived from these investments. The results of these priority analyses may be used to inform future decision-making by funders, collectively and individually, on investments in plant breeding, including the relative importance of crops in specific geographic areas, taking account of the investors' criteria of choice (e.g. economic impact, poverty reduction, nutrition, or regional importance).

The donor group over the course of the next year--while modernization proceeds--will agree on a core set of crops x geographies that will have priority for funding. The donors will commit to having that core financed for a specific number of years at specific dollar amount. Other crops and geographies will also be supported under the Initiative but will not be included in this prioritized shared agenda.

However, IFPRI notes that these modelling studies are only one of the inputs to inform decisions on future investments by the CGIAR system in plant breeding. Other factors also need to be considered in reaching decisions on future investments, including new scientific opportunities; the technical feasibility of achieving increased productivity through genetics and breeding; the comparative advantage of the CGIAR Centres and breeding programs; availability of other providers, including the role of the private sector; and the likelihood of high rates of adoption of new varieties with product profiles that respond to farmers' requirements and consumer preferences.

What the prioritization studies means for future funding of CGIAR breeding programs

The modelling analysis has confirmed that the 20 CGIAR crops considered in the analysis have either global and/or regional importance in meeting the SDG2 goals in the future. Given segmentation of public and private sector efforts, and the relatively short time frame to convert approaches into impact before 2030, there is no crop amongst this 20 that merits elimination, rather the future focus will be shifting breeding emphasis to specific geographies where there is greater strategic importance of specific crops for reducing poverty and strengthening food security. Further, the priority is to focus each of the CGIAR's crop breeding programs within specific geographic areas on developing a series of **priority product profiles**, developed in partnerships with NARS and others along the value chain, which will contribute maximum impact from delivering these improved varieties/product profiles to deliver genetic gains in farmer's fields as rapidly as possible and to make the programs agile enough to respond to the exigencies of climate change.

It should be noted that, to be eligible for continued support, all CGIAR breeding programs, regardless of their inclusion in the prioritized core set, should have in place a continuous improvement plan to increase breeding program effectiveness. These plans will be developed and implemented with the technical support of the EIB.

A modernization agenda for CGIAR plant breeding programs

The implementation of the initiative will build on existing CGIAR programs and expertise, while seeking additional advice and support for these programs from the world's strongest public and private sector breeding organizations. It aims to strengthen current CGIAR plant breeding programs and enable CGIAR Centres to expand their partnerships with national plant breeding programs, including by creating regional plant breeding networks that focus on accelerating genetic gains for improving agricultural productivity and profitability in the crops most important in the developing world.

These international plant breeding partnerships/networks will link international agricultural research centres, national agricultural research systems (NARS), private sector companies, and advanced research institutes (ARIs), around the common purpose of developing and delivering new crop varieties that increase productivity, and/or have other attributes that lead to increased productivity, profitability and/or sustainability (such as consumer preferences in taste, colour or quality).

A series of independent assessments of the CGIAR breeding programs were commissioned by the Bill & Melinda Gates Foundation (BMGF) during 2016-18, using the Breeding Program Assessment Tool (BPAT), and led by the University of Queensland, Australia. Approximately 20 BPAT assessments, have identified areas of strength and weakness in crop breeding programs common across a range of CGIAR programs and areas of opportunities where the current breeding programs urgently need to be strengthened to improve their efficiency and effectiveness.

Key components of a modernization agenda for CGIAR plant breeding programs

The key components of a modernization agenda and best practises recommended for CGIAR plant breeding programs are:

1. More systematic use of **Product profiles**, based on continually updated market intelligence and stakeholder consultations, to ensure that new varieties are designed to meet the requirements and preferences of women and men farmers, consumers, traders, processors and others along the crop value chain.
2. **Institutional accountability** of the CGIAR Centres to be responsible for the delivery of genetic gains in farmers' fields, through institutional ownership of product profiles, and institutionally managed product advancement systems.
3. **Continually optimized breeding pipelines** that maximize genetic gains vs the time and cost of plant breeding programs through the use of rapid breeding cycles that accurately integrate genotypic and phenotypic information in selection decisions.
4. **Mechanized and digitized phenotyping and data collection systems** that increase accuracy and throughput while reducing costs
5. **Breeding information management systems** that support the integration of genotypic, pedigree, and phenotypic information in selection decisions.
6. **Variety testing (on-station and on-farm) and advancement systems** that clearly identify new products (new varieties) that are demonstrably superior to the varieties that farmers currently grow.
7. **Demand creation and dissemination** of new varieties through strong linkages with seed systems, and clear messaging on the need to replace obsolete varieties with proven new products.
8. **Stronger partnerships with NARS** that involve co-design of product profiles, joint testing from Stage 1 (the initial yield testing phase), joint selection of parents, and joint advancement and dissemination decisions.

All breeding programs operated by CGIAR Centres and their NARS partners should develop and implement a modernization program based on current best practices, commensurate with their resources. Modernising all CGIAR plant breeding programs will require strengthening capacity within individual breeding programs as well as enabling access to new technologies applicable across a range of crops (e.g. high-throughput genotyping) via services that are efficiently shared; as well as greater sharing of new technologies and research facilities amongst CGIAR Centres, NARS partners and universities. The newly formed CGIAR Excellence in Breeding platform (EiB) is charged with the responsibility of working with the CGIAR Centres and their NARS partners to help all Centre-led breeding programs achieve these aims.

Modernization at the breeding program level

The modernization process should include three basic steps:

- i) A baseline assessment using the BPAT, highlighting key opportunities for improvement;
- ii) The development of a breeding program modernization plan, with the technical support of the EiB.
- iii) The implementation of the modernization plan, with technical support of the EiB and periodic re-assessment via the BPAT.

Future Challenges to the CGIAR System and Actions Required

The CGIAR's crop breeding programs and their extensive breeding networks with national partners are well positioned to take advantage of new technologies and best practices for plant breeding and apply these technologies more widely to crops in various regions of the developing world. However, the modernization of CGIAR supported plant breeding programs to better deliver genetic gains in farmers' fields will require actions by all levels of the CGIAR system and with their partners. The priority actions are:

➤ **Stronger research culture, leadership and accountability by both the CGIAR System and CGIAR Centres for the delivery of genetic gains from new crop varieties**

More strategic leadership, direction and accountability is needed from the CGIAR System's leadership (System Council and System Management Board) and by Centres' and CRP leadership. This will require leadership by people knowledgeable about modern plant breeding and able to ensure accountability by the CGIAR Centres that CGIAR-supported plant breeding programs (including regional breeding networks and partnerships with national plant breeding programs) efficiently deliver products that lead to new varieties and result in genetic gains in farmers' fields. CGIAR leaders need to effectively support their breeding teams and hold them accountable for the delivery of genetic gains in farmers' fields. This will require sharing services (such as high-throughput genotyping and breeding information management system development) that are more efficiently provided across the entire system than by individual centers.

➤ **Continuous professional development of plant breeders and new recruitment to strengthen CGIAR crop improvement teams:**

Modernising CGIAR plant breeding programs will require continuing professional development of the cadre of approximately 150 plant breeders currently working in the CGIAR system. The newly formed Excellence in Breeding Platform (EiB) will play an important role in this regard. The CGIAR Centres responsible for the implementation of modern breeding programs also require new recruitments of scientists with additional skills in modern plant breeding and related disciplines (including the engineering skills needed to mechanize and digitize experiment stations). In addition to strategically hiring new CGIAR staff, the breeding programs will need access to skills in complementary areas, such as market analysis, to enable CGIAR crop improvement teams to address current gaps, such as developing product profiles for new varieties that better reflect farmer and consumer preferences;

and to enable better interaction of plant breeding programs with seed system participants to ensure the delivery and wider adoption of new varieties.

➤ **Financial resources: More efficient use of current resources and mobilising new investments in plant breeding**

The CGIAR system currently invests about USD 120m per year in plant breeding (2017\$), the majority of which (about 80%) comes through (Window 3) bilateral funding to CGIAR centres for plant breeding projects. Modernizing CGIAR plant breeding programs will require making the most efficient use of current resources as well as mobilizing additional financial resources to drive substantial investments in modern plant breeding to underpin agricultural transformation in the developing world. Because of the continuous and long-term nature of plant breeding, sustained and predictable funding will be needed.

A balanced portfolio of future investments by the CGIAR in crop improvement would include a selection of priority crops, targeted to geographic and agri-ecological environments where increasing crop productivity, profitability and/or sustainability will contribute to: agricultural transformation; nutritional security; and enabling agricultural systems to be more resilient to climate change. All three targets are part of the CGIAR's strategy whereby food and agriculture will contribute towards achieving the Sustainable Development Goals.

PART B: PRIORITIZATION ANALYSIS AND IMPLICATIONS FOR FUTURE SUPPORT

This section contains a summary of the prioritization analysis conducted by IFPRI and USDA, on 20 crops, in various geographic regions, and their implications for future support for plant breeding

3. PRIORITIZATION

3.1 Prioritization studies: IFPRI approach to modelling and analysis

The initiative aims to make a systematic prioritization of crops for research investments that will contribute towards achieving SDG goals by 2030, in terms of the likely benefits from investment in accelerating breeding of various crops. The initiative has convened a Priorities Group (PG) of eminent agricultural economists to contribute to a poverty-weighted, economic modelling exercise on crop prioritisation amongst the 20 principal CGIAR crops. The modelling studies were undertaken by IFPRI and USDA and reviewed by the Prioritization Group and a member of the ISPC.

The 20 crops analysed in the prioritization studies were:

Cereal grains: rice, maize, wheat, sorghum, millet, barley

Roots, tubers and banana (RTB): potato, cassava, yams, sweet potato, banana, plantain

Oilseeds and pulses: Pulses (aggregate); beans (*Phaseolus*); chickpea (*Cicer*); cowpea (*Vigna unguiculata*); pigeon pea (*Cajanus*); lentil (*lens*); other pulses (*pisum*); groundnuts; soybean (SSA only).

The geographic area of interest included 106 countries, including all countries in Africa, Asia, and Latin America, except China, Brazil, and southern cone countries of Latin America. A summary of the methodology and the main findings are given in Annex A, including several Tables that summarise the data from the modelling and analysis by IFPRI and partners.

Summary of findings from the prioritization studies

The models presented a range of options on relative priority of crops, depending on the approach and the criteria used. The results were presented by IFPRI under four scenarios:

- Economic surplus model results (with and without poverty weighting)
- Parity model results (with and without poverty weighting)
- Regional importance of crops
- Impacts on nutrient availability in crops

Both the economic surplus model and the parity model highlight the overall importance of cereal grains in the food systems of developing countries to 2030. The major difference between the two main modelling approaches (economic surplus or parity model) was the greater relative contribution of root crops and legumes in the parity model (focussed on developing country consumption measures). Regional shares also move substantially towards Africa in the economic surplus model when using the poverty head count index.

The foresight modeling results presented by IFPRI, covering both the agricultural sector and the broader economy, provides key insights for the impact of crop breeding on multiple indicators in future years under alternative scenarios. The summary graph (IFPRI Figure 6, below) summarizes the different metrics explored in this analysis and helps illustrate their implications for R&D allocations.

For each of the metrics in figure 6, a “parity rule” would suggest that the crop value share could help inform an efficient R&D allocation. Importantly, they help illustrate how CGIAR system goals might move the R&D portfolio. The parity (crop value) and economic surplus value shares give greater emphasis to total income growth; economic surplus weighted by the poverty indices gives greater prioritization to poverty reduction; while undernourished children and population at risk of hunger give greater importance to food security.

While rice comes out as the dominant crop globally under all these metrics, the relative importance of crops differs significantly among them. Weighting income by the poverty gap index significantly raises the profile of sorghum, millet, yam, and groundnuts, and reduces the importance of wheat, potato, and to some extent, rice. IFPRI notes that this modeling approach helps explore alternative futures, including the impacts of research investment and productivity growth, but it is only one dimension of a science-based decision-making process for prioritization.

3.2 Implication of the results of the prioritization Studies

Global benefits from increasing productivity of crops

- There are sizable economic impacts from increasing productivity for the 20 crops analysed, largest for some cereals and some RTB crops, varying by region. Poverty weighting raises the profile of crops that are important in poor countries.
- Generally, there are small impacts of increasing productivity on micronutrient adequacy ratios during this timeframe (to 2030).
- Continually increasing crop productivity to 2030 will lead to substantial economic and social benefits, as estimated for increased economic benefits, poverty reduction and food security.
- The analyses provide evidence that investing in accelerating increases in crop productivity through plant breeding is a good investment for the 20 crops analysed.

Relative scale of benefits varies by crop

- The scale and type of the benefits varies amongst the 20 crops, with some crops giving more benefits than others, largely due to their value of production, predicted impact on poverty reduction and predicted trends in production and use of the crop through to 2030.

Relative scale of benefits per crop is also affected by geographic region

- The scale and type of benefits varies not only amongst crops, (according to their value of production), but is also affected by geography (i.e. some crops are more important [to poor people] in one geographic region than in another).
- The relative (rank) order of crops for the combined benefits of economic benefits and impact on poverty reduction, for different geographic regions, is shown in IFPRI Table 3b (Annex A).

Impacts on nutrient availability

- Increasing productivity of crops increases nutrient availability (IFPRI Tables 5 and 6, Annex A).
- Increasing nutrient availability does not necessarily lead to impact on human nutrition, as many other factors come into play in terms of changing diets and the importance of public health education, to lead to better nutritional outcomes. (See A4NH annual report 2017). (A4NH Annual report 2017).

Prioritization leads to a menu of options for funders

The relative ranking of crops by their share of expected benefits provides a menu of choices for investments in crop improvement on one crop or groups of crops, globally or in different regions and the share of benefits to be derived from these investments. As all crops are treated similarly, modelling outputs have the advantage of providing an objective comparison of crop priority for subsequent analysis purposes. The results of these priority analyses may be used to inform future decision-making by funders, collectively and individually, on investments in plant breeding, including the relative importance of crops in specific geographic areas, taking account of the investors' criteria of choice (e.g. economic impact, poverty reduction, nutrition, or regional importance).

However, IFPRI notes that these modelling studies are only one of the inputs to inform decisions on future investments by the CGIAR system in plant breeding. Other factors also need to be considered

in reaching decisions on future investments, including new scientific opportunities; the technical feasibility of achieving increased productivity through genetics and breeding; the comparative advantage of the CGIAR Centres and breeding programs; availability of other providers, including the role of the private sector; and the likelihood of high rates of adoption of new varieties with product profiles that respond to farmers' requirements and consumer preferences.

Future Investment Scenarios

The breeding pipeline (crop x product profile x geography) as the proposed unit of plant breeding investment

In further consideration of how to determine priorities for future investments in breeding, including at a meeting of a technical experts' group and donor representatives in mid-2018, BMGF proposed and USAID strongly supported the concept of using *the unit of investment to be the breeding pipeline delivering a particular product profile in a particular region* (this unit is referred to as the "pipeline" for the sake of brevity henceforth).

The estimated cost of running a pipeline ranges from USD 0.75m to USD 5m annually, depending on the cost of generating and phenotyping selection candidates. The cost of operating a breeding pipeline is proportionate to the number of candidates generated and phenotyped; even small programs, if effectively managed, can generate high rates of genetic gain at modest cost.

Thus, under this scenario, it was concluded that the prioritization exercise should not be framed around the idea of eliminating certain species from the CGIAR portfolio, but rather to weight future investment in pipelines in proportion to their potential impact on poverty in particular geographies. Thus, if a crop such as (for example) climbing bean is of limited importance globally but great importance in parts of Eastern Africa, it should not be eliminated from the program based on its relatively localized importance; rather, a modestly scaled program, targeting only Eastern Africa, it should be supported.

For the breeding pipeline to serve as the unit of investment, CGIAR breeding programs and potential donors must have the following information:

- What product profiles, in what geographies, are the Centres and CRPs and committed to delivering (*based on the crop x geographies identified by donors as priorities for future investments, depending on their criteria of choice*);
- What is the potential impact on poverty, livelihoods, and nutrition of successfully meeting genetic gain and varietal replacement targets for these product profiles;
- How many hectares are grown in the target geographic region or how many smallholders in that region will grow the crop, as metrics for the volume/significance of the crop in the target region(s);
- How much will it cost to operate the pipeline

With this information, donors can choose to support the pipelines with the greatest impact on poverty in particular geographies, rather than deciding to fund a crop globally. Thus, a critical step in the prioritization process will be for the CGIAR breeding programs to clearly describe the product profiles they commit to delivering, cost the pipelines needed to deliver the products, and provide a quantitative estimate of the impact of delivering these products on poverty.

What the prioritization studies means for future funding of CGIAR breeding programs

The modelling analysis has confirmed that the 20 CGIAR crops considered have either global and/or regional importance in meeting the SDG2 goals in the future. Given segmentation of public and private sector efforts, and the relatively short time frame to convert approaches into impact before 2030,

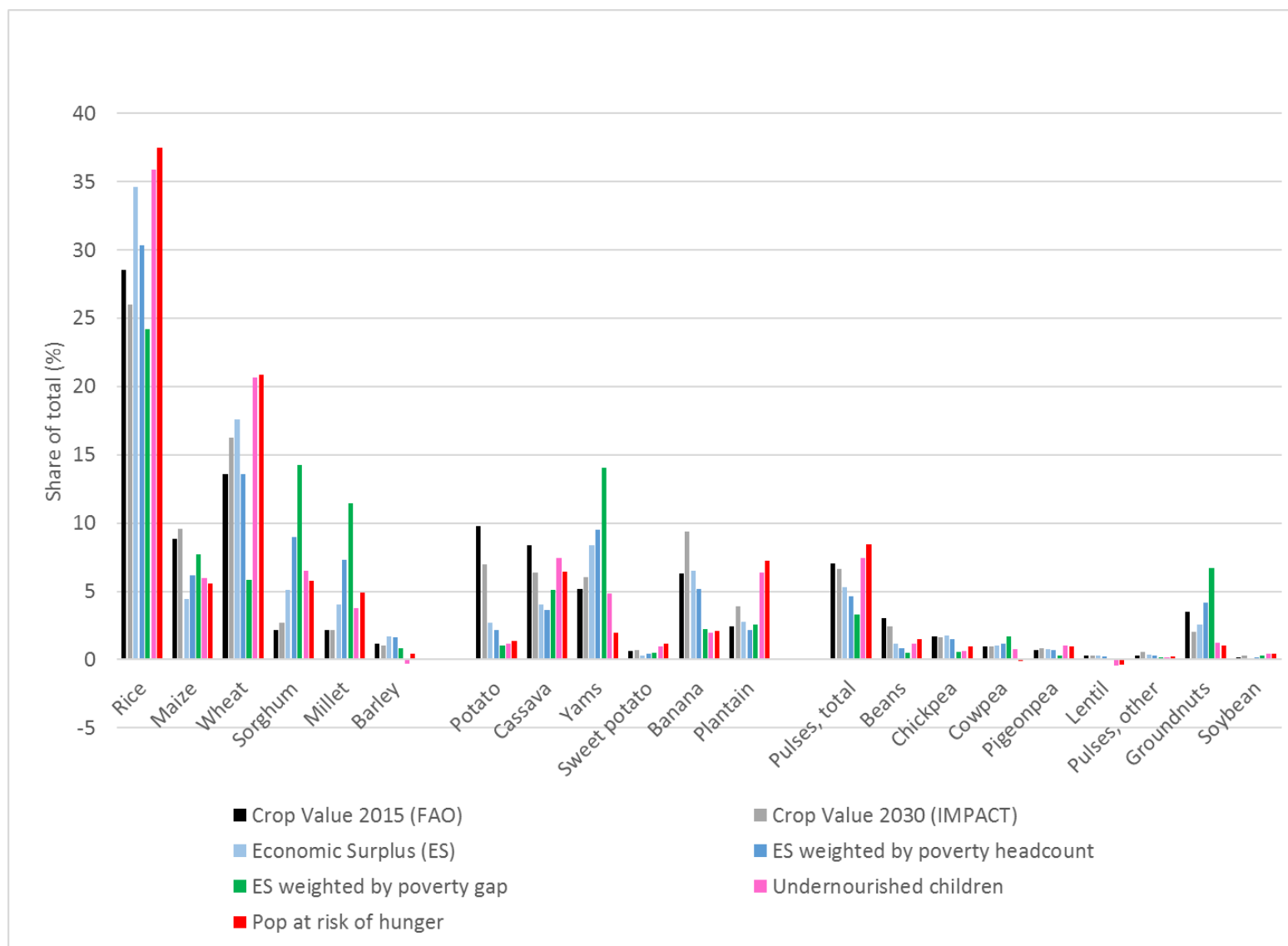
there is no crop amongst this 20 that merits a reduction of effort, rather the focus is shifting to specific geographies where there is greater strategic importance of specific crops for reducing poverty and strengthening food security. Further, the priority is to focus each of the CGIAR's crop breeding and improvement programs within specific geographic areas to contribute maximum impact from improved varieties in farmer's fields as rapidly as possible and to make the programs agile enough to respond to the exigencies of climate change.

The funder initiative calls for a response to the BPAT analysis by each crop breeding program through the design of a modernized and improved breeding plans in concert with the Excellence in Breeding Platform (EiB) acting as a resource and potential broker of system services. The plans will be comprehensive and address the key national partner entities which are actively involved with CGIAR breeding programs. Plans will distinguish crop by geographic settings and a key component of the plans will be the identification of a focussed set of product profiles as agreed targets for the breeding program to work towards and to deliver demonstrable genetic gain to farmers' fields. The development of product profiles is expected to be a properly collaborative process taking into account national partners and market demands as well as expert advice on targets.

Funder investment in the modernization process will be guided by the following considerations:

- All crop programs of the CGIAR are expected to develop new breeding plans and to commit the necessary human and management resources for the continuation of program funding.
- In many cases, modernization is effectively a more committed way of designing impactful programs which is as much managerial commitment, reorganization and mind-set towards delivery of varieties on the basis of existing resources.
- Funders in 2019 will continue to support the Excellence in Breeding Platform to provide design support. The funders will also provide modest funds to Centre breeding programs or "breeding flagships" of CRPs for collaborative identification of product profiles suitable for discrete geographic regions and their nutritional, climatic and market contexts.
- It is recognized that in the CGIAR there are Centers which act as hubs serving more than one crop. Funders want to build on this and see cross-center efficiencies identified to inform the process for upgrading the major breeding sites (through installation or improvement of appropriate mechanization, information management, genotyping services, phenotyping sites and target monitoring practices) and selected outstations, when adequate modernization of breeding plans are to hand starting in 2020.
- The intent therefore is that each crop breeding program will benefit from new collaborative development of modernized breeding plans towards 2030 and that system effort and funder support will be put into upgrading breeding programs, Centre hubs and cross system services.
- Suitable analysis of scope and needs per crop breeding program will define the exact costs of the scientific, technical and financial inputs required in the future.
- Individual funders may wish to augment activities responding to particular crop x geography priorities according to their priorities for beneficiary concerns.
- Funders will continue to confer to ensure complementary resourcing for the modernization agenda over the next three years.
- Funders will continue to seek to facilitate CGIAR relationships with seed and other delivery system initiatives which may be aligned with this Initiative through other funding channels.
- The immediate priority for the CGIAR is the modernization of the crop breeding agenda.

IFPRI Report - Figure 6 – Relative impacts of crop productivity shocks according to income, poverty and food security indicators



PART C: DETAILS OF CGIAR CROP BREEDING PROGRAMS AND AREAS FOR IMPROVEMENT

This section focuses on the current CGIAR breeding programs, the results of the breeding program assessments and the constraints and areas of improvement identified, where action is required, at the CGIAR System level and by individual Centres and CRPs and by cross system entities

4. Overview of Current CGIAR Crop Improvement Programs:

4.1 What do CGIAR breeding programs produce?

CGIAR breeding programs as currently structured have three main products:

- i) *Finished varieties* that can either be directly released by NARS or used as elite parents by national partners in crosses to varieties from their own programs. Finished varieties have been by far the most impactful products of the CGIAR system to date. They should be (but in the CGIAR currently often are not) designed to conform to a *product profile* (PP), a detailed product description specifying the geography and farming system targeted, the variety to be replaced, the features of the old variety that must be retained to be acceptable to farmers, processors, and consumers, and the trait improvements that will attract market share from the old variety. Breeding programs need to deliver improved finished varieties continuously, because most important crop traits are controlled by many genes with small effects. With this genetic architecture, favorable alleles are accumulated in elite varieties over many cycles of breeding. However, finished varieties also need to carry disease and stress tolerance genes with major effects, emerging from a *trait pipeline*.
- ii) *Traits*: Many breeding organizations also identify, and mobilize for use in breeding, DNA alleles with large effects on biotic and abiotic stress tolerance and quality. Several CGIAR programs have mapped and deployed such traits. These “trait pipelines”, which often exploit genetic variation in CGIAR gene banks, should be described and prioritized similarly to the varietal product profiles described above, but they differ in some important respects. First, not all breeding organizations need to operate their own trait pipelines. For example, the CIMMYT wheat program has been very effective in deploying fungal disease resistance genes, but other specialized organizations identify, map, and sequence these genes. Trait pipelines need to be prioritized similarly to product profiles, i.e. according to potential impact on productivity, poverty, and nutrition. However, unlike variety development programs, some trait pipelines are expected to reach a point when no additional investment is warranted. For example, IRRI has identified several genes conferring the ability for rice to germinate under water. There may be no need for more work on this trait. Trait pipelines must be regularly assessed in terms of their priority.
- iii) *Donor lines*: Major gene traits isolated from the trait pipelines of CGIAR or ARI programs are often derived from unimproved landraces that are not suitable for modern agriculture. The trait of interest must be “packaged” in an elite “donor” line before it can be moved into commercial germplasm at a reasonable cost. For example, the *Sub1* submergence tolerance trait in rice was derived by researchers at IRRI and UC Davis from a landrace, FR13A, that is extremely low-yielding and of poor quality. The *Sub1* allele could not be routinely used in breeding until it was introgressed into an elite variety, *Swarna* via multiple backcrosses using marker-assisted selection. The *Swarna-Sub1* donor variety is much more easily used as a source of submergence tolerance than the original source, FR13A. The development of elite donor lines and the rapid and efficient deployment of trait pipeline products is a complex and highly skilled process that should be a key role for the CGIAR but has been under-emphasized relative to the elite line and trait pipelines.

The Crops to End Hunger Initiative focuses primarily on improving the effectiveness of pipelines that develop finished varieties, and on the process of developing donor lines and using them to incorporate new traits in finished varieties.

4.2 Current CGIAR crop improvement programs

The CGIAR system currently supports breeding programs on some 20 crop and forage species, targeted to various agro-ecologies throughout Asia, Central and South America, sub Saharan Africa, West Asia and North Africa. These global and regional crop breeding programs are led by 10 CGIAR Centres and the respective multi-centre CGIAR Research Programs (CRPs). Most efforts are directed towards crops important in sub Saharan Africa (SSAf) and South Asia (SA). There are also significant CGIAR breeding programs in West Asia/North Africa (WANA) and Latin America (LAC).

The target crops are:

Cereals: Rice, maize, wheat, millets, sorghum, barley

Root, tubers and banana (RTB): cassava, yams, potato, sweet potato, banana and plantain

Oilseeds and pulses: *Phaseolus* bean, chickpea, cowpea, groundnut, pigeon pea, lentils, faba bean, soybean

Forage crops: *Brachiaria* spp. and other forage species

In terms of scientific and technical resources, there are approximately 155 plant breeders working on plant breeding programs. This estimate is based on the Centres' numbers of research staff with Master's or PhD level education currently working as plant breeders in Centre-led programs. These plant breeders lead larger crop improvement teams that also include expertise in bioinformatics, genetics, molecular biology, plant protection, agronomy, seed systems, and other skills relevant to the development and delivery of improved crop varieties.

In terms of financial resources, the annual budget for plant breeding across all crops for all Centres and CRPs in 2017 was in the order of USD 120 million p.a. Financial support for the breeding programs is channelled either directly to the Centres, or in the case of CGIAR central funds (Windows 1 and 2) through the CGIAR Research Programs (CRPs). In practice, about 80% of the current funding directed at CGIAR Centre-led plant breeding programs comes to the responsible Centre via project funds to the Centres (Window 3 funds). The balance (ca. 20%) is provided to the breeding programs via the CRP funds (Window 1 and 2).

There are additional technical resources available to all breeding programs for common services, education and training activities through the new Excellence in Breeding Platform (EiB). The EiB has a budget of approximately USD 5m in 2018.

5. Breeding Programs Assessments and Common Areas for Improvement and Action

5.1 Breeding program assessments: Methodology

A systematic program of breeding program assessments (BPAT) to evaluate the performance, scientific capacity and technical quality of current CGIAR Centre-led plant breeding programs was commissioned by BMGF in 2016 and is on-going. The BPAT Program is managed by the University of Queensland, Australia with technical and financial support from the Gates Foundation and its senior program officers.

The breeding program assessment process includes a comprehensive questionnaire addressing all aspects of the breeding program, to be completed in advance by the breeding team, followed by an on-site visit of an international review team commissioned by the BPAT program, to meet with the breeding team, review their programs and make recommendations to the breeding team and Centre management on areas for improvement. The assessments are done using a formal rubric that facilitates comparability across assessments. BPAT assessment of all CGIAR crop breeding programs are expected to be completed in 2019.

The BPAT assessments are providing an objective diagnosis of the effectiveness of breeding programs of the CGIAR centres/programs and selected NARS breeding programs in generating genetic gains; an assessment of their progress and performance in implementing the key elements of modern plant breeding programs; and their progress towards developing new varieties that are responsive to market demands and have a high level of uptake by farmers, thereby delivering genetic gains in farmers' fields.

Summarised information, from all completed BPAT assessments as well as from the responses to a survey questionnaire completed by several other CGIAR crop breeding programs that are yet to undergo full BPAT assessments (scheduled for 2018-19), was presented by the BPAT /BMGF team at the first meeting of a Technical Experts Group (TEG) in April 2018. The technical experts were commissioned by the multi-donor group sponsoring this initiative to review the BPAT assessments and related information, and identify areas where improvements are required within and across current CGIAR breeding programs.

5.2 Summary of constraints and areas for improvement across the CGIAR system

The BPAT assessments and other reviews of CGIAR-supported global and regional crop breeding programs have identified several areas for improvement that are common to most Centres and most breeding programs, and therefore where system-wide action are required. These various areas for improvement are relevant to different levels of the CGIAR system, from the Centre/programs that are implementing breeding programs; through to the CGIAR System leadership, including the System Council and the System Management Board, concerning overall strategy, management and finance for plant breeding; as well as improvements and new opportunities for cross-system co-operation and activities, common technical advisory services and more sharing of technologies and facilities across CGIAR-led breeding programs and their partners in national and regional plant breeding programs.

Constraints and Areas for Improvement

CGIAR System Council and Funders: Constraints and Areas for Improvement

- **Strategic directions:** There is a need for strategic direction of modern plant breeding at the CGIAR system level; including having an overall CGIAR strategy crop genetic improvement that is linked to stable, long term funding and accountability for delivery of genetic gains on-farm, with agreed metrics for assessing performance and delivery. A key strategic question for the system is the nature of its future interaction with increasingly capable NARS, including in plant breeding.
- **Priorities for investment in plant breeding:** Decisions on funding of crop/regional priorities, collectively and/or by individual funders, depending on the funder's global/regional policies and priorities and areas of interest;
- **Finance:** CGIAR reform processes and CRP financing modalities have led to short term financing of long-term breeding programs across the CG system; very limited W1/W2 funding is available for breeding programs; Window 3 bilateral projects that provide most of the funding for plant breeding within Centres and CRPs are often narrowly focussed and relatively short term (3-5years); (80% funding of CRPs is Window 3, bilateral funding for R&D).
- **Future funding modalities,** to support global and regional breeding programs/networks; level and type of investments by funders; including addressing stability of funding, and ways of reducing the over dependence of long-term breeding programs on short term, project funding; and address the lack of capital investment by the CGIAR funders for upgrading of infra-structure and equipment essential for modern plant breeding;
- **Identify levels of investment** necessary to deliver benefits; identify current and future investments by the CGIAR system in crop breeding in total; as well as relative investments by crop, geography and product profile for Centre/breeding programs; identify crops x geographic areas where new funds are needed to accelerate breeding programs to deliver new varieties with characteristics (product profiles) that meet farmer needs and market requirements;
- **Common metrics for assessing the effectiveness of breeding investments.** Agreement among funders on common high-level metrics for the effectiveness of breeding programs (rate of genetic gain delivered in the form of farmer-preferred and market-demanded products, and the rate of uptake of these products expressed as the average area-weighted age of varieties in farmers' fields) will enhance the ability of funders to align investments and provide clear guidance to the leaders and managers of the system on how to design and operate more effective breeding programs.
- **Clarify relative responsibilities** of the System Council, System Management Board, individual funders, Centres/CRPs implementing crop breeding programs, and the Excellence in Breeding Platform (EiB) in providing technical advice and organising shared services to all breeding programs.

CGIAR System Management Board: Constraints and Areas for Improvement

- **Strategic leadership and overall responsibility** to the System Council for the delivery of successful plant breeding programs that are implemented by the CGIAR Centres/programs, with success defined in terms of the overall high-level metrics of genetic gain and varietal replacement, as described above;
- **Inform decisions on priorities** by the System Council and funders on crop/regional priorities for investments in plant breeding;
- **Mobilise new funding** for CGIAR/NARS breeding programs, in line with the agreed priorities and agreed metrics to measure performance and delivery of products by the breeding programs that deliver genetic gains to farmers;
- **Facilitate new public-private partnerships** amongst CGIAR Centres, national breeding programs, advanced research institutes, private sector companies and the seed sector, as part of strengthening the CGIAR's overall efforts in plant breeding and delivery of new varieties;

CGIAR Centres and Breeding Programs: Constraints and Areas for Improvement

The BPAT assessments of the CGIAR breeding programs during 2016-18, as well as other processes, have identified several issues common to most CGIAR breeding programs, which need to be addressed to improve their efficiency and effectiveness, particularly:

- More systematic use of, and institutional ownership of, **product profiles**, based on continually updated market intelligence and stakeholder consultations, to ensure that new varieties are designed to meet the requirements and preferences of farmers, consumers, traders, processors and others along the crop value chain.
- **Institutional accountability** of the CGIAR Centres who are responsible for the delivery of genetic gains in farmers' fields, through new varieties that fit specific product profiles. This includes the organization, support, and management of product development and supporting teams around the delivery of genetic gains in those product profiles.
- **Continually optimized breeding pipelines** that maximize genetic gains vs the time and cost of plant breeding programs. There are particularly severe system-wide deficiencies in engineering and mechanization support and the implementation of integrated breeding informatics systems.
- **Variety testing and advancement systems** that clearly identify new products (new varieties) that are demonstrably superior to the varieties that farmers currently grow.
- **Demand creation and dissemination** of new varieties through strong linkages with seed systems, including public and private-sector partners who are responsible for seed multiplication and distribution within countries.
- **Strengthening partnerships with national breeding programs** to agree on priority product profiles and to develop new varieties of priority crops in target geographies, through jointly-managed breeding networks, including forming regional breeding networks focussed on improving genetic gains in specific crops for a number of countries.
- **Strategic partnerships for trait discovery** with advanced research institutes (ARIs) and private companies, for identifying the genetic basis of priority traits identified within the target product profiles, and for which adequately-characterized sources do not currently exist;

Excellence in Breeding platform (EiB)

- **Excellence in Breeding Platform (EiB):** To provide support for implementation of modern plant breeding programs by CGIAR Centres/NARS plant breeding programs, by providing technical advice and common services in support of all CGIAR Centre-led breeding programs;

The new Excellence in Breeding platform (EiB) will provide technical advice and support to individual crop breeding programs. The EiB will be an important source for advice and support for modernising CGIAR Centre-led plant breeding programs. The EiB was conceived as a technical advisory service to promote best practices in plant breeding, to support Centres in upgrading their breeding programs, to form a “Community of Practice” among plant breeders working in CGIAR centres and their NARS partners, and to support common and scientifically valid approaches to the documentation of genetic gain. It is also managing shared services required by all CGIAR breeding programs, including the development of breeding and genomics information management systems and the contracting out of high-throughput genotyping services.

Linkages with other cross-system entities

- **Cross-system linkages with the integrating CRPs:** There are opportunities for CGIAR breeding programs to link more strongly with the integrating CRPs, such as Agriculture, Nutrition and Health (A4NH), Climate Change (CCFAS), Water, Land and Environment (WLE), Policy and Management (PIM), all of whom could provide inputs into identifying the priority traits required within product profiles in target environments and farming systems; for example, A4NH could advise breeding programs on nutritional issues, including micronutrient priorities, by crop and by region and on biofortification strategy; CCFAS can advise Centres on crops and characteristics useful in more climate resilient crops, as part of climate adaptation strategies.
- **Linkages with other CGIAR platforms:** There are also skills in other CGIAR platforms (e.g. gender; genetic resources; data management), which are complementary to the skills in the CGIAR Centres’ plant breeding programs, which could be mobilised to strengthen the CGIAR’s overall efforts in plant breeding (e.g. the gender platform is informing breeding programs as to the crop’s characteristics preferred by women and mechanisms for incorporating the input of women farmers and consumers into the design of product profiles.
- **Upgrading and sharing of infrastructure and services among CGIAR Centres, NARS and universities:** The Centres and CRPs will work with the EiB and others to identify needs and opportunities for sharing of facilities, equipment and technology platforms across Centres, NARS and universities, including costs of any upgrades required. For example, a single breeding informatics software development hub should manage the development and deployment of systems for phenotypic, genotypic and pedigree data for selection decision support, replacing current redundant development of the Breeding Management System, B4R, CassavaBase, and other similar systems. Within Africa, ILRI hosts the BecA-ILRI Hub in Nairobi as a shared research platform, where several CGIAR Centres and NARS scientists are working on crop improvement for several crops important in eastern and southern Africa.

PART D: DETAILED IMPLEMENTATION PLAN FOR MODERNIZATION OF CGIAR BREEDING PROGRAMS

This section proposes a seven-step, detailed implementation plan for the modernization of CGIAR breeding programs and stronger partnerships with national plant breeding programs for the delivery of genetic gains, and areas where future funder support is required.

6 Initial Implementation Plan for Modernization of CGIAR Plant Breeding Programs

An initial implementation plan has been developed over the course of the initiative, with emphasis on the actions required for the successful modernization of the current CGIAR plant breeding programs in the near term. The proposed implementation plan contains seven key elements, elaborated below:

1. **CGIAR breeding programs and their donors/investors agree, use and report on common metrics** for the effectiveness of plant breeding and seed dissemination programs, so that Centers and investors organize around a common vision of success. The two high-level metrics proposed are:
 - (i) *The rate of genetic gain* (change in trait value from breeding) delivered, under farmer management, in the form of farmer- and market-preferred products, improved for productivity while meeting the quality, maturity, stress-tolerance, and disease resistance requirements of end-users and farmers. Rate of genetic gain for yield under farmer management while retaining or improving quality and resistance traits is the key performance metric for breeding pipelines. Across species, the most effective breeding programs generate rates of genetic gain of 1-2% annually. Evidence exists that rates of gain of 3% per year are achievable. A minimum target of 1.5% should be set and monitored annually.
 - (ii) *The average area-weighted age of varieties (AAWAV) in farmers' fields*, confirmed by DNA testing of samples collected on-farm. AAWAV is an overall measure of the effectiveness of the breeding and seed system in delivering a steady stream of improved varieties in farmers' fields; if new varieties do not regularly reach farmers, there is no point in investing in breeding. AAWAV is 3-5 years for maize and soybean in the US Corn Belt, and for barley in Western Europe. It averages 12 to 25 years in many staple cropping systems served by the CGIAR. A baseline estimate of AAWAV for each crop x geography combination will be generated, against which progress will be measured over the next decade. Use of old varieties leaves farmers at risk from evolving pests and diseases and a changing climate and deprives them of the benefits of breeding progress.

By focusing on common metrics around breeding gains and rate of adoption, CGIAR centers and programs, and their donors and investors will provide research managers and scientists with clear and consistent guidance on how breeding programs should be organized and evaluated.

It should be noted that a focus on delivering genetic gains in productivity in no way means that biotic and abiotic stress tolerance are de-emphasized. These are critical components of yield stability across years and locations. Nor does it mean that nutritional or culinary quality should be sacrificed to productivity enhancement; rather, gains in productivity must be delivered in the form of varieties with quality traits demanded by the market and supportive of poverty alleviation.

One of the main performance metrics currently used to evaluate CGIAR/NARS breeding networks has been number of varieties released. This metric is severely flawed because many varieties are released but never adopted, either because they are not truly superior to those currently grown, or because dissemination efforts are ineffective. Another metric, total area planted to varieties from the program, gives too much weight to popular varieties released many years ago. Breeding programs need to be judged by their current products, not the ones developed 15 to 20 years ago.

2. **CGIAR Centers and their partners in national breeding programs will clearly identify the products they commit to develop and deliver.** Successful breeding programs work toward the delivery of a specific *product profile* (PP). Product profiles both guide breeders and allow Centers and donors to assign priorities to the development of particular products based on the area and population to which they are targeted and the potential for poverty alleviation or nutritional gains resulting from the new variety. It is critical for CGIAR centers to clearly describe the specific varietal products they commit to deliver and develop them in a participatory process ensuring that they meet the requirements of the women and men who will produce, market, process, and consume them, along the crop value chain.

With the option of using the product profile as the unit of investment in breeding, this provides a useful level of granularity for prioritization decisions. Investors can decide to invest in crop x geographic region, and with product profiles that will have the greatest impact on poverty alleviation per dollar spent. For example, investors can decide to support the development of bean varieties that will have a large impact on productivity and nutrition for highly impoverished populations in the Great Lakes region of Eastern Africa. Or investors may decide to invest in rice breeding for variety profiles in Bangladesh without supporting the development of varieties for Southeast Asia. Depending on the species, and therefore on the cost of generating and phenotyping candidate varieties, the cost of operating a modest but effective breeding pipeline serving a regional product profile is estimated to be in the range of USD 1m to USD 3m annually (perhaps slightly higher for banana/plantain). If, for example, a breeding program requires USD 2 million annually to deliver a product profile in a specific geography, an investor could allocate the first USD2m million to the PP predicted to deliver the highest impact on poverty, the second USD 2 million to the PP generating the next highest impact, etc, until its breeding budget was fully allocated or no further product profiles with an adequate impact on poverty are available.

3. **Centers commit to a continuous, rapid process of optimizing their breeding pipelines,** using expert technical advice from the EiB and other external support as required, both in terms of breeding technology and management approaches, adopting and adapting state-of-the-art methods pioneered in leading public and private sector programs. BPAT evaluations of over 20 CGIAR breeding programs indicate that many are using obsolete breeding methods, data management systems, and field phenotyping technology. Application of DNA marker technology has been limited, and most programs require support to automate and digitize field phenotyping. The application of DNA marker technology to improve selection accuracy and accelerate breeding cycles will require comprehensive redesign and quantitative genetic optimization of breeding pipelines. Centers should commit to support this optimization process and incentivize staff to continually increase phenotyping accuracy and throughput, reduce line development cost, and shorten breeding cycles. A critical element of the quantitative optimization process is accurately estimating the costs of achieving an adequate level of genetic gain, so that investments in specific product pipelines can be scaled and prioritized relative to their impact on poverty. CGIAR programs should also support NARS partners in adopting these approaches.
 - The Excellence in Breeding (EiB) Platform will play a critical role in supporting this modernization and optimization process. The EiB's role is to:
 - Support the design and implementation of improvement plans;
 - Provide technical backstopping to all centers in product profile design, quantitative genetic optimization of breeding pipelines, application of DNA marker technology, breeding information management, and process engineering for population development and phenotyping;
 - Facilitate engagement with multinational seed companies wishing to share know-how or technology with the CGIAR system;

- Establish a consistent framework for monitoring and reporting on the rate of genetic gain delivered by CGIAR breeding programs.
4. **The CGIAR system commits to a high degree of collaboration across centers and species, including sharing of breeding support services**, to permit the system to deliver world-class breeding programs at reasonable cost. For example, individual centers lack the critical mass to develop needed software tools for breeding information management or the bargaining power to negotiate from strength with outsourced service providers. Gates Foundation projects, including the Integrated Breeding Platform (IBP), Global Open Breeding Informatics Initiative (GOBII), and the High-Throughput Genotyping Project (HGTP), have established shared breeding informatics and low-cost genotyping services at the system level. In addition to its technical support functions, the EiB Platform, established in 2017, for the first time provides a mechanism for coordinating these shared services, and a common (Window 2) budget line for supporting them. Center and CRP leaders need to fully commit to supporting and using these shared services where cost-effective and appropriate.
5. **CGIAR breeding programs commit to operating in strong partnerships with the national programs they serve.** CGIAR breeding programs have collaborated closely with NARS partners since the creation of the system, but there is a wide range in the quality of partnerships. Donors expect that CGIAR teams will operate in a highly collaborative manner with NARS and others along the value chain, to develop product profiles; jointly identify parents with high breeding value; test selection candidates collaboratively at NARS sites in the target environment from Stage 1 (the first multi-location yield testing step), and jointly determine which candidates to advance to on-farm testing and dissemination. Critically, this “strong partnership” model must commit the CGIAR/NARS breeding programs to fully supporting the identification of new products emerging from its breeding programs that should replace what farmers currently grow. Regular meetings with national partners to update product profiles, plan crosses and trials, analyze data, and make joint product advancement and dissemination decisions are critical to strengthening NARS capacity to apply state-of-the-art breeding approaches. A strong partnership mode for CGIAR-NARS breeding networks implies that some investment in upgrading NARS research stations to improve data quality will need to be built into both on-going CGIAR breeding projects and the modernization investments in modernization currently being formulated. It also implies ensuring that NARS partners have access to sufficient staff and operating funds, from national and international resources, to enable them to be effective partners in proposed CGIAR/NARS breeding networks.
6. **CGIAR funders will commit to fund the necessary additional investments for capital, equipment, software, and human capacity investments required to modernize the CGIAR/NARS breeding system over three to five years**, based on their informed decisions and choices on how to focus on the programs with the highest potential impact on poverty or those programs contributing towards other key donor priorities. Supporting CGIAR/NARS breeding programs deliver higher rates of genetic gain by applying modern breeding approaches will require two principal kinds of investment:
- (i) Support for planning and implementing optimized breeding pipelines, including training staff to design and implement them (which is best done as part of the planning process). This type of investment includes:
 - Assessment and cost analysis of the current program
 - Stakeholder engagement for product profile design
 - Consultancy and workshops for development of optimized breeding pipeline
 - Equipment for digitization and mechanization of plot management, data collection, and tissue sampling

- Support for full implementation of breeding informatics software
 - Training for researchers and research managers
- (ii) Upgrading of key CGIAR stations and NARS sites to support rapid cycle breeding, including:
- Automation and mechanization of field operations
 - Upgrading of greenhouse and irrigation facilities for industrial-scale production of selection candidates
 - GPS and wireless upgrades to support precise georeferencing, web-based data collection
 - Upgrading of managed-stress and inoculated disease screening facilities
 - Upgrading of key NARES sites to support high-quality Stage 1 field testing.

The cost of planning and implementing modernized breeding programs is estimated to be in the order of USD 2 million per cluster of related crop product profiles delivered by the same breeding team, in total, over about three years. The cost of upgrading a core CGIAR breeding facility and several associated NARS stations is likely to be in the order of \$5 to 10 million, depending on the Center and the extent of mechanization undertaken. These cost estimates are somewhat flexible; there is no specific minimum below which improvements cannot be made.

7. **CGIAR funders will commit to coordinated, longer-term funding appropriate for consistent support of high-quality breeding efforts**, providing the stability of funding needed to attract world-class staff and support continuous improvement efforts. Ideally, funding commitments should be made to support all program elements needed to deliver genetic gains in specific product profiles for four to five years, or roughly a full breeding cycle. Projects to develop and deliver specific product profiles could be nested within Window 2 Flagships, providing centers and CRPs with stability and focus, while permitting donors to invest in the specific cropping systems and geographies they are mandated to support.

The commitments outlined above will provide support and guidance to CGIAR breeding programs in moving to a higher level of effectiveness in fulfilling their mission and provide investors with clarity about what products the system is committed to delivering, and assurance that they will be delivered efficiently. They also formalize a mutually supportive relationship between the CGIAR and NARS in delivering the new varieties needed by smallholder farmers in the developing world to raise their productivity and cope with climate change.

Next steps

1. *Enabling prioritization decisions on crop x geography x product profiles*

To support the prioritization of investment in a renewal of CGIAR breeding, Centers and CRPs are requested to provide, as soon as possible, a menu of the crops x geographies, and, if or when available, the product profiles they are committed to delivering, with supporting information on populations served and potential poverty impact. Trait pipelines should also be described, with quantitative information supporting the impact of their outputs on productivity. Trait pipelines can be prioritized for funding similarly to product profiles. Donors can then identify the crop x geographies and the product profiles PPs and trait pipelines they plan to support for a specified period, and which will be prioritized to receive funding for program modernization.

2. *Developing improvement plans for current levels of funding*

BPAT assessments have shown that most breeding programs in the CGIAR can improve their effectiveness with current levels of funding. Following the completion of a BPAT evaluation, all CGIAR breeding programs will develop improvement plans for their current resource levels, with the support of the EiB, and begin the implementation of these plans.

3. *Developing investment plans for upgrading key research station networks*

Centers should develop capital investment plans for modernization of their core breeding facilities and research substations (including key NARS partner sites that provide critical network functions). These investments will improve the level of mechanization, automation, and digitization at the main research stations, benefiting breeding efficiency in all crops that use the site. These plans may be selected for funding depending upon donor priorities and funding availability. It is expected that investment plans will be coordinated among Centers by the SMB to ensure that duplication of facilities is avoided and that Centers working at the same NARS sites collaborate in their improvement. These investment plans will be developed with the support and advice of the EiB Platform.

4. *Developing investment plans for optimizing breeding pipelines for when additional funds become available*

Plans to upgrade the effectiveness of breeding pipelines will be made, assuming that funds are available to support a major redesign and staff training. Generally, these plans will involve development facilities for rapid generation advance, mechanization and automation of phenotyping and genotyping, and other requirements for reducing breeding cycle time and increasing selection accuracy.

Proposed timeframe for implementation

2019:

- BPAT evaluations for all CGIAR breeding programs will be completed
- Crop x geography and product profiles will be formalized by the Centers and NARS partners and prioritized by donors
- Plans for improved breeding program effectiveness at current investment levels and at uplift levels will be formulated.
- Donors will define the level of investment that will be provided for (a) upgrading key research stations and (b) modernizing specific breeding pipelines
- CGIAR centers will prepare plans for modernizing key research stations

2020:

- Investments will be made to upgrade key research stations. This will likely be completed over two years
- Investments will be made to modernize prioritized breeding pipelines. These will likely be completed over three years.

Annex A: Crop Prioritization: IFPRI Modelling and Analysis for 20 crops

This Annex contains a summary of the prioritization analysis conducted by IFPRI and USDA

IFPRI Approach to prioritization studies

Two models were run by IFPRI: (1) *a parity model* which projects the importance of consumption of individual crops to poor people in developing countries based on current farm gate prices; and (2) *an economic surplus model (IMPACT)*, which examines how economic surplus from accelerated crop yield increases accrues to poor people, taking account of market trends in prices under the influence of trade and population growth. The modelling results were presented with and without poverty weightings. In addition, the impact of increased productivity on nutrient availability was considered. The regional distribution of benefits by crop was also analysed.

An overview of the approach used to derive estimates of potential impacts of accelerated yield growth in target crop commodities is illustrated in IFPRI Figure 1 below. The IFPRI/USDA team first prepared estimates of the total value of production for each crop in the geographic area of interest using data from FAOSTAT. The team then used IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) and the GLOBE general equilibrium model to estimate changes in the total value of production of those crops to 2030, as well as changes in economy-wide income (or economic surplus) that would result under scenarios of faster crop productivity growth.

The scenario of accelerated productivity growth in the IFPRI/USDA prioritization report assumes that an increased investment in plant breeding will result in a 25% increase in the annual rate of yield growth above "baseline" or historical yield growth in farmers' fields over 2015-2030. Potential impacts on poverty were determined by weighting the estimates of production value and income by the extent and depth of poverty in each country. Scenario results from IMPACT were also used to estimate potential impacts on hunger and selected nutrient indicators.

The 20 crops analysed in the prioritization studies were:

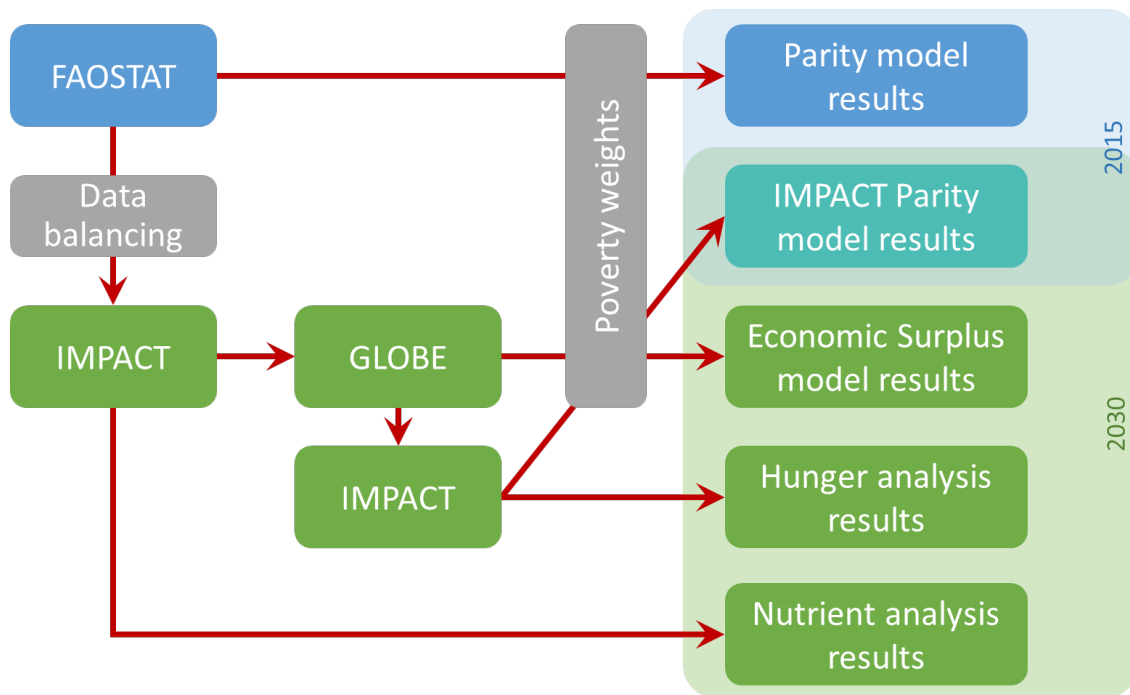
Cereal grains: rice, maize, wheat, sorghum, millet, barley

Roots, tubers and banana (RTB): potato, cassava, yams, sweet potato, banana, plantain

Oilseeds and pulses: Pulses (aggregate); beans (*Phaseolus*); chickpea (*Cicer*); cowpea (*Vigna unguiculata*); pigeonpea (*Cajanus*); lentil (*lens*); other pulses (*pisum*); groundnuts; soybean (SSA only).

The geographic area of interest included 106 countries – all countries in Africa, Asia, and Latin America except for China, Brazil, and southern cone countries of Latin America.

IFPRI Figure 1 – Summary of methods used for prioritization studies (Source: Wiebe, *et al* 2018)



Summary of results of prioritization studies

Value of Production

Total value of production – all countries (IFPRI Table 3a, Annex A)

The total value of production in 2015 and 2030 for all 106 developing countries is shown in IFPRI Table 3a (Annex A). Results for 2015 are shown both as estimated by the Parity model (average for 2014-2016), and as modeled by IMPACT. Results for 2030 are modeled by IMPACT (for the reference case, i.e. before the productivity enhancement scenarios are applied). The modeled IMPACT estimates for 2015 closely match FAO data for this period. Not surprisingly, total values are highest for the major staple crops, especially rice and wheat, reflecting the scale of their production and consumption. Between 2015 and 2030, IMPACT projects modest changes in the value shares of these cereal crops.

Potato, banana and plantain and cowpea production are projected to grow by 70% or more, while rice, barley, and soybean are projected to grow by 35% or less (see last column of IFPRI Table 3a, Annex A). The value share of rice, the most significant crop of the group, is expected to fall from 28.8% to 26.0%. When values are weighted by World Bank poverty measures, the share of some crops declines (e.g. for rice, wheat, potato) and the share of other crops increases (e.g. for cassava, yams, cowpea, and groundnuts), reflecting the importance of the latter crops in poorer countries.

Value of production - Regional variations amongst crops (IFPRI Tables 3b, 3c, Annex A)

The crops accounting for the largest share of the value of production in 2015 vary by region (IFPRI Table 3b, Annex A). Cassava and yams dominate in sub-Saharan Africa, followed by maize. In South Asia the largest values are for rice and wheat, followed by potato; in Southeast Asia rice dominates by far, followed by cassava; in WANA-CAC wheat and potato dominant; and in LAC maize and banana, followed by potato are the most important crops.

Shares of the value of production also vary across sub-regions within sub-Saharan Africa (IFPRI Table 3c, Annex A). Cassava and plantain dominate in Central Africa, followed by groundnut; in southern Africa maize and cassava have the highest value, followed by potato and rice; in West Africa (excluding Nigeria) yams and cassava lead, followed by sorghum and rice, while yams and cassava dominate in Nigeria. Crop shares are more evenly distributed in eastern Africa, with maize, millet, potato, cassava, banana and pulses all representing 10-20% of total value, depending on how they are weighted.

Applying poverty weights to crop values significantly affects the relative importance of crops across regions but the effect is less within regions. For example, the value share of cassava for LDCs as a group is estimated by FAO to be 8.39% in 2015, but when weighted by the poverty gap it rises to 24.07%. Within sub-Saharan Africa, cassava's value share is 19.82%, which rises to 27.04% when weighted by the poverty gap. This reflects the larger differences in poverty rates across regions.

Economic surplus

Changes in economy-wide income (economic surplus, all countries) (IFPRI Table 4a, Annex A)

For LDCs as a group, projected changes in economy-wide income (economic surplus) between 2015 and 2030 due to productivity enhancement are largest for rice and wheat, followed by yams and banana (IFPRI Table 4a, Annex A). The income results change when weighted by the poverty headcount or poverty gap. Poverty-weighted income shares decline for rice and wheat, reflecting the dominance of richer countries in the production and utilization of these crops, and increase for crops such as maize, sorghum, millet, yams, and groundnut, which are relatively more important in poorer countries.

Poverty weighting also increases the share of increased income (i.e., the share of total benefits accruing to poor households) accounted for by sub-Saharan Africa, while decreasing it in the other regions.

Rice, sorghum, yams and millet represent the largest shares of economic surplus in 2030 in sub-Saharan Africa (IFPRI Table 4b, Annex A); rice and wheat in South Asia and WANA-CAC; rice in Southeast Asia; and rice and wheat followed by plantain and pulses in LAC. Within sub-Saharan Africa (IFPRI Annex Table 4c), economic surplus is highest for rice, cassava and groundnuts in Central Africa; for wheat, sorghum, millet and plantain in Eastern Africa; for rice and wheat in Southern Africa; for rice and maize in West Africa (excluding Nigeria); and for rice, sorghum, yams and millet in Nigeria. Poverty weighting makes less difference in the results within regions and sub-regions, as progressively smaller country groupings become more homogeneous.

Faster productivity growth generates economic surplus shares that are higher than the parity model's shares of production value for most cereals and for groundnuts, and lower for most other crops. Differences are particularly large for sorghum and millet (higher shares) and cassava and yams (lower shares). Shares for oilseeds and pulses are broadly similar between the two approaches. Economic surplus shares are higher than parity model shares in Asia, and lower in the other regions. This likely reflects the relative roles of crops in value-added food systems. Cereal grains are easily stored and traded and widely used by animal feed, food manufacturing and biofuel industries, and thus may have larger multiplier effects in the general economy.

Impact on nutrient availability: Hunger and nutrient indicators

The impacts of the productivity scenarios on the number of undernourished children and the population at risk of hunger in 2030 is shown in IFPRI Table 5, Annex A. Improvements (i.e. reductions in numbers) are greatest for rice and wheat (roughly 2% and 1% respectively), (as may be expected, since these two measures are based on availability of dietary energy). The pulses, plantain, cassava, sorghum, maize and millet scenarios also reduce the population at risk of hunger by a million or more, with roughly proportionate reductions in child undernourishment.

Investments to increase productivity of a crop will increase the aggregate availability of all the nutrients it contains. IFPRI reports changes to the adequacy ratios due to faster crop productivity growth for 12 micronutrients that are deficient in many countries (IFPRI Table 6, Annex A). At this level of aggregation, total production volume of a crop affects nutrient availability and thus adequacy ratios. A specific percentage increase in productivity for a crop with large total production volume will have a much greater effect on nutrient availability of even its less important nutrients than will the same percentage increase in productivity for a crop with high content of deficient nutrients but small production volume. Even for the largest crops, however, there are relatively small changes in the adequacy ratios for any of these 12 micronutrients.

For specific nutrients, the IFPRI analysis noted that:

- None of the yield increases change the zinc adequacy ratios by more than a very small amount.
- In Asia, rice and wheat yield growth improves the adequacy ratios for many nutrients. None of the other yield increases contribute much.
- In LAC, wheat yield growth improves adequacy ratios for many nutrients. Maize increases benefit a few adequacy ratios. Rice increases have very little impact on any adequacy ratios.
- In SSA, cassava yield growth improves adequacy ratios for many nutrients. Cowpeas, millet, plantain, sorghum, wheat and yams also make improvements in some adequacy ratios. Rice yield increases have little effect on SSA adequacy ratios.

A crop usually contributes to many required nutrients. IFPRI presents a Nutrient Investment Productivity Index (NIPI) that ranks crop-specific productivity growth for its contributions across multiple deficit nutrients (IFPRI Table 7, Annex A). NIPI sums the rank order values for each nutrient and then rank orders the results. The result is an index from 1 (most number of deficient adequacy ratios improved) to the number of crops considered (fewest adequacy ratios improved). The index does not capture the extent to which any particular adequacy ratio is improved or distinguish between minerals and vitamins. By this measure, the wheat, rice, and maize productivity-increasing scenarios have the highest scores in Asia, LAC, and SSA, reflecting the existing volume of production of those crops (as highlighted in red in IFPRI Table 7, Annex A).

Additional findings in relation to nutrients

The IFPRI/USDA report illustrates adequacy ratios in 2030 for a variety of nutrients in the reference case without faster productivity growth. In the IFPRI report, calcium, iron, potassium and zinc stand out for global deficiencies. Vitamins A, B12, D, E and K, and folate all have widespread deficiencies. Variation is large across nutrients and between countries, and average ratios (whether above or below 1) hide important differences within countries. These findings on nutrient deficiencies are illustrated in the Figures contained in the full report from IFPRI. (add link)

Beyond contributions to adequacy of nutrient intake, agricultural productivity investments can also affect dietary diversity. Several measures of diversity are available. For this report, the study used the non-staple share of energy intake. The findings clearly show the heavy dependence on staples for dietary energy in most of Africa and parts of Central Asia. Impacts of the productivity scenarios on this indicator are generally small. Most of the crops considered in this analysis are in the staple category, so increasing their productivity generally increases their consumption and decreases the non-staple share of energy intake. The only yield increases that raise the non-staple share more than 0.01 percent are for groundnuts in SSA (0.08 percent) and banana in Asia and SSA (0.03 and 0.04 respectively).

In regard to micro-nutrients, the IFPRI study presented for each crop/scenario a selected prominent micronutrient impact (excluding carbohydrates, protein, and fiber) in 2030. Results provide an indication of the spatial distribution and magnitude of the impacts for the selected nutrients for each crop/scenario.

Other findings from the prioritization studies

Both the economic surplus model and the parity model highlight the overall importance of cereal grains in the food systems of developing countries to 2030. The major difference between the two different modelling approaches was the greater relative contribution of root crops and legumes in the parity model (focussed on developing country consumption measures). Regional shares also move substantially towards Africa in the economic surplus model when using the poverty head count index.

The foresight modeling presented by IFPRI, covering both the agricultural sector and the broader economy, provides key insights for the impact of crop breeding on multiple indicators in future years under alternative scenarios. The summary graph (IFPRI Figure 6, below) summarizes the different metrics explored in this analysis and helps illustrate their implications for R&D allocations. For each of the metrics in the figure, a “parity rule” would suggest that the crop value share could help inform an efficient R&D allocation. Importantly, they help illustrate how CGIAR system goals might move the R&D portfolio. The parity (crop value) and economic surplus value shares give greater emphasis to total income growth; economic surplus weighted by the poverty indices gives greater prioritization to poverty reduction; while undernourished children and population at risk of hunger give greater importance to food security.

While rice comes out as the dominant crop under all of these metrics, the relative importance of crops differs significantly among them. Weighting income by the poverty gap index significantly raises the profile of sorghum, millet, yam, and groundnuts, and reduces that of wheat, potato, and to some extent rice.

IFPRI notes that this modeling approach helps explore alternative futures, including the impacts of research investment and productivity growth, but it is only one dimension of a science-based decision-making process for prioritization.

IFPRI Annex A Summary of data underpinning prioritization studies (IFPRI/USDA)

IFPRI Table 3a – Parity Model results: Gross production value from FAOSTAT in 2015, and as modelled by IFPRI's IMPACT model for 2015 and 2030

Commodity	PARITY MODEL from FAO Data 2015 (small group of countries)				PARITY MODEL with IMPACT MODEL PROJECTIONS: 2015 (small group)				PARITY MODEL with IMPACT MODEL PROJECTIONS: 2030 (small group)				IMPACT PARITY Ratio of 2030 GPV to 2015 GPV
	Gross Production Value (avg 2014-16)	Value Share (VS)	VS w eighted by		Gross Production Value in 2015	Gross Value Share	VS w eighted by		Gross Production Value in 2030	Gross Value Share	VS w eighted by		
			poverty count	poverty gap			poverty count	poverty gap			poverty count	poverty gap	
	(million\$)	(%)	(%)	(%)	(billion\$)	(%)	(%)	(%)	(billion\$)	(%)	(%)	(%)	
Cereal Grains													
Rice	101,082	28.56	19.93	11.33	95,953	28.81	20.66	11.40	129,227	26.02	18.80	11.92	1.35
Maize	31,314	8.85	8.22	8.83	28,715	8.62	7.35	7.79	47,633	9.59	7.78	7.92	1.66
Wheat	48,134	13.60	8.18	2.73	55,993	16.81	9.36	3.00	80,665	16.24	9.23	2.90	1.44
Sorghum	7,660	2.16	3.42	2.86	8,797	2.64	3.95	4.36	13,401	2.70	3.99	4.31	1.52
Millet	7,709	2.18	2.65	2.75	7,037	2.11	3.93	4.19	10,753	2.17	3.97	4.24	1.53
Barley	4,028	1.14	0.34	0.16	3,847	1.16	0.24	0.11	5,024	1.01	0.22	0.10	1.31
Roots, Tubers & Bananas													
Potato	34,687	9.80	7.35	4.82	20,277	6.09	4.75	3.52	34,515	6.95	4.96	2.95	1.70
Cassava	29,693	8.39	13.97	24.07	22,355	6.71	12.20	20.96	31,682	6.38	11.62	19.65	1.42
Yams	18,236	5.15	11.80	17.67	17,925	5.38	12.73	18.77	29,991	6.04	13.61	19.49	1.67
Sweet potato	2,324	0.66	1.17	1.65	2,149	0.65	1.18	1.72	3,333	0.67	1.21	1.67	1.55
Banana	22,422	6.33	6.01	5.21	27,562	8.28	7.30	6.47	46,410	9.35	8.06	6.87	1.68
Plantain	8,588	2.43	2.68	3.10	11,040	3.31	4.84	5.93	19,526	3.93	5.49	6.32	1.77
Oilseeds & Pulses													
Pulses, total	24,980	7.06	8.55	8.12	22,975	6.90	7.77	7.15	32,924	6.63	7.54	7.14	1.43
beans (<i>phaseolus</i>)	10,763	3.04	3.13	3.23	8,772	2.63	2.57	2.64	11,986	2.41	2.35	2.49	1.37
chickpea (<i>cicer</i>)	6,094	1.72	1.68	0.68	5,513	1.66	1.45	0.53	8,191	1.65	1.38	0.50	1.49
cow pea (<i>vigna unguiculata</i>)	3,381	0.96	2.24	3.02	2,516	0.76	1.89	2.69	4,617	0.93	2.22	3.09	1.84
pigeonpea (<i>cajanus</i>)	2,536	0.72	0.86	0.79	2,671	0.80	0.84	0.49	4,050	0.82	0.83	0.48	1.52
lentil (<i>lens</i>)	1,129	0.32	0.25	0.09	1,166	0.35	0.22	0.08	1,401	0.28	0.17	0.06	1.20
other pulses (<i>pisum</i>)	1,077	0.30	0.39	0.31	2,337	0.70	0.79	0.73	2,679	0.54	0.58	0.53	1.15
Groundnuts	12,429	3.51	5.39	6.20	7,223	2.17	3.27	4.18	9,988	2.01	3.13	4.15	1.38
Soybean (SSA only)	651	0.18	0.35	0.50	1,188	0.36	0.48	0.44	1,509	0.30	0.40	0.35	1.27
SSA benefit share (%)		26.63	58.44	88.38		25.38	57.93	88.64		28.14	60.62	89.62	
LAC benefit share (%)		7.08	1.65	0.36		8.28	1.86	0.38		8.65	1.86	0.36	
ASIA benefit share (%)		55.79	39.45	11.23		54.27	39.70	10.94		51.73	37.03	9.97	
WANA-CAC benefit share (%)		10.50	0.46	0.04		10.71	0.41	0.04		10.19	0.39	0.04	
Total for all crops	353,937	100.00	100.00	100.00	333,036	99.13	100.00	100.00	496,580	100.00	100.00	100.00	

Notes:

1. Table shows relative gross value of commodities in 2014-2016, using global average commodity prices from 2004-06 (2005\$), and projected by IFPRI's IMPACT model.

2. Small group excludes China, Brazil and Southern Cone countries. (see map).

4. Value weighted by poverty headcount: Value in each country is multiplied by its \$1.9/day poverty headcount index (share of population earning less than \$1.9/day).

5. Value weighted by poverty gap: Value in each country is multiplied by its poverty headcount index times its poverty gap index. The poverty gap is the difference between \$1.9 and the mean income of the poor in a country, expressed as a percent of \$1.9.

Sources: Commodity production value from FAOSTAT. IMPACT projections from IFPRI. Poverty headcount and poverty gap indexes are from World Development Indicators, latest available year.

IFPRI Table 3b – Parity Model results: Gross production value from FAOSTAT in 2015, by region

Commodity	SSA, All Countries				South Asia				SE Asia				WANA-CAC				LAC (excluding Brazil, Southern Cone)			
	Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by		Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by		Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by		Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by		Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by	
	(million\$)	(%)	poverty count	poverty gap	(million\$)	(%)	poverty count	poverty gap	(million\$)	(%)	poverty count	poverty gap	(million\$)	(%)	poverty count	poverty gap	(million\$)	(%)	poverty count	poverty gap
Cereal Grains																				
Rice	5,940	6.30	7.29	8.15	41,564	34.59	35.48	35.86	48,759	63.08	59.54	43.35	2,266	6.10	7.27	1.48	2,553	10.19	8.66	7.13
Maize	10,515	11.16	10.00	9.38	5,324	4.43	4.13	3.98	6,581	8.51	9.99	8.31	2,887	7.77	9.98	5.92	6,008	23.96	20.11	14.78
Wheat	1,776	1.88	1.26	0.64	29,265	24.35	21.81	21.09	36	0.05	0.05	0.04	16,071	43.25	34.09	19.00	985	3.93	2.82	1.14
Sorghum	3,935	4.18	3.99	2.86	3,613	3.01	3.23	3.30	75	0.10	0.11	0.08	38	0.10	1.29	5.00	0	0.00	0.00	0.00
Millet	4,337	4.60	3.95	3.00	822	0.68	0.74	0.76	46	0.06	0.06	0.08	1,328	3.57	5.17	18.11	1,176	4.69	3.95	2.98
Barley	444	0.47	0.33	0.15	454	0.38	0.33	0.33	3	0.00	0.00	0.00	2,927	7.88	5.29	2.60	201	0.80	0.56	0.21
Roots, Tubers & Bananas																				
Potato	3,944	4.18	3.66	3.74	17,038	14.18	14.47	14.33	721	0.93	1.09	0.76	9,504	25.58	28.27	29.81	3,480	13.88	12.67	8.79
Cassava	18,684	19.82	22.60	27.04	726	0.60	0.64	0.65	9,570	12.38	7.81	7.97	0	0.00	0.00	0.00	714	2.85	3.50	5.42
Yams	17,801	18.89	20.00	19.89	0	0.00	0.00	0.00	120	0.16	0.93	5.91	0	0.00	0.00	0.00	314	1.25	3.21	7.82
Sweet potato	1,632	1.73	1.81	1.80	107	0.09	0.09	0.10	425	0.55	1.07	3.76	35	0.09	0.14	0.03	126	0.50	1.05	2.68
Banana	4,685	4.97	4.75	4.73	7,250	6.03	6.63	6.84	4,654	6.02	9.77	23.06	601	1.62	3.39	7.56	5,232	20.87	24.35	25.29
Plantain	4,903	5.20	4.10	3.46	159	0.13	0.01	0.00	1,038	1.34	1.88	1.33	0	0.00	0.00	0.00	2,488	9.92	9.68	9.70
Oilseeds & Pulses																				
Pulses, total	8,113	8.61	8.60	8.02	10,158	8.45	9.08	9.28	3,854	4.99	5.62	3.76	1,263	3.40	4.50	10.35	1,591	6.35	8.43	12.65
beans (<i>phaseolus</i>)	3,562	3.78	3.47	3.33	2,380	1.98	2.14	2.20	3,095	4.00	4.48	2.99	394	1.06	1.35	1.02	1,332	5.31	6.25	7.91
chickpea (<i>cicer</i>)	372	0.39	0.36	0.26	4,832	4.02	4.28	4.38	316	0.41	0.47	0.32	493	1.33	2.37	7.67	81	0.32	0.21	0.06
cow pea (<i>vigna unguicu</i>)	3,275	3.48	3.81	3.42	8	0.01	0.00	0.00	65	0.08	0.10	0.07	4	0.01	0.02	0.00	28	0.11	0.39	0.98
pigeonpea (<i>cajanus</i>)	475	0.50	0.52	0.69	1,650	1.37	1.51	1.56	336	0.43	0.50	0.34	0	0.00	0.00	0.00	76	0.30	1.31	3.53
lentil (<i>lens</i>)	86	0.09	0.07	0.03	714	0.59	0.62	0.61	1	0.00	0.00	0.00	321	0.86	0.54	1.16	7	0.03	0.02	0.01
other pulses (pisum)	343	0.36	0.36	0.29	575	0.48	0.52	0.53	42	0.05	0.06	0.04	51	0.14	0.22	0.49	67	0.27	0.25	0.15
Groundnuts	6,886	7.31	7.06	6.59	3,690	3.07	3.35	3.46	1,410	1.82	2.07	1.61	240	0.65	0.60	0.14	202	0.81	1.01	1.41
Soybean (SSA only)	651	0.69	0.59	0.57	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
Cereal Grains	26,947	28.59	26.83	24.17	81,042	67.44	65.72	65.33	55,499	71.80	69.77	51.85	25,516	68.67	63.11	52.11	10,923	43.57	36.10	26.25
Roots, Tubers & Bananas	51,650	54.80	56.92	60.65	25,279	21.04	21.85	21.93	16,529	21.38	22.55	42.79	10,140	27.29	31.80	37.39	12,353	49.27	54.47	59.69
Oilseeds & Pulses	15,650	16.61	16.25	15.17	13,849	11.52	12.43	12.74	5,264	6.81	7.68	5.36	1,503	4.05	5.09	10.49	1,793	7.15	9.43	14.06
Total for all crops (million\$)	94,247	100.00	100.00	100.00	120,170	100.00	100.00	100.00	77,292	100.00	100.00	100.00	37,159	100.00	100.00	100.00	25,069	100.00	100.00	100.00

Notes:

1. Table shows relative gross value of commodities in 2014-2016, using global average commodity prices from 2004-06 (2005\$).

2. Value weighted by poverty headcount: Value in each country is multiplied by its \$1.9/day poverty headcount index (share of population earning less than \$1.9/day).

3. Value weighted by poverty gap: Value in each country is multiplied by its poverty headcount index times its poverty gap index. The poverty gap is the difference between \$1.9 and the mean income of the poor in a country, expressed as a percent of \$1.9.

Sources: Commodity production value from FAOSTAT. Poverty headcount and poverty gap indexes are from World Development Indicators, latest available year.

IFPRI Table 3c – Parity Model results: Gross production value from FAOSTAT in 2015, by sub-region in SSA

Commodity	SSA, Central				SSA, Eastern				SSA, Southern				SSA, Western (except Nigeira)				SSA, Nigeria			
	Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by poverty count	VS weighted by poverty gap	Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by poverty count	VS weighted by poverty gap	Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by poverty count	VS weighted by poverty gap	Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by poverty count	VS weighted by poverty gap	Gross Production Value (avg 2014-16)	Value Share (VS)	VS weighted by poverty count	VS weighted by poverty gap
	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)
Cereal Grains																				
Rice	138	1.93	2.31	2.51	164	0.97	1.13	1.37	1,660	8.68	11.99	16.08	2,544	11.18	12.62	12.81	1,436	5.05	5.05	5.05
Maize	542	7.59	9.09	9.88	2,380	14.18	12.06	8.73	4,369	22.84	18.88	16.98	1,567	6.89	7.83	8.59	1,657	5.83	5.83	5.83
Wheat	2	0.03	0.04	0.04	1,259	7.50	7.35	4.44	488	2.55	1.25	0.69	13	0.06	0.07	0.08	15	0.05	0.05	0.05
Sorghum	51	0.71	0.85	0.93	746	4.44	3.48	1.87	167	0.87	0.85	0.64	2,524	11.10	14.20	14.37	447	1.57	1.57	1.57
Millet	198	2.77	3.32	3.61	1,776	10.58	7.96	4.19	237	1.24	1.22	1.04	1,044	4.59	5.80	5.96	1,082	3.80	3.80	3.80
Barley	0	0.00	0.00	0.00	373	2.22	2.33	1.37	70	0.37	0.15	0.05	0	0.00	0.00	0.00	0	0.00	0.00	0.00
Roots, Tubers & Bananas																				
Potato	127	1.77	2.12	2.31	1,417	8.44	7.98	10.22	1,902	9.94	8.53	7.91	136	0.60	0.77	0.80	362	1.27	1.27	1.27
Cassava	2,704	37.86	45.37	49.31	1,164	6.93	11.24	17.79	3,807	19.90	23.34	26.76	4,110	18.07	14.81	14.83	6,900	24.26	24.26	24.26
Yams	383	5.37	6.43	6.99	363	2.16	2.18	1.44	4	0.02	0.02	0.01	4,814	21.17	16.82	16.48	12,237	43.02	43.02	43.02
Sweet potato	61	0.85	1.02	1.11	546	3.25	3.79	4.29	594	3.11	3.28	3.08	123	0.54	0.66	0.71	309	1.09	1.09	1.09
Banana	411	5.76	2.44	0.62	1,816	10.82	14.35	21.94	2,211	11.56	10.51	8.22	247	1.09	1.09	0.96	0	0.00	0.00	0.00
Plantain	1,387	19.42	7.90	1.94	1,044	6.22	6.87	4.64	238	1.25	1.54	1.60	1,492	6.56	3.84	2.21	742	2.61	2.61	2.61
Oilseeds & Pulses																				
Pulses, total	487	6.82	8.17	8.88	2,548	15.18	14.85	15.56	1,811	9.47	10.52	9.88	1,879	8.26	10.47	10.68	1,388	4.88	4.88	4.88
beans (<i>phaseolus</i>)	338	4.73	5.67	6.16	1,684	10.03	10.81	13.00	1,091	5.70	5.80	4.79	450	1.98	2.20	2.67	0	0.00	0.00	0.00
chickpea (<i>cicer</i>)	0	0.00	0.00	0.00	277	1.65	1.75	1.03	94	0.49	0.60	0.62	1	0.00	0.01	0.01	0	0.00	0.00	0.00
cow pea (<i>vigna unguicu</i>)	141	1.98	2.37	2.58	149	0.89	0.21	0.07	176	0.92	1.11	1.11	1,420	6.25	8.25	7.99	1,388	4.88	4.88	4.88
pigeonpea (<i>cajanus</i>)	3	0.05	0.05	0.06	136	0.81	0.08	0.09	336	1.76	2.29	2.64	0	0.00	0.00	0.00	0	0.00	0.00	0.00
lentil (<i>lens</i>)	0	0.00	0.00	0.00	85	0.51	0.54	0.32	1	0.01	0.01	0.01	0	0.00	0.00	0.00	0	0.00	0.00	0.00
other pulses (<i>pisum</i>)	4	0.06	0.07	0.08	217	1.29	1.47	1.05	114	0.60	0.71	0.71	8	0.03	0.02	0.02	0	0.00	0.00	0.00
Groundnuts	639	8.95	10.72	11.65	1,116	6.65	3.90	1.71	1,218	6.37	6.86	6.20	2,204	9.69	10.75	11.07	1,708	6.01	6.01	6.01
Soybean (SSA only)	12	0.17	0.21	0.23	77	0.46	0.53	0.42	353	1.84	1.08	0.85	44	0.20	0.28	0.43	165	0.58	0.58	0.58
Cereal Grains	930	13.03	15.61	16.97	6,698	39.90	34.31	21.99	6,991	36.54	34.34	35.50	7,692	33.82	40.51	41.81	4,636	16.30	16.30	16.30
Roots, Tubers & Bananas	5,072	71.03	65.29	62.28	6,350	37.82	46.41	60.33	8,756	45.77	47.21	47.57	10,922	48.03	37.99	36.01	20,550	72.24	72.24	72.24
Oilseeds & Pulses	1,138	15.94	19.10	20.76	3,741	22.28	19.29	17.69	3,382	17.68	18.46	16.93	4,128	18.15	21.50	22.18	3,261	11.46	11.46	11.46
Total for all crops (million\$)	7,141	100.00	100.00	100.00	16,788	100.00	100.00	100.00	19,129	100.00	100.00	100.00	22,741	100.00	100.00	100.00	28,447	100.00	100.00	100.00

Notes:

- Table shows relative gross value of commodities in 2014-2016, using global average commodity prices from 2004-06 (2005\$).
- Value weighted by poverty headcount: Value in each country is multiplied by its \$1.9/day poverty headcount index (share of population earning less than \$1.9/day).
- Value weighted by poverty gap: Value in each country is multiplied by its poverty headcount index times its poverty gap index. The poverty gap index is the difference between \$1.9 and the mean income of the poor in a country, expressed as a percent of \$1.9.
- SSA REGIONS:
 Central: Cameroon, Central African Republic, Chad, Congo, DRC, Eq. Guinea, Gabon, Sao Tome & Principe
 Eastern: Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, South Sudan, Sudan, Uganda
 Southern: Angola, Botswana, Comoros, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe
 Western: Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Senegal, Sierra Leone, Togo, Nigeria
 Sources: Commodity production value from FAOSTAT. Poverty headcount and poverty gap indexes are from World Development Indicators, latest available year.

IFPRI Table 4a – Economic Surplus Model results: Change in economy-wide income in 2030 from faster productivity growth, as modeled by IFPRI’s IMPACT model

Commodity/Scenario	ECONOMIC SURPLUS MODEL			
	ES for LDC in 2030 from yield shock	ES share	ES weighted by	
			poverty count	poverty gap
	(million\$)	(%)	(%)	(%)
Cereal Grains				
Rice	59,256	34.63	30.37	24.20
Maize	6,933	4.44	6.18	7.71
Wheat	26,560	17.58	13.56	5.81
Sorghum	8,011	5.08	9.00	14.22
Millet	6,219	4.01	7.29	11.45
Barley	2,802	1.68	1.65	0.79
Roots, Tubers & Bananas				
Potato	4,607	2.71	2.15	1.05
Cassava	4,310	4.02	3.61	5.11
Yams	9,104	8.34	9.48	14.04
Sweet potato	708	0.30	0.43	0.53
Banana	9,342	6.53	5.19	2.22
Plantain	3,000	2.73	2.17	2.59
Oilseeds & Pulses				
Pulses, total	7,464	5.30	4.61	3.31
beans (<i>phaseolus</i>)	1,547	1.14	0.84	0.49
chickpea (<i>cicer</i>)	2,681	1.76	1.47	0.58
cow pea (<i>vigna unguiculata</i>)	1,187	1.05	1.14	1.69
pigeonpea (<i>cajanus</i>)	1,137	0.73	0.68	0.29
lentil (<i>lens</i>)	413	0.27	0.21	0.09
other pulses (<i>pisum</i>)	499	0.35	0.26	0.18
Groundnuts	4,257	2.55	4.14	6.71
Soybean	181	0.10	0.17	0.27
SSA benefit share (%)		22.14	47.28	82.44
LAC benefit share (%)		1.45	0.24	0.04
ASIA benefit share (%)		69.01	52.31	17.50
WANA-CAC benefit share (%)		7.58	0.24	0.02
Total for all crops	152,753	100.00	100.00	100.00

All results use the small group, 25% multiplicative yield shock (NEW FIGURES WITH CORRECTED DATA)

Notes:

- Table shows benefits in 2030 from increasing rate of crop yield improvement by 25%/year multiplicatively above baseline yield growth over 2010-30. Yield shock is applied to one commodity at a time, holding other crops to their baseline rate of yield growth.
 - Yield shock affects all LDCs except China, Brazil and Southern Cone countries.
 - Economic surplus (ES) is the benefits to producers and consumers from the yield shock.
 - ES weighted by poverty headcount: ES in each country is multiplied by its \$1.9/day poverty headcount index (share of population earning less than \$1.9/day).
 - ES weighted by poverty gap: ES in each country is multiplied by its poverty headcount index and its poverty gap index. The poverty gap is the difference between \$1.9 and the mean income of the poor in a country, expressed as a percent of \$1.9.
 - For Soybean, yield shocks affect small group of LDCs, but ES benefits only counted for Sub-Saharan Africa (SSA). [IMPACT model produces zero benefits from soybean yield shock to small group of LDCs].
- Sources: Economic Surplus estimates generated by IFPRI's IMPACT Model. Poverty headcount and poverty gap indexes are from World Development Indicators, latest available year.

X

IFPRI Table 4b – Economic Surplus Model results: Change in economy-wide income in 2030 from faster productivity growth, as modelled by IFPRI’s IMPACT model, by region

Commodity/Scenario	SSA, All countries				South Asia				SE Asia				WANA-CAC				LAC (excluding Brazil, Southern Cone)				
	ES for LDC in 2030 from yield shock	ES share	ES weighted by poverty count poverty gap		ES for LDC in 2030 from yield shock	ES share	ES weighted by poverty count poverty gap		ES for LDC in 2030 from yield shock	ES share	ES weighted by poverty count poverty gap		ES for LDC in 2030 from yield shock	ES share	ES weighted by poverty count poverty gap		ES for LDC in 2030 from yield shock	ES share	ES weighted by poverty count poverty gap		
	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	
Cereal Grains																					
Rice	7,051	20.85	21.28	21.57	32,283	38.17	37.02	35.85	16,132	77.41	76.00	70.46	3,400	28.35	29.19	19.63	389	25.71	24.11	22.92	
Maize	3,315	9.80	9.06	8.51	3,168	3.75	3.92	4.03	213	1.02	0.97	1.14	212	1.77	2.60	3.67	26	1.69	1.89	2.64	
Wheat	1,023	3.03	2.22	1.69	20,533	24.28	25.12	25.75	207	0.99	0.75	0.76	4,465	37.23	23.62	7.89	331	21.89	19.17	10.24	
Sorghum	5,412	16.00	16.60	16.71	2,086	2.47	2.56	2.63	163	0.78	0.00	0.00	324	2.70	6.39	11.41	26	1.72	1.48	0.82	
Millet	4,383	12.96	13.46	13.46	1,665	1.97	2.03	2.08	43	0.20	0.10	0.04	106	0.88	7.21	26.45	22	1.44	1.25	0.63	
Barley	157	0.46	0.34	0.31	2,492	2.95	3.07	3.15	52	0.25	0.23	0.27	95	0.79	1.04	1.48	6	0.37	0.41	0.55	
Roots, Tubers & Bananas																					
Potato	231	0.68	0.53	0.48	3,465	4.10	3.85	3.75	208	1.00	0.90	0.89	626	5.22	5.01	6.10	78	5.14	5.10	5.31	
Cassava	1,720	5.08	5.37	5.85	1,431	1.69	1.51	1.51	826	3.96	3.98	5.23	310	2.58	2.58	3.63	23	1.55	1.53	3.42	
Yams	4,961	14.67	15.77	16.34	2,555	3.02	3.00	3.03	935	4.49	6.33	9.92	586	4.88	4.86	6.84	68	4.50	5.82	11.38	
Sweet potato	244	0.72	0.61	0.57	269	0.32	0.30	0.30	126	0.60	0.48	0.49	56	0.47	0.47	0.66	13	0.85	0.85	1.04	
Banana	465	1.37	0.97	0.73	7,267	8.59	9.03	9.23	956	4.59	5.53	6.09	565	4.71	7.09	5.61	89	5.87	6.06	6.04	
Plantain	1,252	3.70	3.21	2.94	961	1.14	0.93	0.91	312	1.50	1.18	1.22	221	1.84	1.85	2.60	253	16.74	20.89	25.80	
Oilseeds & Pulses																					
Pulses, total	937	2.77	2.68	2.63	5,426	6.42	6.49	6.59	402	1.93	1.98	2.06	532	4.44	4.71	3.11	166	10.99	10.09	8.30	
beans (<i>phaseolus</i>)	169	0.50	0.38	0.33	1,035	1.22	1.23	1.25	134	0.64	0.61	0.57	117	0.97	0.82	0.73	93	6.15	5.62	4.10	
chickpea (<i>cicer</i>)	63	0.19	0.14	0.10	2,379	2.81	2.83	2.88	77	0.37	0.29	0.29	139	1.16	0.75	0.72	22	1.46	1.30	0.79	
cow pea (<i>vigna unguicu</i>)	592	1.75	1.90	1.98	316	0.37	0.35	0.35	112	0.54	0.73	0.83	137	1.14	2.13	0.64	31	2.02	2.01	2.35	
pigeonpea (<i>cajanus</i>)	32	0.09	0.07	0.06	1,045	1.24	1.31	1.35	28	0.13	0.18	0.21	26	0.22	0.22	0.31	5	0.33	0.15	0.16	
lentil (<i>lens</i>)	15	0.04	0.03	0.02	332	0.39	0.40	0.39	14	0.06	0.05	0.05	49	0.41	0.22	0.14	4	0.27	0.26	0.21	
other pulses (<i>pisum</i>)	66	0.19	0.16	0.14	319	0.38	0.37	0.36	38	0.18	0.12	0.12	64	0.53	0.56	0.57	11	0.76	0.75	0.69	
Groundnuts	2,527	7.47	7.57	7.89	965	1.14	1.17	1.19	256	1.23	1.57	1.41	486	4.05	3.39	0.94	23	1.50	1.35	0.92	
Soybean	147	0.44	0.35	0.32	15	0.02	0.00	0.00	10	0.05	0.00	0.00	9	0.07	0.00	0.00	1	0.04	0.00	0.00	
Cereal Grains	21,341	63.09	62.94	62.24	62,227	73.57	73.72	73.49	16,810	80.66	78.05	72.67	8,603	71.73	70.04	70.53	799	52.83	48.30	37.80	
Roots, Tubers & Bananas	8,872	26.23	26.47	26.92	15,949	18.86	18.62	18.72	3,363	16.14	18.40	23.86	2,363	19.70	21.86	25.42	524	34.65	40.26	52.99	
Oilseeds & Pulses	3,611	10.68	10.59	10.84	6,406	7.57	7.66	7.78	667	3.20	3.55	3.47	1,027	8.57	8.10	4.04	189	12.52	11.44	9.22	
Total for all crops	33,825	100.00	100.00	100.00	84,582	100.00	100.00	100.00	20,840	100.00	100.00	100.00	11,993	100.00	100.00	100.00	1,513	100.00	100.00	100.00	

All results use the small group, 25% multiplicative yield shock (NEW FIGURES WITH CORRECTED DATA)

Notes:

- Table shows benefits in 2030 from increasing rate of crop yield improvement by 25%/year multiplicatively above baseline yield growth over 2010-30. Yield shock is applied to one commodity at a time, holding other crops to their baseline rate of yield growth.
- Yield shock affects all LDCs except China, Brazil and Southern Cone countries.
- Economic surplus (ES) is the benefits to producers and consumers from the yield shock.
- ES weighted by poverty headcount: ES in each country is multiplied by its \$1.9/day poverty headcount index (share of population earning less than \$1.9/day).
- ES weighted by poverty gap: ES in each country is multiplied by its poverty headcount index and its poverty gap index. The poverty gap is the difference between \$1.9 and the mean income of the poor in a country, expressed as a percent of \$1.9.
- For Soybean, yield shocks affect small group of LDCs. but ES benefits only counted for Sub-Saharan Africa (SSA). [IMPACT model produces zero benefits from soybean yield shock to small group of LDCs].

Sources: Economic Surplus estimates generated by IFPRI's IMPACT Model. Poverty headcount and poverty gap indexes are from World Development Indicators, latest available year.

IFPRI Table 4c – Economic Surplus Model results: Change in economy-wide income in 2030 from faster productivity growth, by IFPRI's IMPACT model, by sub-region in SSA

Commodity/Scenario	SSA, Central				SSA, Eastern				SSA, Southern				SSA, Western (except Nigeria)				SSA, Nigeria			
	ES for LDC in 2030 from yield shock	ES share	ES weighted by		ES for LDC in 2030 from yield shock	ES share	ES weighted by		ES for LDC in 2030 from yield shock	ES share	ES weighted by		ES for LDC in 2030 from yield shock	ES share	ES weighted by		ES for LDC in 2030 from yield shock	ES share	ES weighted by	
			poverty count	poverty gap			poverty count	poverty gap			poverty count	poverty gap			poverty count	poverty gap			poverty count	poverty gap
(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	(million\$)	(%)	(%)	(%)	
Cereal Grains																				
Rice	362	17.97	16.69	15.11	210	7.04	6.45	7.64	220	22.82	28.98	35.28	891	29.94	30.38	30.00	5,368	21.57	21.57	21.57
Maize	202	9.99	7.35	4.56	195	6.54	6.01	7.19	49	5.03	8.06	10.03	923	31.04	31.04	32.08	1,947	7.82	7.82	7.82
Wheat	25	1.25	1.27	1.21	435	14.59	16.64	15.43	219	22.63	11.69	3.98	4	0.15	0.17	0.19	340	1.37	1.37	1.37
Sorghum	127	6.30	5.62	3.62	510	17.10	15.46	12.15	25	2.57	1.87	1.30	138	4.63	5.41	5.50	4,613	18.54	18.54	18.54
Millet	122	6.03	6.21	5.00	444	14.89	15.13	13.11	28	2.89	2.04	1.26	154	5.17	6.62	6.90	3,636	14.61	14.61	14.61
Barley	36	1.80	1.81	1.59	84	2.81	2.59	3.09	21	2.16	3.52	4.40	5	0.17	0.17	0.18	10	0.04	0.04	0.04
Roots, Tubers & Bananas																				
Potato	39	1.92	1.77	1.69	52	1.74	1.59	1.84	51	5.32	4.10	3.19	17	0.58	0.59	0.61	72	0.29	0.29	0.29
Cassava	313	15.50	18.76	24.09	84	2.83	3.26	3.89	72	7.44	9.66	10.95	56	1.89	1.36	1.13	1,194	4.80	4.80	4.80
Yams	42	2.07	1.78	1.87	64	2.15	2.02	1.77	26	2.66	1.74	1.06	231	7.75	6.28	5.55	4,599	18.48	18.48	18.48
Sweet potato	38	1.90	1.66	1.54	39	1.31	1.20	1.40	17	1.77	2.22	2.49	54	1.81	1.83	1.88	96	0.38	0.38	0.38
Banana	200	9.91	8.65	6.29	73	2.46	2.25	3.32	47	4.87	4.08	3.54	105	3.53	3.35	2.86	39	0.16	0.16	0.16
Plantain	143	7.10	7.24	8.29	399	13.38	16.52	19.47	48	4.94	5.76	6.20	134	4.51	3.31	2.42	528	2.12	2.12	2.12
Oilseeds & Pulses																				
Pulses, total	94	4.68	4.48	4.09	132	4.42	4.44	4.74	42	4.39	4.45	4.41	62	2.10	2.36	2.51	606	2.44	2.44	2.44
beans (<i>phaseolus</i>)	55	2.71	2.42	2.02	45	1.52	1.41	1.74	20	2.10	2.07	2.03	20	0.67	0.71	0.79	29	0.12	0.12	0.12
chickpea (<i>cicer</i>)	7	0.33	0.33	0.29	33	1.11	1.37	1.31	5	0.53	0.50	0.47	11	0.36	0.46	0.50	8	0.03	0.03	0.03
cowpea (<i>vigna unguiculata</i>)	17	0.82	0.93	1.03	12	0.39	0.26	0.28	6	0.63	0.59	0.55	18	0.62	0.74	0.76	539	2.17	2.17	2.17
pigeonpea (<i>cajanus</i>)	6	0.31	0.33	0.29	11	0.38	0.24	0.27	3	0.35	0.46	0.52	4	0.13	0.13	0.14	7	0.03	0.03	0.03
lentil (<i>lens</i>)	1	0.05	0.04	0.03	8	0.27	0.35	0.34	1	0.09	0.08	0.07	2	0.06	0.06	0.06	3	0.01	0.01	0.01
other pulses (<i>pisum</i>)	9	0.46	0.43	0.42	22	0.74	0.80	0.81	7	0.69	0.75	0.77	8	0.26	0.26	0.26	20	0.08	0.08	0.08
Groundnuts	264	13.07	16.35	20.75	249	8.36	6.01	4.14	75	7.74	8.34	8.40	110	3.69	3.54	3.27	1,830	7.35	7.35	7.35
Soybean	11	0.52	0.38	0.30	11	0.38	0.42	0.82	27	2.79	3.49	3.49	91	3.04	3.60	4.93	8	0.03	0.03	0.03
Cereal Grains	874	43.33	38.94	31.10	1,878	62.98	62.29	58.61	561	58.08	56.16	56.26	2,115	71.09	73.78	74.83	15,913	63.95	63.95	63.95
Roots, Tubers & Bananas	775	38.40	39.86	43.76	711	23.86	26.84	31.70	261	26.99	27.56	27.44	597	20.07	16.72	14.45	6,529	26.23	26.23	26.23
Oilseeds & Pulses	368	18.27	21.20	25.13	392	13.16	10.87	9.69	144	14.93	16.28	16.31	263	8.84	9.50	10.72	2,443	9.82	9.82	9.82
Total for all crops	2,017	100.00	100.00	100.00	2,982	100.00	100.00	100.00	966	100.00	100.00	100.00	2,975	100.00	100.00	100.00	24,885	100.00	100.00	100.00

All results use the small group, 25% multiplicative yield shock (NEW FIGURES WITH CORRECTED DATA)

73.6%=Nigeria's share of SSA Econ. Surplus

Notes:

- Table shows benefits in 2030 from increasing rate of crop yield improvement by 25%/year multiplicatively above baseline yield growth over 2010-30. Yield shock is applied to one commodity at a time, holding other crops to their baseline rate of yield growth.
- Yield shock affects all LDCs except China, Brazil and Southern Cone countries.
- Economic surplus (ES) is the benefits to producers and consumers from the yield shock.
- ES weighted by poverty headcount: ES in each country is multiplied by its \$1.9/day poverty headcount index (share of population earning less than \$1.9/day).
- ES weighted by poverty gap: ES in each country is multiplied by its poverty headcount index and its poverty gap index. The poverty gap is the difference between \$1.9 and the mean income of the poor in a country, expressed as a percent of \$1.9.
- For Soybean, yield shocks affect small group of LDCs. but ES benefits only counted for Sub-Saharan Africa (SSA). [IMPACT model produces zero benefits from soybean yield shock to small group of LDCs].
- SSA Regions:

Central: Cameroon, Central African Republic, Chad, Congo, DRC, Eq. Guinea, Gabon, Sao Tome & Principe

Eastern: Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, South Sudan, Sudan, Uganda

Southern: Angola, Botswana, Comoros, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe

Western: Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Senegal, Sierra Leone, Togo, Nigeria

Sources: Economic Surplus estimates generated by IFPRI's IMPACT Model. Poverty headcount and poverty gap indexes are from World Development Indicators, latest available year.

IFPRI Table 5 – Change in undernourished children and population at risk of hunger in 2030

Commodity/Scenario	Change from Reference Scenario in 2030					
	Undernourished Children			Population at Risk of Hunger		
	(% reduction)	(total number)	share of total (%)	(% reduction)	(total number)	share of total (%)
	(%)	(total number)		(%)	(total number)	
Cereal Grains						
Rice	-0.29	-360,803	35.91	-2.05	-10,605,373	37.47
Maize	-0.05	-59,700	5.94	-0.31	-1,580,570	5.58
Wheat	-0.17	-207,550	20.66	-1.14	-5,907,435	20.87
Sorghum	-0.05	-65,250	6.49	-0.32	-1,629,587	5.76
Millet	-0.05	-68,162	3.80	-0.27	-1,385,064	4.89
Barley	0.00	-3,306	-0.33	-0.02	-123,187	0.44
Roots, Tubers, & Bananas						
Potato	-0.01	-11,809	1.18	-0.08	-390,109	1.38
Cassava	-0.06	-74,618	7.43	-0.35	-1,827,935	6.46
Yams	-0.04	-48,572	4.83	-0.11	-551,343	1.95
Sw eet potato	-0.01	-9,635	0.96	-0.06	-330,793	1.17
Banana	-0.02	-19,434	1.93	-0.12	-597,944	2.11
Plantain	-0.05	-63,761	6.35	-0.40	-2,056,017	7.26
Oilseeds & Pulses						
Pulses, total	-0.06	-74,871	7.45	-0.46	-2,397,277	8.47
beans	-0.01	-11,383	1.13	-0.08	-432,706	1.53
chickpea	0.00	-5,970	0.59	-0.05	-269,158	0.95
cow pea	-0.01	-7,591	0.76	0.01	30,854	-0.11
pigeonpea	-0.01	-10,059	1.02	-0.05	-263,570	0.93
lentil	0.00	4,469	-0.44	0.02	104,498	-0.37
other pulses	0.00	-1,533	0.15	-0.01	-71,076	0.25
Groundnuts	-0.01	-12,120	1.21	-0.06	-293,528	1.04
Soybean	0.00	-4,245	0.42	-0.02	-121,558	0.43
Total for all crops		-1,004,650	100.00		-28,301,601	100.00

All results use the small group, 25% multiplicative yield shock.
Source: Based on results from IFPRI's IMPACT model.

IFPRI Table 6 Change in nutrient adequacy ratios in 2030 (percentage change relative to baseline in 2030)

Crop/ Scenario	Region	Folate	Iron	Magnesium	Phosphorus	Potassium	Total Fiber	Vitamin A (RAE)	Vitamin B6	Vitamin C	Vitamin E	Vitamin K	Zinc
Cereal Grains													
Maize	LAC	0.06	0.12	0.12	0.10	0.06	0.11	0.02	0.08	0.00	0.05	0.03	-0.02
Millet	SSA	0.15	0.13	0.12	0.14	0.04	0.14	-0.02	0.10	0.00	0.01	0.03	-0.01
Rice	Asia	0.12	0.17	0.21	0.26	0.16	0.16	0.05	0.28	0.06	0.08	0.07	0.06
Rice	SSA	0.06	0.04	0.09	0.14	0.07	0.07	0.02	0.11	0.04	0.05	0.05	0.04
Sorghum	SSA	0.04	0.14	0.17	0.14	0.07	0.11	-0.01	0.12	0.00	0.06	0.00	-0.02
Wheat	Asia	0.20	0.39	0.41	0.33	0.22	0.50	0.03	0.24	0.02	0.27	0.09	0.07
Wheat	LAC	0.11	0.16	0.17	0.15	0.09	0.23	0.02	0.10	0.01	0.12	0.06	0.03
Wheat	SSA	0.10	0.12	0.17	0.17	0.10	0.22	0.01	0.10	0.01	0.13	0.07	0.05
Roots, Tubers & Bananas													
Cassava	SSA	0.31	0.08	0.15	0.09	0.29	0.20	0.00	0.16	0.53	0.11	0.28	0.07
Plantain	SSA	0.04	0.05	0.09	0.03	0.15	0.07	0.20	0.16	0.13	0.02	0.00	0.01
Sweet potato	SSA	0.01	0.01	0.01	0.01	0.02	0.02	0.48	0.02	0.00	0.01	0.02	0.00
Yam	SSA	0.11	0.06	0.05	0.07	0.31	0.17	0.04	0.20	0.17	0.08	0.13	0.03
Oilseeds & Pulses													
Chickpea	Asia	0.12	0.03	0.01	0.02	0.00	0.02	-0.04	0.01	-0.06	0.01	-0.03	0.01
Cowpea	SSA	0.24	0.12	0.09	0.06	0.06	0.05	-0.03	0.01	-0.05	0.00	-0.01	0.06
Groundnuts	SSA	0.07	0.04	0.04	0.04	0.03	0.03	0.01	0.02	0.01	0.15	0.01	0.00

Note: Rows for crops/scenarios and regions where all effects are less than 0.10 percent are omitted. Values of 0.10 or greater are highlighted in red to highlight the largest changes. Source: IFPRI/USDA

x

IFPRI Table 7 NIPI values for 2030 crop productivity increase scenarios (ranking scenarios by impact across multiple nutrients)

Crop/Scenario	Asia	LAC	SSA
Cereal Grains			
Barley	9	10	8
Maize	3	3	3
Millet	4	4	9
Rice	2	2	2
Sorghum	6	5	4
Wheat	1	1	1
Roots, Tubers & Bananas			
Banana	16	13	14
Cassava	12	11	15
Plantain	19	13	6
Potato	5	6	5
Sweet potato	11	18	16
Yam	15	9	10
Oilseeds & Pulses			
Beans	14	20	17
Chickpea	20	8	20
Cowpea	17	19	18
Groundnuts	7	7	7
Lentils	18	17	19
Other pulses	13	16	11
Pigeonpea	8	14	13
Soybean	10	15	12

Note: The Nutrient Investment Productivity Index (NIPI) ranks crop-specific productivity growth for its contributions across multiple deficit nutrients. NIPI sums the rank order values for each nutrient and then rank orders the results. The result is an index from 1 (most number of deficient adequacy ratios improved) to the number of crops (fewest adequacy ratios improved). The four highest-ranked crops/scenarios are highlighted in red for each region.

x

Revised Oct 10 2018

Annex 3: Modernizing CGIAR crop breeding programs: Draft 2019-2021 implementation plan

Purpose

Funders have taken the lead in defining a comprehensive modernization agenda for crop breeding in the CGIAR (see *Initiative on “Crops to End Hunger”. Strategy and Options for CGIAR Support to Plant Breeding, vers. Oct 10, 2018*).

In response, and at the request of the System Management Board at its 10th Meeting¹, the System Management Office has engaged with Center Directors General, the Excellence in Breeding Platform and heads of breeding to develop the current Draft implementation plan, as a further demonstration of the System Management Board’s strong commitment to support the Funders’ “Crops to End Hunger” initiative.

It is intended that the final endorsed plan serve as a coherent and system-wide response to enhancing capacity in this area critical to CGIAR delivery. Centers and CRPs for which crop breeding is an element will have accountability to the System Management Board, and through it, to the Funders for the enhancement of individual crop breeding programs. The Excellence in Breeding Platform will play a pivotal role in the process. The plan recognizes:

- a. the need for commitment at all levels of the CGIAR, particularly from Centers’ senior management and the breeding leads (with enhanced managerial “clout”); and
- b. that the plan applies to all crop breeding programs; none will be exempted from the modernization drive.

This implementation plan should start immediately upon endorsement, such that it forms a key element of the CGIAR System 2019-2021 Business Plan.

Background/Rationale

1. Crop breeding for improved varietal performance, and the agricultural and human welfare benefits which flow from such improvements, have been a mainstay of the historical success of the CGIAR system and a pillar of its theory of change. This should continue – despite the welcome increase in research by the private sector, there are still many crucial gaps that must be filled by public sector efforts for crops critical to the food security agenda of developing countries. Crop breeding has the power to provide varieties relevant to food productivity, human nutritional improvement and stability and resilience in the face of climate variability and pests and diseases. The focus of this plan should not imply that breeding is the only important area of CGIAR’s

¹ Action point SMB/M10/AP2: The Board requested that the System Management Office put together a high-level (iterative) implementation plan on the modernization and prioritization agenda for discussion at SC7.

work – other areas are addressed through many other parts of our portfolio and through similar strategies and special initiatives.

2. This initiative aims to accelerate a transition in CGIAR crop breeding for human consumption² to address very different challenges from those faced in the green revolution. As set out in the CGIAR 2019-2021 Business Plan Foreword from CGIAR Board Chairs: “The need for a global partnership to transform the food system while restoring our environment has never been greater. The task before us is momentous: a sustainable food systems revolution – as urgent as the agricultural revolution that launched CGIAR, yet exponentially more complex.” One part of this challenge is for breeding in the CGIAR System to modernize in terms of its objectives beyond pure yield gain – to address the expanding demand for improved varieties to meet biotic and abiotic stresses, such as climate change and environmental degradation, and to include a wider set of nutritional and market traits, as well as traits relevant to both end-users and value chains, which would increase the adoption rate of newly bred varieties.
3. Another part is to modernize how it works - to keep up with advances in all the contributory fields including genetics, experimental design, mechanization, monitoring and data analysis so as to ensure that CGIAR is up to date and delivering on its promises; and to position itself squarely as one contributor to an innovation value chain that works through others, often the private sector.
4. CGIAR addresses some 20 crops through a larger number of crop breeding and improvement programs. Funders have used an independent assessment tool, the Breeding Program Assessment Tool (or BPAT) to gauge the current quality and capacity of breeding programs. Whilst some of the System’s historical comparative advantage is maintained in a few of the better-funded breeding programs, the assessments suggest that many crop breeding programs are below modern standards in one or more areas such as organization, skills, staff commitments or funding levels and quality required to ensure that CGIAR can meet its development goals. These reports collectively suggest that CGIAR is not where it needs to be on the threshold of a new phase of the portfolio and in the relatively short time until the SDG target date of 2030. Funders have therefore taken the lead in defining a comprehensive modernization agenda for crop breeding in the CGIAR System (see *Initiative on “Crops to End Hunger”. Strategy and Options for CGIAR Support to Plant Breeding, vers. Oct 10 2018*).
5. This paper seeks to provide a comprehensive CGIAR agenda for implementation of the changes required to meet Funder demands for the modernization of CGIAR breeding. Our response acknowledges the seriousness of that challenge to CGIAR. For CGIAR stakeholders – the System Management Board, the Directors General of Centers leading the relevant Agri-Food System CRPs, their CRP Directors, DDG’s Research and

² Funders chose to focus on 20 CGIAR crops (cereals, legumes, root crops and *Musa* spp.) for this breeding initiative, not including fodder species, livestock or fish which are the subjects of other work within the CGIAR.

Breeding Leads – this is a moment of opportunity to identify the implementation steps of an ambitious modernization agenda.

What is meant by a “modern” breeding program?

6. A well-functioning modern breeding program is one that has a process of continuous improvement, which is always implementing ways to increase rates of genetic gains, while continually asking if there can be closer alignment between what will have maximum impact and the targeted and realized outputs. To be effective each crop breeding program will need to establish critical mass for product development and rigorous metrics for success: means to regularly measure genetic gains and the rate of varietal turnover in farmers’ fields will be required. The system as a whole will be expected to seek efficiencies through better use of common services (shared and outsourced) and the use of shared infrastructure at CGIAR breeding hubs where appropriate.

A partnership approach

7. The modernization agenda is predicated on methods and practices which provide rapid and efficient varietal development in the private sector. Private sector experts are expected to continue to provide advice and best practice and opportunities for the provision of services to breeding programs through the EiB and potential partnerships. The Breeding Initiative views CGIAR crop breeding as taking place in the context of national system breeding programs. This means that in planning breeding programs, national demands and market considerations, collaboration in phenotyping networks and identification of opportunities for seed delivery system alignment and improvement should all be considered. The Initiative highlights that to have effect, crop varieties need to perform demonstrably better in farmers’ fields and to be desired commodities by farmers. CGIAR can and should promote its outputs but it does not control delivery pipelines. To this end, whilst the Initiative focusses on the modernization of CGIAR breeding programs, it invites full collaboration with national programs as scientific and commercial partners to achieve the outcomes and impact sought.

What will result?

8. By going through this process of improvement and modernization, there will be multiple benefits. Firstly, for a given level of investment it is anticipated that each breeding program will achieve increased rates of genetic gain and scale of impact - what CGIAR breeding is all about. Secondly, there will be further opportunity to gather together allied CGIAR crop programs and to promote and work with standardized methodologies across Centers. Thirdly, adopting standardized ways of reporting needs, opportunities and progress will provide Funders with a transparent view of where and how they are getting high rates of return for their investment. It is anticipated that this will in turn lead to sustained and increased funding. Finally,

implementing current best practices and utilizing latest technologies to their full advantage can only provide Funders, both current and potential, with increased confidence to continue, increase or start investing in CGIAR breeding.

Establishing commitment and the necessary staffing

9. The Breeding Initiative makes it clear that SMB and CGIAR Center management commitment to the modernization agenda is paramount, and continued funding of breeding programs depends upon the successful implementation of the steps outlined below.
10. The System Management Board agrees that the underlying tenet of the modernization agenda is Center managerial and staff commitment to the process. The implementation plan is as much a managerial challenge as a scientific and logistical one. It will be necessary to galvanize all players, to treat the implementation plan as a stimulus to necessary change, and an opportunity to gain new skills and scientific excellence to underpin CGIAR 's programs. Crop breeding programs encompass our colleagues in collaborating national programs. There is an opportunity to develop better approaches and facilities to benefit developing country agricultural research in a global manner.
11. This implementation plan therefore envisages Center leadership and development of new crop breeding plans by Center crop breeding teams. Modern programs are characterized by continuously looking to make improvements in each of the following areas:
 - a. Standardized product profiles (developed with NARS partners and with due regard to socio-economic and market demands) that describe varietal lines that will have maximum impact
 - b. A formalized and documented breeding process with pre-defined requisites as found in a stage gate process, including clear plans for involvement of CGIAR clients (including NARS breeders) into the processes of testing, selection, release and commercialization
 - c. Optimized breeding schemes that routinely seeks to increase selection accuracy and selection intensity, while still maintaining sufficient levels of genetic diversity
 - d. Routine genetic gains assessment
 - e. Access to low-cost, well targeted genotypic data strategically integrated into the breeding process
 - f. Ability to generate low-cost, well targeted and accurate phenotypic data
 - g. All breeding data handled and stored in a way that supports automation, integration (at all levels), decision making and use of best-practice biometrics

12. A significant element of modernization can be realized within existing funding envelopes and may even lead to cost efficiencies³. However, this is a skills-led process. Costs incurred by the breeding Centers associated with executing the improvement plans are likely to come in the form of personnel in the first instance⁴, then access to services and capital and infrastructure:
- a. To drive the modernization agenda within a Center from technical, logistical and administrative perspectives and to bridge support from EiB to the programs will likely require a dedicated person, perhaps a **Head of Breeding Modernization**. This person should be technically highly skilled, including experience with modern breeding approaches and also have management skills.
 - b. To drive successful implementation of the improvement plan will require a **project manager**
 - c. To develop well informed product profiles and to be the bridge between the market (farmers and end users) and the breeding program may require a **product manager**.
 - d. To ensure optimal breeding schemes are being used and that new technologies are being applied optimally will require **access to quantitative genetics support**. This support will need to apply quantitative genetic principles to a functioning field breeding program considering all biological, logistical and resource constraints. These skills are difficult to attract. The person/people providing this support will need to spend considerable time on site with the breeding program(s) but may not need to be based at the Center.
 - e. To ensure that maximum value is extracted from each data point, **biometrics support** will be required. It is possible that this could be sourced together with quantitative genetics support. As breeding programs evolve to require these new positions, other positions within the program should also be critically reviewed. As the program evolves there may not necessarily be an increase in the total number of positions, or, there may even be a reduction.
 - f. More sophisticated **data management systems** will be required, including **IT support**, which will need to be budgeted for.

Overall process to modernize CGIAR breeding programs

13. The first step towards modernization of breeding programs is to identify the gaps - the areas that need to be addressed or improved. The Breeding Program Assessment Tool (BPAT) has been developed for this purpose. The deployment of BPAT has been funded by the Bill & Melinda Gates Foundation (BMGF) and administered by the University of Queensland (UQ) and has now been used to assess the breeding programs at more than half of CGIAR's Centers. The process has involved use of a standard and detailed

³ The Initiative focusses very specifically on improving the breeding element of crop improvement programs. Some assessments to date have noted that breeding has been surrounded by other activities which consumed breeding staff time or were of limited or competing value to the development of important new varieties.

⁴ Leadership and dedicated support in these roles will be required for each breeding program although synergies can be expected to result from Centers responding to the BPAT recommendations where they host more than one crop breeding program and through shared system services.

survey questionnaire about a specific crop breeding program run by a CGIAR Center. The survey is administered by a small team of visiting experts conducting an on-site assessment. This is followed 3-4 months later by a formal written report by the BPAT team which includes recommendations resulting from the assessment. This process has been rolled out across CGIAR starting in early 2016 and is due to be concluded in 2019. A common gap identified from these assessments is that CGIAR breeding Centers need access to tools and services, some of which cannot justifiably be developed for individual Centers or crops but could be developed for common use if shared across the whole of CGIAR. Examples include data management tools and access to low-cost genotyping. To achieve many of the recommendations arising from the BPAT process and fill the identified gaps will require CGIAR breeding Centers to plan the future with access to high-quality technical advice. Hence the Excellence in Breeding Platform (EiB) has been established to provide technical consultancy and access to shared breeding tools and services.

Table 1: Status of BPAT assessments of CGIAR Center hubs for crop breeding⁵ (as of October 2018)

Center	Program	Status
ICRISAT	All except finger millet	Completed
IITA	All	Completed
CIMMYT	Spring bread wheat	Completed
IRRI	All	Completed
CIAT	Beans, forages	Completed
AfricaRice	All	Completed
CIP	All	Complete*
CIAT	Rice, cassava	Nov-18
ICARDA	TBC	TBC
CIMMYT	All maize programs	Nov-18
CIMMYT	Durum, winter wheat, hybrid wheat	No plans

*Center awaiting final report

14. Only once the diagnosis has been made, a quality plan designed, and the necessary skills engaged, would it be appropriate to upgrade infrastructure, machinery and equipment at breeding hubs and as part of a shared strategy for breeding across all of CGIAR. The Center breeding programs and Center hubs will need to establish the basis collaboratively to attract Funder support on the scale required.
15. As programs take advantage of new tools and technologies this should not require additional resources as the value proposition of adopting new technologies should be such that a higher rate of genetic gain can be achieved for the same level of investment. Reallocation of resources may be required, however. To implement

⁵ It should be noted that BPAT assessments have been carried out on CGIAR Centers and a crop by crop assessment conducted for crop breeding programs led by that Center. The BPAT planning cycle will continue until all 20 crops considered by the Breeding Initiative have been included. This may introduce a naturally staggered development of new breeding plans per crop subsequently.

genomic tools may require investment in salaries or field nurseries to pay for genotyping conducted by an external laboratory. Much can be achieved with current infrastructure but to be truly “modernized” is likely going to require capital investment in infrastructure, machinery and equipment. Examples include machinery for moving towards mechanized processes for trial packing, sowing, harvesting and post-harvest handling, equipment for seed handling, sample tracking, data collection, etc. and infrastructure for rapid generation advance and managed environment facilities (if and when required). Anticipated additional costs arising from modernization in the form of additional staffing, infrastructure and services beyond current levels will be set out in modernization plans.

Approach to Funding

16. On fundraising for the costs of the above, the System Management Board will facilitate a collective engagement with Funders attached to CGIAR’s half-yearly System Council meetings to seek additional funding, where required, to support implementation of these costed modernization plans and any additional supporting shared services and infrastructure required.
17. Funding for breeding, like other areas of CGIAR’s work, is fragmented and suffers from a proliferation of separate projects, leading to a fragmentation of efforts by Centers and leverage by Funders, alongside inefficiencies from multiple reporting and weak core programs.
18. The System Management Board therefore urges Funders to provide funding:
 - a. of sufficient volume
 - b. through the pooled funding arrangements of W1 and 2
 - c. on a multi-year basis (even where through W1 and 2)
 - d. coordinated among Funders to reflect collective priorities
 - e. through the agreed CRP and Platform portfolio
19. One aspect that will require monitoring is the capacity of the BPAT evaluation teams and EiB itself to maintain the review of breeding hubs and support functions to breeding programs (respectively) according to the schedule outlined in this plan within their current capacity. Should commissioning extra capacity be required to manage the simultaneous modernization of CGIAR breeding programs, these may require future additional funding.

Technical support for breeding plan development

20. The EiB Platform is essentially constructed as a shared service to Centers (see Box). Once recommendations from the BPAT assessments have been made, and the EiB team is established together with the communities of practice, plans for responding to these recommendations will need to be developed. These plans will be crop-specific breeding program improvement plans or “improvement plans”. One of the roles of EiB is to offer assistance to CGIAR breeding Centers to develop these plans, so that these

plans will include recommendations made by both BPAT and EiB. As autonomous Centers, each CGIAR Center will choose how to prioritize these recommendations and will commit to their implementation.

21. For each of these improvements the plan will include:
 - a. All action steps required to make each targeted improvement
 - b. For each action step, a deadline by which it will be completed
 - c. For each action step, the person accountable for ensuring the action is completed, the people responsible for making the action happen and the people that need to be informed and consulted
 - d. Methods for monitoring progress towards and completion of each action step.
 - e. Estimated costs or savings (if any) expected to be associated with any particular action
22. It is expected that each improvement plan will include the identification of responsibilities for each member of breeding team personnel, senior Center management and the EiB Platform.
23. Center senior management (DG and DDG-R) will be accountable⁶ for the modernization of breeding programs, both directly to Funders and indirectly via the System Management Board. EiB is responsible for enabling CGIAR Centers to deliver against these plans by providing technical consultancy and access to shared tools and services and for reporting progress against the improvement plans. Shared tools and services (that pre-date EiB but will be supported by EiB going forward) are already being used within CGIAR, for example access to high-quality cheap genotyping through the High Throughput Genotyping Project or access to a Breeding (data) Management System through the Integrated Breeding Platform.
24. Across CGIAR there is an opportunity to aggregate demand for breeding services to create economies of scale for driving down per unit prices to access these services, whether they are outsourced or provided from within CGIAR for the whole of CGIAR. EiB is tasked with achieving this wherever possible.
25. A key early step is for EiB to develop specific tools and templates to facilitate the process of developing the improvement plans. Examples of these might include tools and/or templates for the development of:
 - a. The improvement plan itself
 - b. Market informed product profiles that, for instance, include gender preferences, nutrition and climate resilience and mitigation traits
 - c. A stage gate process for the development of germplasm/variety lines
 - d. Robust analyses of rates of genetic gains in farmers' fields
 - e. Documented breeding schemes
 - f. Documented use of (including usefulness of) specific molecular tools

⁶ This statement does not devalue the role of Center boards but rather identifies Directors General and their program leaders as being operationally responsible for program management.

- g. Documented approaches to and processes for phenotyping
- h. Breeding use cases and work flows currently supported by data management systems
- i. Breeding use cases and work flows still needing to be supported by data management systems

Text Box 1: The Excellence in Breeding Platform

The Excellence in Breeding Platform (EiB) is designed to provide advice and access to services for the breeding programs of the CGIAR. Currently EiB is close to having its team established, at which point it will have an expert in each of the following areas:

1. Product design and management to ensure breeding objectives and processes are aligned for maximum scale of impact
2. Breeding pipelines, quantitative genetics and biometrics
3. Genotyping for breeding purposes including quality control (QC), forward Marker Assisted Selection (MAS) and Genomic Selection (GS)
4. Mechanization and automation of breeding process to increase quality and drive down cost of phenotypic data
5. Development of data management solutions for breeding

These 5 areas of expertise have been identified in consultation with all the Agri-Food System CGIAR Research Programs to cover the major technical areas of the breeding process. Sources of advice in these areas will be a resource for CGIAR breeding Centers and will simultaneously lead a community of experts contributing to EiB to address issues such as what is current best practice and to develop plans for development of breeding tools and access to services. This community will be sourced from all areas of the broad breeding community globally including from CGIAR, National breeding programs, Advanced Research Institutes (ARIs) (including universities and government research organizations) and the private sector. From these communities, implementation and support networks can be developed. These networks will serve as a resource for the CGIAR community to make tangible advancements toward improved practices.

26. Some of these tools will be required for the development of the improvement plan itself, others will be required for the execution of the improvement plan. As the improvement plans are developed, additional tools and services that will be required to enable the plans to be executed may become apparent. Examples of such tools might include methods for assigning values to specific traits to determine their validity on a product profile, decision support tools for parent selection, cross combinations, hybrid combinations or selections, or, simulation tools to simulate outcomes from alternative breeding schemes.

27. CGIAR Centers engaged in the Breeding Initiative will develop a draft improvement plan by 31 March 2019 and a fully comprehensive plan by 30 September 2019⁷. Once the necessary tools and templates are developed, for Centers wishing to utilize EIB to develop these plans, a process for both engagement and the development of the plans must be developed together by the Centers and EIB. The process of engagement is to be worked out and must balance commitment, funding and Center and EIB capacity.
28. These improvement plans will become living documents as they should continually be updated (which is why each is a “comprehensive” rather than a “completed” plan). The fluid nature of each plan does not diminish the accountability for any particular action point agreed to in the plan. The improvement plans will include many individual actions, some that could be actioned within weeks or months and others that will be part of a larger more complex outcome that might take up to 2-3 years. Improvements that are to be implemented over a longer timeframe than 2-3 years will be added later as the plan is updated. Plans will need to be formally updated every 6 months according to progress made during the first three years of the Initiative.

Accountability, Oversight and Monitoring of implementation progress.

29. Progress against the plans must be monitored and Funders expect some oversight to assess the quality of implementation. The CGIAR breeding modernization agenda has to be Center-led but framed with respect to the effective strategies of the CRPs. Breeding management is managed at the level of crops and Centers (or sometimes groups of Centers). CGIAR’s existing governance arrangements and their principle of subsidiarity will apply.
30. Key roles are:
 - a. Centers – to lead the detailed design and implementation of the Initiative and their modernization plans
 - b. CRPs - frame the work that encompasses varietal improvement research towards measurable outcomes
 - c. System Council – to assess implementation as reported on in the annual CGIAR Performance Report
 - d. SMB – leading the overall design and oversight of the implementation plan
 - e. Funders – to match the implementation plan with appropriate volumes and quality of funding
 - f. EIB – to support the design and implementation of the plan
31. Key elements will include:

⁷ This schedule is proposed for Centers for which a BPAT assessment report is currently available. Others would be expected to join in and develop draft breeding plans for individual crops approximately three months after the delivery date of the relevant BPAT assessment report.

- a. Each individual breeding program will go through a BPAT process no less frequently than every two-three years⁸. The BPAT was used as the initial mechanism for assessing program quality and capacity and will likely be the best mechanism for routine assessment and for monitoring progress against improvement plans.
- b. Breeding programs will be assessed by common metrics, namely, extent of genetic gain and rate of varietal turnover in farmers' fields.
- c. Breeding Centers will report annually on implementation of their modernization plan [to the System Management Office] and this will be featured in a special section of CGIAR's annual performance report and accompanying dashboard.
- d. *An alternative*⁹ is that the EiB as part of its Annual Platform report is the channel for reporting on the modernization agenda (reports provided by Centers to the EiB through its contributor meeting or similar).
- e. CRPs will continue to report on planned programmatic outputs and progress towards outcomes from CRP research.
- f. EiB may be requested additionally by SMB to analyze and verify the reports provided, and where requested provide updates on the implementation of the Breeding Initiative to SMB, SC and Funders.

Continuing interaction by EiB

32. In addition to working with CGIAR breeding Centers to develop improvement plans, EiB will also be providing technical consultancy and access to shared tools and services. Many of the ways in which EiB is expected to provide this have already been defined as a result of:
 - a. The BPAT reports
 - b. Surveys sent out by EiB
 - c. Feedback from CGIAR breeding teams and Centers via the annual EiB Contributors Meeting
 - d. Engaging with CGIAR breeding teams and management during EiB visits to CGIAR Centers
33. EiB's engagement strategy for assisting programs to develop improvement plans will be different from its strategy for providing technical advice or access to tools and services. Therefore, the priority and urgency with which EiB allocates resources to assisting with the development of improvement plans should be clearly defined by the Funders and senior management of the CGIAR breeding Centers.

A philosophy of critical mass and sharing of services

⁸ Two years is preferable; however, this will be influenced by the nature of crops (potentially slightly longer for root and tuber crops versus cereals) and the practical capacity of the BPAT assessment teams for such a re-review schedule – for instance if a full team assessment was anticipated, or re-reviews were conducted by only one member of the former assessment panel.

⁹ Recognizing that that some reporting of the process of implementation of breeding modernization per Center may precede the outcome measure reporting through CRPs.

34. A risk of a Center-by-Center process is that opportunities to invest in shared facilities and services are missed, even if these would be better value for money. Hence a key first step in this plan will be a request from the SMB to EiB to facilitate a discussion among breeding Centers to identify the scope for such shared activities, where it makes sense to have these.
35. [This will be undertaken in Q1 2019 for submission to the SMB meeting in April 2019].

3-year Sequencing of Actions

- a. CGIAR breeding programs assessed with the BPAT (immediately, as per schedule in Table 1)
- b. Draft Implementation Plan considered by DGs, breeding leads and the SMB in October
- c. Implementation Plan revised with stakeholder inputs and discussed with Funders at SC7 Seattle USA in November.
- d. Breeding Initiative formally announced and commences January 2019
- e. CGIAR breeding Centers develop draft crop improvement plans (immediately)
- f. SMB request to EiB to identify emerging need for shared services (early 2019 for April 2019 review)
- g. EiB completes putting team together (by April 2019)
- h. EiB develops tools to assist development and execution of improvement plan (ongoing but significant progress by end of 2018)
- i. EiB assists CGIAR Centers wanting assistance to develop an improvement plan (immediately)
- j. CGIAR breeding Centers complete draft improvement plans (no later than by March 2019)
- k. CGIAR breeding Centers complete comprehensive improvement plans (no later than by September 2019)
- l. CGIAR breeding programs begin regular reporting through Annual report processes¹⁰ in 2020
- m. Upgrade of breeding hubs begins 2020
- n. Improvement plans updated every 6 months
- o. BPAT assesses progress against the improvement plans no less than every 2-3 years

¹⁰ See section on Accountability, Oversight and Monitoring for the alternatives