5.10 TOOLS FOR ACCELERATED BREEDING AND TRAIT MINING UNDERSERVED CROPS

Germplasm, Sequencing, Trait mining, Phenotyping, Precision Agriculture

What problem is the solution trying to address?

Climate change is having far-reaching impacts on agriculture and food systems across the globe. Climate-resilient agriculture needs tools to address the impacts of abiotic stresses (e.g., drought, heat, salinity) and biotic stresses (e.g., diseases and pests), as well as well to manage and minimize inputs (e.g., water, fertilizer), while still meeting the nutritional needs and preferences of consumers.

In the past, the Green Revolution tackled hunger using a combination of genetic and agronomic improvements to key crops in the developing world. More than 60 years have passed since then and most of the cultivated crop varieties were selected when the carbon dioxide levels were lower, and temperature ranges narrower than today. There also continue to be negative impactors of production (e.g., poor soil fertility, limiting water, diseases, and pests). Research will need to focus on these targets and facilitate and integrate genetic improvements with modern agronomic practices using sensors and data-driven management to achieve sustainable, climate resilient agricultural systems.

New research outcomes will be essential to produce these novel, accessible and affordable tools and technologies for the developing world. Where possible, these should be developed through coordinated global partnerships with stakeholder input and be deployed through local and regional networks.

What, in brief, is the solution?

Tools for accelerated breeding and trait mining for underserved crops

Germplasm: There are estimated to be approximately seven million crop accessions conserved in gene bank collections worldwide.

The CGIAR Genebank Platform led by The Crop Trust represents a rich resource for genetic diversity of regional importance to developing world farmers, representing about 10% of the worldwide gene bank collections. Through this platform, the eleven CGIAR Genebanks safeguard a unique global resource of crop and tree diversity and respond to thousands of requests for germplasm from users in more than one hundred countries worldwide every year. They are working towards more targeted use and exploitation of the collections by enriching the associated data through the use of large-scale genotyping and phenotyping. Their location in centers of crop diversity ensure that acquisitions are global with a diverse partner and user base. The Crop Trust also manages the Svalbard Global Seed Vault, the world's largest collection of crop diversity that serves as an important safeguard against natural and man-made disasters.

In the UK, the Germplasm Resource Unit serves as a long-term repository for some of the most comprehensive wheat, barley, oat and pea collections globally, accessible through SeedStor. The European Cooperative Program for Plant Genetic Resources (ECPGR) is a CGIAR network that promotes conservation, management and sustainable use of plant genetic resources.

In the U.S., the U.S. Department of Agriculture (USDA) germplasm resources are accessible through the GRIN Global portal. In China, the China National Crop Germplasm Gene Bank at the Chinese Academy of Agricultural Sciences (CAAS) in Beijing holds over 400,000 crop accessions, over 65% of which were land races and varieties collected from China. The China National Gene Bank (CNGB) in Shenzhen also serves as an integrated repository for data and plant, animal and microbial resources of importance to agriculture. A noteworthy feature of CNGB is its integration in one place of the germplasm and one of the largest sequencing output capacities in the world (about 24 Pb/year).

There is little information available about the genetic composition of the majority of these accessions, making it difficult and time-consuming for breeders to identify sources of desired traits or introduce them into local crops to create new, more climate-resilient varieties. This is a critical step to maximizing the utility of available germplasm resources to widest range of global stakeholders.

Sequencing: The first step to capturing the genetic diversity within and across crop species is to sequence their genomes. Advances in sequencing technology have led to a reduction in cost of an assembled 1Gb genome to the ~$2,500 range, and resequencing a plant genome to about $5/Gb.

- Selection of sequencing targets should include stakeholders as well representatives of ongoing efforts such as DivSeek International and EarthBioGenome.
- Potential sequencing partners would include the U.S. Department of Agriculture's Agricultural Research Service and National Institute for Food and Agriculture, as well as the U.S. Department of Energy Joint Genome Institute and CNBG. There are comparable sequencing core facilities across Europe.

Trait mining: Trait mining tools are needed to accelerate identification of targets for breeding. Trait mining is currently a far more expensive and challenging step than obtaining sequence information and achieving high throughput will require artificial intelligence-based approaches, like machine learning. The tools for mining livestock traits are currently more advanced than for crops.

Machine learning tools are evolving quickly, primarily for non-agricultural applications in the private sector. Rather than duplicating these tools, it would make sense to catalyze their application to agricultural datasets in the public sector. This approach is likely to be especially effective in plants because there are more than 300,000 species adapted to numerous environments.

Through public-private partnerships, machine learning strategies could be developed to mine sequence data for key traits at a reasonable cost. Important target traits would include:

- Photosynthesis under diverse environments
- Disease resistance
- Nutrient and water sensing
- Thermotolerance

Potential partners for this strategy include, but are not limited to:

- Google, which has an agricultural focus area
- Facebook AI Research (FAIR), which has been working with biomedical groups but could potentially apply its tools to agricultural problems
- The Peng Cheng Laboratory in Shenzhen, China, a newly established research center of excellence in AI, space networking, and their applications.

Phenotyping: The plant phenotype represents the set of its observable characteristics resulting from the interaction of the plant genotype with the environment ("GxE"). For crops, the "environment" includes biotic (beneficial and pathogenic microbes), abiotic components (water and temperature) as well as managed inputs (nitrogen, phosphorus, and potassium). Plant phenotyping under field conditions is lagging sequencing but is a key part of understanding crops in their agricultural contexts.

There is a need to evaluate phenotypes as part of understanding the performance of new crops and varieties in the regions into which they will be introduced. There are multiple international initiatives that focus on regional crops, including the U.S. Genomes to Fields Initiative, the European EMPHASIS program, and the International Plant Phenotyping Network, which includes Austria, Australia, China, Germany, Italy and France as national partners and regional partners in Europe, North America and Latin America. These tools and

resources need to be extended to allow evaluation of new crop varieties under local conditions, for example, in partnership with CGIAR centers.

Sensors: Currently, most sensors have been developed for use in large-scale farming operations for major crops such as maize and soybean. They provide diverse read-outs for such variables as moisture, soil pH, soil nutrients and compaction. Optical sensors are also used to measure plant variables from surface readings. In the U.S., start-up companies such as FloraPulse are commercializing microsensors inside plants for monitoring water use by commercial crops while in Europe, the Plantenna consortium is developing innovative sensors for plant stress and environmental strain for sustainable farming. These advances need to be extended to serve the broad needs of smallholder farmers.

Low-cost sensors of multiple types are needed for field management of the broader range of crops grown globally. This could be accomplished efficiently *via* public research and public-private partnerships for deployment. Greater investment is needed to bring sensor costs down, to meet specific needs, and to ensure widespread availability.

Outputs from sensors can allow farmers to respond quickly to environmental changes by adjusting water and nutrient inputs. High income countries make substantial investments in precision technology for a few major crops but in other parts of the world, there is little control of water or fertilizer use. Significant opportunities also exist in Africa to increase food productivity without huge infrastructure or input investments through the use of sensors. Expanding networks of sensors connected to cell phones could help farmers accelerate the use of more sustainable and productive agricultural systems.

Precision agriculture: Also termed "smart agriculture", this approach relies on a combination of new technologies (improved germplasm, sensors, data-driven management practices) to increase crop yield while reducing inputs: getting more with less. New germplasm that is better adapted to local conditions (e.g., drought, heat, salinity) can be better managed through data obtained from sensors to maximize yield and reduce environmental impacts. This is a major research direction in the U.S., with public funding programs supported through the U.S. Department of Agriculture as well as extensive R&D in the private sector. The focus is largely on major crops such as maize and soybean but there are tremendous opportunities to extend these benefits to smallholder farmers through global public/private partnerships.

There is an ongoing Precision Agriculture for Development (PAD) initiative, which currently supports smallholder farmers in Ethiopia, Bangladesh, India, Kenya, Nigeria, Pakistan, Rwanda, Uganda, and Zamia through local partnerships. It could serve as a hub for regional deployment of improved tools and resources.

What were the source(s) from which this solution emerged?

The solution emerged from two workshops convened in August 2018 and August 2020 by The Supporters of Agricultural Research (SoAR) Foundation. Each convening comprised more than a dozen eminent scientists from the United States, the European Union, and China, from a range of research fields including biotic and abiotic stress tolerance, breeding strategies, photosynthetic efficiency, nitrogen fixation, and soils. The report, entitled "Developing Global Priorities for Plant Research: Adapting Agriculture to Climate Variability", provides more detail about the specific goals, current players and funders.

How can this solution address that problem?

This solution can address the problem because it will combine:

- Financial support for research innovations to address key needs
- Coordination of existing and new participating organizations

- Potentially measurable benchmarks and outcomes
- Engagement of key stakeholders

Why does this solution align to the definition and criteria for a 'game changing solution' developed by the Summit?

This solution meets the criteria for a "game changing and systematic" solution because:

- It will have the potential, when implemented, to impact a broad range of stakeholders whose needs are not currently being met
- There are existing research efforts and potential funders who can be connected to achieve its goals
- It has the potential to evolve and grow as it meets its initial objectives

What is the current and/or likely political support for this idea?

Individual member states and foundations are already supporting aspects of this research. In addition, there is the potential to partner with the private sector to extend the utility of existing tools to serve the needs of smallholder farmers. In addition to support from the US Department of Agriculture Agricultural Research Service and National Institute of Food and Agriculture, the European Commission, Research Councils UK (RCUK), the Bill & Melinda Gates Foundation and the Rockefeller Foundation also provides funding for aspects of this work.

Are there certain contexts for which this solution is particularly well suited, or, conversely, contexts for which it is not well-suited at all?

This solution would work well in areas that are part of the CGIAR system and/or have strong national agriculture research systems. It will be more challenging, but not impossible, to extend the benefits of research outcomes to smallholder farmers in conflict settings or areas where the infrastructure is less developed.

What do you think are the key actions required to address this solution?

- Establishment of international coordination bodies to synergize and focus existing programs and initiatives for each goal.
- Financial support for coordination activities.
- Formation of public-private partnerships where these make sense.