DEVELOPING INSTITUTIONAL CAPACITY METRICS FOR NATIONAL AGRICULTURE RESEARCH SYSTEMS (NARS) CROP IMPROVEMENT PROGRAMS

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ABSTRACT

National Agriculture Research Systems (NARS) perform a unique context-specific role in agriculture research and development, impacting food security in developing countries. NARS contribute to crop improvement research by generating improved plant varieties adapted to diverse agro-ecological zones and preferences of target populations. They are responsible for addressing the demands for orphan crops economically, culturally, and nutritionally relevant to specific populations in developing countries. The Feed the Future Innovation Lab for Crop Improvement (ILCI) aims to support NARS in developing and implementing Tools, Technologies, and Methodologies (TTMs) that enhance the delivery of genetic gains in crops that advance economic growth, crop resilience, and nutritional development in target populations. The Tata-Cornell Institute for Agriculture and Nutrition (TCI) is part of a multidisciplinary team within ILCI, tasked with researching institutional components that contribute to the capability of NARS to implement innovative TTMs to achieve genetic gain. This paper outlines the methodologies and outcomes of the approach implemented by TCI to establish baseline metrics to assess the capacities of ILCI partner NARS. To develop the metrics, TCI undertook a robust research process, incorporating a systematic literature review, evaluation of existing tools to measure breeding program capacity, consultation with experts, implementation of the Delphi technique, and a pilot with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) crop improvement programs. The scarcity of institutional capacity literature confirms the need for the framework TCI created. Currently, standardized methodologies to assess crop improvement programs with limited resources to contract experts for program evaluation are inadequate, exposing the potential demand for a low-input assessment tool. The metrics will be implemented through a survey instrument to compare institutional level capacities at the start and end of the ILCI project. An index will be constructed from survey responses to simplify multivariate indicators and enable comparisons over time. The objective is to assess the impact of TTM adoption through the ILCI project on capacity indicators.

BIOGRAPHICAL SKETCH

Sage Grasso-Monroe was born in Fort Collins, Colorado, on September 17, 1995. She received her elementary education at the Glens Falls Elementary School in New York. Her secondary education was completed at Queensbury High School in Queensbury, New York. In 2013, Sage entered the University of Massachusetts, Amherst, Massachusetts, majoring in Public Health. Upon graduation in 2017, she joined the Peace Corps Ethiopia, facilitating a nutrition-sensitive agriculture initiative in a food insecure community. In September 2020, she entered the Master of Professional Studies program at Cornell University to pursue a degree in Global Development with a concentration in International Agriculture and Rural Development. She received a one-year Coverdell Fellowship from 2020-21. In May 2021, Sage began a job at the Tata-Cornell Institute for Agriculture and Nutrition as a research support specialist.

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LIST OF ABBREVIATIONS

AoI	Area of Inquiry
BPAT	Breeding Program Assessment Tool
CGIAR	The Consultative Group for International Agricultural Research
CoI	Center of Innovation
EiB	Excellence in Breeding
FTE	Full Time Equivalent
FtF	Feed the Future
FTIR	Fourier Transform Infrared
GoHy	Goal-directed Hypothesis-driven
IARC	International Agriculture Research Centers
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ILCI	Innovation Lab for Crop Improvement
INTA	National Institute for Innovation and Transfer of Agricultural Technology
NARS	National Agriculture Research Institutes
PHG	Practical Haplotype Graph
TCI	Tata-Cornell Institute
TTM	Tools, Technologies, and Methodologies
USAID	U.S. Agency for International Development

Introduction

The influence of public plant breeding is subject to fluxes in donor support, impinged on perceptions of the severity of food insecurity in low-income countries. The green revolution advanced the adoption of technologies that increased yield and economic growth, triggering diminished donor investment as poverty indicators improved. Agricultural development benefited farmers in favorable environments and populations with access to inputs in the form of fertilizer and pesticides. The most resource-poor farmers and vulnerable populations did not profit from agriculture technology progress. Specifically, public plant breeding experienced an economic decline as donors shifted funding to other pressing global development challenges in the public health and education sectors.

Consequently, gaps emerged in crop improvement research for development, eventually filled through private firm's funding. Privatized plant breeding emphasizes research and development of staple crops, yielding the highest returns to investment. Pervasive concerns of micronutrient malnutrition emerged as caloric dense grains took precedence over nutrient-rich traditional crops, illustrated by the unwavering investment in maize, wheat, and rice research over orphan crops like millets and beans.

National Agriculture Research Systems (NARS) perform a unique context-specific role in agriculture research and development, impacting food security in developing countries. NARS fill the gap in agricultural research by developing improved varieties adapted to diverse agro-ecological zones and target population preferences. Public plant breeding initiatives linked to regional communities are responsible for local people's economic development and food security. By employing genetic improvement in crop varieties, NARS contribute to sustainable development goals in economic productivity, food and nutritional security, and poverty reduction. Enhanced cultivars maximize farm yield and profitability, diversify affordable agriculture goods accessible to consumers, and mitigate risks associated with climate variability (Boughton & Win, 2019).

NARS are well-positioned to respond to the demands of value chain actors and address the preferences of local communities. Efficient crop improvement research requires innovative technology, technical training, access to genetic resources, stakeholder engagement, and managerial capabilities (*World food summit*, 1996). In contrast to public plant breeding efforts, the private sector profits from sustained funding, skilled and qualified scientific personnel, and technological development. Crops released by the private sector concentrate on few staple grains, impeding nutrition outcomes of dietary diversity for small-scale farmers. Moreover, private-led agricultural research has resulted in technology that may be unavailable to the public sector. Consequently, these gains do not necessarily favor the most food insecure and vulnerable populations. Long-term funding remains a challenge for NARS, but investment returns are more substantial in plant breeding programs with enhanced capacity, enabling efficient and effective resource utilization. NARS are an essential complement to international breeding efforts, representing national interests and equipped with the potential to respond to stakeholder preferences. In collaboration with International Agriculture Research Centers (IARCs), NARS contribute adapted varieties considering gender equity, nutritional requirements, marketable products, and strengthening farmer's resilience to changing climates (*The Way Forward to Strengthen National Plant Breeding and Biotechnology Capacity*).

NARS maintain the potential to develop improved varieties that respond to the priorities of targeted populations by advancing genetic gain in locally adapted varieties and crops that are relevant to producers and consumers. A significant challenge involves the integration of regional knowledge and practices to consider the needs and preferences of local stakeholders. Priority setting and breeding objectives controlled by NARS and national stakeholders, instead of external experts and donors with competing interests, culminate in a more sustainable approach to plant breeding to address food insecurity, poverty, and social inclusivity.

Plant breeding in the global south prevails in the public sector, especially for crops that do not deliver significant economic returns. NARS' role in plant breeding lies in their responsibility to address the preferences and demands for orphan crops economically, culturally, and nutritionally relevant to specific populations in developing countries. For example, sorghum is widely consumed and cultivated in low-income countries as an essential source of nutrients. Even so, the private sector does not invest in sorghum research and development, considering the insignificant profit potential. The principal concern of the private sector is to breed for traits that increase yield and productivity, intensifying disparities among crops targeted for research. There is a pressing need to concentrate on nutritional characteristics, quality traits, and breeding for resilience in changing climates. Quality traits that respond to biotic and abiotic stressors may not be the most profitable or highest yielding. Nevertheless, they enable farmers to maintain livelihood strategies in drought conditions, high precipitation, pest pressure, and low-input farming systems. NARS has a responsibility to the nation's public interest, including the equity and inclusivity of women and youth, frequently under-represented in efforts to enhance genetic gains in crop varieties. Tracking institutional capacity in plant breeding programs is essential to monitor the success of novel agriculture research on adoption outcomes and reveal bottlenecks to technology development. Furthermore, measuring capacity of crop improvement programs enables assessment of research impacts on productivity, farm income, food security, and social inclusivity. Enhancing the capability of NARS crop improvement programs to achieve genetic gains in priority traits impact food security and poverty in developing countries.

Institutional capacity in breeding programs refers to the human capital, technical expertise, resource endowment, and collaborative capabilities of programs to conduct crop improvement research. Capacity signifies the competence of breeding programs to implement and innovate agricultural research to meet food and nutritional security challenges. Setting and achieving specific goals is imperative to sustain plant breeding research and deploy suitable Tools, Technologies, and Methodologies (TTMs) to achieve breeding objectives. The principal purpose of crop improvement programs is to deliver genetic gain in traits that demonstrate the priorities of target populations and regions.

Feed the Future (FtF) ventures to establish networks of partners throughout the globe in multidisciplinary sectors to innovate sustainable solutions to food insecurity and pervasive poverty. FtF Innovation Labs are a focal point in research and development, harnessing the expertise and scientific capacity of the top U.S. universities in partnership with research centers in low-income countries. The FtF Innovation Lab for Crop Improvement (ILCI) is a unique project that aims to empower NARS to set their own goals and priorities to enhance genetic improvement. The project is led by Cornell University's Department of Global Development and supported by the U.S. Agency for International Development (USAID). ILCI seeks to enable scientific collaboration by creating Centers of Innovation (CoIs) for crop improvement in East, West and South Africa, Latin America, and the Caribbean. ILCI is working with various stakeholders to innovate and implement TTMs in crop enhancement research that will address the specific needs of vulnerable populations. Equipping NARS to establish their goals and select traits directs breeding activities to achieve genetic improvement. ILCI encourages bottom-up methodologies to address malnutrition and hunger through diverse stakeholder input and institutional collaboration (Feed the Future Innovation Lab for Crop Improvement, 2021). ILCI aims to support NARS in developing and implementing TTMs necessary to enhance the delivery of genetic gains in crops that advance economic growth, crop resilience, and nutritional development in target populations.

ILCI endeavors to advance crop improvement programs in developing countries by facilitating global communication through a network of experts in NARS and universities, prioritizing gender and youth inclusivity, nutrition, market relevance, and crop resilience. The Tata-Cornell Institute for Agriculture and Nutrition (TCI) is part of a multidisciplinary team within ILCI, tasked with researching institutional components that contribute to the capability of NARS to implement innovative TTMs to achieve genetic gain. Through integrated research and implementation of TTMs, NARS crop improvement programs introduce resilient crops for traits that align with the priorities of local populations and contribute to development goals.

Understanding the impact of TTM adoption on NARS ability to achieve genetic gain begins with the establishment of baseline measurements of institutional capacity. TCI designed metrics, intended to be administered in the ensuing project via a survey instrument, supplemented with qualitative data collection with participating NARS partners. The survey was established employing a robust research process that incorporates a systematic literature review, evaluation of existing tools to measure breeding program capacity, consultation with experts, implementation of the Delphi technique, and a pilot with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) crop improvement programs. This paper aims to present a preliminary overview of the research process and the tool developed to assess institutional strength in NARS breeding programs by presenting:

1. Evidence of the metrics used by TCI to evaluate institutional capacity in breeding programs extracted from existing literature.
2. Discussion of the methodological process implemented in developing the institutional capacity measurement tool.
3. Analysis of the tool by drawing connections from existing literature and approaches to measure institutional capacity in crop improvement programs.

Background

The ILCI framework (**Figure 1**) outlines the theory of change attributed to TTMs in five areas of inquiry (AoIs) and cross-cutting themes in gender and youth inclusivity, nutrition, economics, and crop resilience. Explicitly, the implementation of TTMs in genomics, phenomics, and breeding informatics influence; a) breeding cycle time, b) heritability, c) selection intensity, and d) genetic variance. These variables determine the rate of genetic gains, impacting efficient release of improved varieties. Priority setting and trait discovery incorporates cross-cutting themes, delivering favorable outcomes for preferred quality traits acceptable by end-users, contributing to food and nutritional security. The five AoIs comprise of;

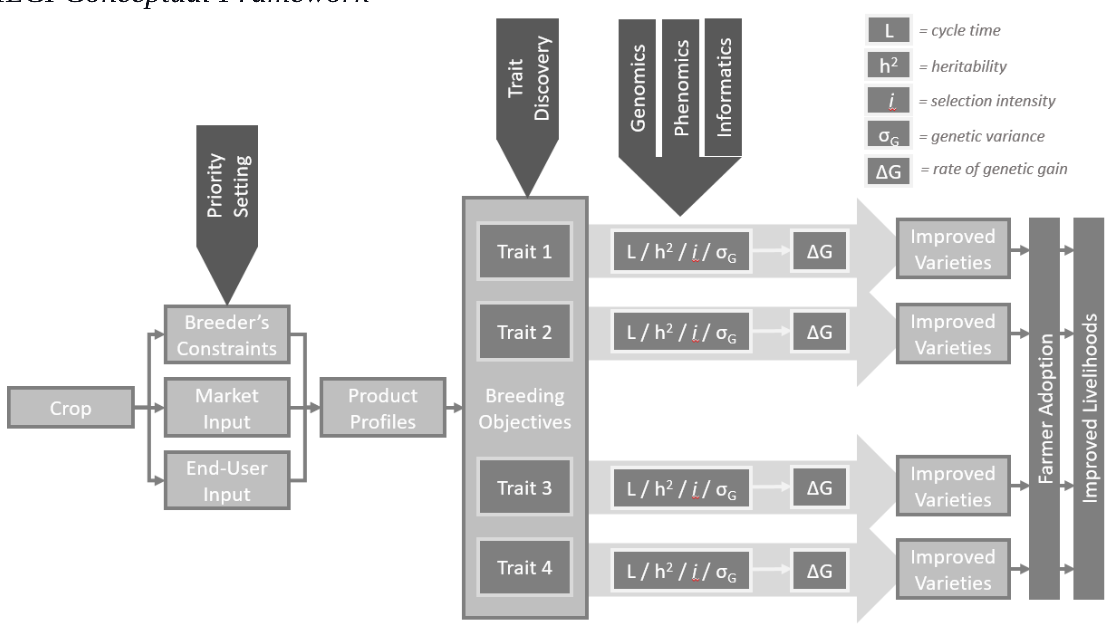
1. **Priority Setting:** developing product profiles and breeding strategies determined by market demand, gender-sensitive traits, and resource use efficiency for crops relevant to target regions and vulnerable populations.
2. **Trait Discovery:** identifying traits associated with product profiles by employing hypothesis-testing and exploiting new genomic resources for explicitly defined priorities.
3. **Genomics:** advancing crosses and developing new varieties by devising efficient schemes to enable marker deployment for quality control, fingerprinting, trait

introgression, marker-assisted selection, genomic evaluation, and genomic selection application.

4. **Phenomics:** collection, management, and analysis of phenotypic data focusing on phenotyping nutritional and resilience traits. Implementing effective experiment design, data collection and management, and statistical approaches.
5. **Breeding Informatics:** data-based simulations and optimization practices to determine technological and methodological interventions for maximizing impact on breeding efficiency and genetic gains.

Figure 1

ILCI Conceptual Framework



ILCI assumes that enhanced institutional capacity in AoIs will result in genetic gains, ultimately influencing farmer adoption outcomes and impacting nutrition, food security, and profitability in targeted regions. TCI is conducting a literature review to synthesize the evidence of the relationship between institutional components in AoIs to genetic gains and adoption outcomes. The systematic review of existing literature aims to answer three questions:

1. How is institutional capacity defined in the context of innovation?
2. What are the linkages between institutional capacity and genetic gains?
3. Does genetic gain influence the impact of breeding programs?

The first stage is to identify models of institutional capacity to develop a concise framework grounded in evidence. AoIs are considered within the context of the institutional crop improvement capacity framework. Next, genetic gain literature is searched to establish connections between TTMs in AoIs and rates of genetic gain. Lastly, literature is appraised for evidence of the relationships between genetic gains in enhanced crop cultivars and impacts of adoption outcomes. This paper will present initial findings from the literature and models of measuring institutional capacity.

Institutional Capacity Literature Review

The systematic literature review was implemented in three stages to locate relevant peer-reviewed and institutional-level publications. First, multiple search strings were plugged into Google Scholar and Web of Science databases (**Table 1**), resulting in a total of 4,592 references. Next, titles and abstracts were screened based on eligibility criteria from 1980 to the present day (**Table 1**), 125 studies progressed to the next phase. Eligible literature consisted of research studies, randomized control trials, review articles, and institutional reports and documents. In the second stage, full texts were reviewed based on inclusion and exclusion criteria (**Table 2**), resulting in 62 studies authorized for extraction. The extracted information will be incorporated in the construction of a conceptual framework of institutional capacity development. The extraction and synthesis of the literature are still in process; this paper presents a preliminary overview of the evidence found in the literature to respond to the question, How is institutional capacity defined in the context of innovation?

Table 1

Literature Review Search Terms

Search Strings	**Database**	**Results**	**Eligible**	**Ineligible**
"Institutional Capacity" **OR** "Organizational Capacity" **OR** "Grant Capacity" **OR** "Grant Readiness" **OR** "institutional capability" **OR** "Institutional strengthening" **OR** "institutional performance"	Google Scholar	2160	- "institution" i.e. organization or program Frameworks - definitions - models - principles - theories of change	- international, national, and sub-national governance EXCEPT if related to collaborative capacity
"R&D capacity" **OR** "research and development capacity" **OR** "institutional efficiency" **OR** "institutional arrangements"	Google Scholar	1560		
("Institutional Capacity" **OR** "Organizational Capacity" **OR** "Grant Capacity" **OR** "Grant Readiness" **OR** "institutional capability" **OR** "Institutional strengthening" **OR** "institutional effectiveness" **OR** "institutional arrangements" **OR** "R&D capacity" **OR** "research and development capacity" **OR** "institutional efficiency" **OR** "institutional performance")	Web of Science	872		

Table 2

Full-Text Review Inclusion/Exclusion Criteria

Inclusion	Exclusion
Breeding Program-level Institutions (not government, sector, consortium, etc.)	Institutions “larger” or “smaller” in scope than the Breeding Program-Level
Presents one or more SPECIFIC FACTORS that contribute to BREEDING CAPACITY (inputs/Activities)	Informal or non-institutional (i.e. participatory, farmer breeding, etc.) breeding without connection to formal breeding programs
Presents one or more SPECIFIC INDICATORS of BREEDING PROGRAM EFFECTIVENESS (outcomes) that result from institutional capacity at the program level	Exclusive focus on one specific component of capacity, without reference to larger framework

1. Priority Setting

Priority setting refers to the process of setting and reviewing breeding objectives and assessing whether trait goals are scientifically robust. Evaluating the capacity to set breeding objectives is indicated by a crop improvement program's aptitude to appraise and incorporate various inputs. Ability to identify traits and feasible trait levels grounded in evidence that align with the needs and characteristics of target populations signify exemplary priority setting processes’ (Lynam, 2011). Breeding objectives determined by market conditions and farmers' needs, substantiated by scientific verification demonstrates comprehensive stakeholder engagement. Priority setting enables robust planning of crop improvement strategies to progress towards defined, time-bound target trait levels. Indicators of breeding program's capacity to set priorities include:

1. knowledge of market conditions for the crop of interest;
2. understanding of the needs and preferences of stakeholders across the value-chain;
3. specific target populations and agro-ecologies;
4. hypothesis testing of end-user preferred traits in well-defined environments; and

5. comprehension of smallholder farmer cropping systems in target regions (Chase & Laliberté, 2016).

Breeding priorities inform crop improvement strategies by determining the appropriate genetic resources to exploit, testing adaptive traits in target agro-ecologies, planning station trials based on genotype by environment interactions, and allocating resources throughout priority areas (Pandey et al., 2015; Reynolds et al., 2012). Demand-driven crop improvement guides breeding programs to plan strategies informed by the acceptability and marketability of improved varieties and identify bottlenecks to farmer adoption and consumer acceptance (Chase & Laliberté, 2016; Pfeiffer, 2010; Weltzien et al., 2001). Capacity building in the area of priority setting is characterized by various stakeholder inputs to ensure adoption of improved varieties and sustained performance in target agro-ecologies, considering diverse cropping systems and climatic variables (Boughton & Win, 2019; Lynam, 2011; Weltzien et al., 2001). The ability for crop improvement programs to deploy robust research requires diverse and competent personnel, such as social scientists, agronomists, and soil scientists, to elicit information regarding the diversity of cropping systems, agro-ecologies, demand profiles, and producer selection criteria (Walker, 2015; Weltzien et al., 2001). Enhanced capacity to set priorities in breeding programs contributes to the development of improved varieties with desirable traits adopted by end-users impacting the food security, profitability, and resilience of target populations (Singh et al., 2017; Woyema et al., 2019).

2. **<u>Scientific Capacity</u>**

Research Capacity

Research capacity concerns the human capital and scientific aptitude required to support breeding activities. Indicators of research capacity include:

1. number of NARS scientists;
2. qualification of researchers;
3. number of years scientists are employed;
4. staff research experience in the specific crop;
5. salary of scientists;
6. training courses;
7. graduate research opportunities;
8. inclusivity of women;
9. age distribution of scientists;
10. publications; and
11. diversity of disciplines that research staff occupy (Collinson & Platais, 1992; Pedersen et al., 2009).

The number of scientists in a crop improvement program, measured by full-time equivalence (FTE), is the number of scientists contributing 100% of their time to the crop improvement program. Additionally, scientific capacity estimated by research intensity refers to FTE scientists per million tons of production (Pandey et al., 2015; Walker, 2015). Mentorship represents an opportunity to retain researchers, attract young scientists, and include women in scientific roles to ensure that positions remain filled by well-qualified staff in the future (Andriatsitohaina & Andrade, 2015). Personnel with advanced degrees have the most impact on the research capabilities of crop improvement programs by maintaining careers as scientists instead of transferring to administrative positions. Performance-based career progression promotes financial and non-monetary incentives to secure scientific staff (Boughton & Win, 2019). Human capacity and research technologies are linked through recurrent training, promoting enriched proficiency in sophisticated tools such as genomic services (Ghimiray, 2013; Lynam, 2011). Relationships with university programs establish incentives to preserve and attract scientific staff through funding and innovative research opportunities (Ribaut et al., 2010). Global networks support modern research capacity by exposing employees to hands-on experiences and advanced technologies (Brennan & Quade, 2004; Ojijo et al., 2010). The inclusion of social scientists and economists competent in value chain analysis and socio-economic assessment enhances crop improvement program’s ability to set and achieve breeding objectives (Boughton & Win, 2019; Weltzien et al., 2001). Research skills enhance the organizational structure of crop improvement programs leading to enhanced capacity to exploit plant genetic resources to improve the productivity of cropping systems and provide profitable returns for farmers adopting improved varieties (Boughton & Win, 2019; Guimaraes & Jueneman, 2008).

Infrastructure and Technical Capacity

Infrastructure and Technical capacity refer to the assessment of technology essential for effective breeding program operation. Adequate facilities, land, and germplasm resources are critical in conducting breeding activities in bioinformatics, genomics, and phenomics. The ability to deploy trait development, molecular methods, and transgenic approaches enhance the aptitude of crop improvement programs to achieve their breeding goals (Lynam, 2011). Indicators of technical capacity include:

1. digitalization of phenotyping platforms;
2. Geographic Information Systems (GIS);
3. advanced statistical methods;
4. communication technologies;
5. field infrastructure for trials;
6. glasshouses;
7. reliable electricity;
8. internet connectivity;
9. germplasm collection;
10. nurseries;
11. irrigation;
12. multi-locational research stations;
13. DNA fingerprinting;
14. technical staff;
15. sufficient laboratories; and
16. the technology to conduct or the ability to outsource genotyping methods, such as SNP genotyping and molecular maps (Brennan & Quade, 2004, Collinson & Platais, 1992; Falck-Zepeda, 2008; Keneni et al., 2016; Lynam, 1996; Ribaut et al., 2010)

Databases are critical to support technological instruments that assess target environments and breeding activities for precise genotype by environment interactions using diverse climatic information. Technological infrastructure enables rapid testing of germplasm and deploying breeding strategies (Reynolds et al., 2012). Relations with research lab networks promote enhanced technical capacity through molecular marker capabilities, germplasm access, and modern technology utilization (Ghimiray, 2013; Lynam, 1996). Innovative phenomic and genomic tools permits a more efficient and rapid breeding progression, and coupled with input processing of environmental variables, results in genetic gains in target agro-ecologies (Malik et al., 2020). Adoption outcomes by farmers are favorable for improved varieties that perform well for priority traits in target agro-ecological zones and farming systems, enhancing productivity in cropping systems and ultimately impacting the profitability of farmers (Boughton & Win, 2019). Technical capacity building of breeding programs generates improved cultivar varieties that strengthen crop resilience, reduce poverty, and improve food security (Bogale et al., 2012).

3. Program Execution

Breeding Activities

Breeding activities are the basic processes and strategies currently employed by the crop improvement program. Indicators of breeding activities include:

1. characterizing parental genetic material;
2. genotype multiplication and distribution;
3. conducting breeding crosses;
4. performing selection;
5. executing yield and trait screening;
6. evaluating advanced breeding lines under diverse agro-ecological conditions;
7. conducting multi-locational trials with genotypic data;
8. incorporating varieties crossed by other programs; and
9. producing seeds (Haile et al., 2019).

Modern technologies and methodologies are indicators of the sophistication of a breeding program, such as employing marker-assisted selection and screening traits for biotic and abiotic stressors (Chase & Laliberté, 2016). The capacity to conduct breeding activities includes the intensity of which NARS screen and release varieties, using parental crosses from external institutes like IARCs (Evenson & Gollin, 2003; Maredia & Eicher, 1995). Integrating crop improvement programs into networks of research groups enables the exploitation of germplasm resources for crosses, selection, and testing to adapt genetic materials for priority traits and environments (Lynam, 2011). However, an advanced crop improvement program is indicated by the ability of the program to conduct their own breeding crosses, using biotechnology, and identifying parental materials within their facilities (Walker, 2015). Capacity in breeding activities is enhanced when a crop improvement program can replicate trials over multiple locations and conduct on-farm trials rather than exclusively in research stations (Weltzien et al., 2001).

Collaborative Capacity

Collaborative capacity refers to the ability of a breeding program to engage with research networks, share resources, and participate in technology transfer. Connecting crop improvement programs with regional and global partners enhances the intensity of genetic exchange with other institutions (Okechukwu et al.). Collaboration accelerates breeding activities by adapting genetic resources to local environments and end-user preferences, improving the rate of genetic gain in priority traits (Malik et al., 2020). Scientific and research capabilities developed in external institutions, such as genetic markers, impact the institutional competencies of numerous crop improvement programs through scientific spillovers within a network (Eicher, 1990).

Collaborative capacity with research centers leads to more efficient and time-saving techniques, faster release of varieties, and genetic gains (Keneni et al., 2016). Genotype multiplication and distribution, germplasm exchange, data compilation, and communication networks indicate coordination with other institutions and across programs, resulting in efficient genetic improvement (Andriatsitohaina & Andrade, 2015, Chase & Laliberté, 2016; Haile et al., 2019). Linking NARS with IARCs, the private sectors, other public sector research institutions, and universities encourage exchange of scientific personnel, technologies, methodologies, and collaborative opportunities (Collinson & Platais, 1992, Ojijo et al., 2010). Educating researchers via site visits for hands-on training, instruction courses in research methods, organization of collaborative networks, and technical advice impact the aptitiude of crop improvement programs to conduct breeding activities to achieve genetic gains (Hoisington, 2013).

4. <u>Output and Performance</u>

Varietal Development

Varietal development is the profiling of historical and recently released genetically improved crop varieties by a breeding program. The ability of the breeding program to deliver finished products that reflect priority objectives and align with the demand of target populations indicates the success of a crop improvement program. Varietal development results from novel crosses and selection made by the breeding program to develop improved genetic lines. The output of a program is measured by the total number of released varieties, annual release, and varietal age of released lines (Andriatsitohaina & Adrade, 2015; Brennan & Quade, 2004; Charyulu et al., 2015; Diagne et al., 2015; Evenson & Gollin, 2003)

Program Management

Program management represents the financial resources available to crop improvement programs and performance evaluations. Breeding program success is indicated by genetic gain, varietal adoption, evaluation methods, and funding streams. Financial support signifies a critical component of success, determined by the size of NARS and the percent of agricultural GDP spend on crop improvement research and development. Program funding is tied to incentive structures to retain well-qualified staff and financial sustainability (Eicher, 1990; Reynolds et al., 2012). Sustained and long-term investment impact crop improvement program's stability, measured by the source of financial support, annual expenditure, and operating budget. The performance of crop improvement programs is commonly indicated by genetic gains in target traits, given that genetic advance is the fundamental goal of breeding programs. Additionally, evaluations conducted internally and externally at the breeding program and institutional level enables crop programs to track their progress in achieving identified breeding priorities (Andriatsitohaina, 2015; Lynam, 2011).

Outcomes of Enhanced Institutional Capacity

Institutional capacity building influences enhanced crop varieties adapted to market conditions and agro-ecological zones, ultimately adopted by farmers (Boughton & Win, 2019). Adoption estimates are measured by:

1. number of improved lines requested by farmers;
2. value of production of the enhanced crop compared to unimproved varieties;
3. total hectares of the growing area;

4. area harvested of all improved varieties divided by total area harvested by the crop;
5. turnover, measured by the age of varieties weighted by their area in production;
6. percent of farmers using improved varieties;
7. rate of change to new varieties; and
8. varietal age (Walker, 2015; Weltzien et al., 2001).

Impacts of Institutional Capacity Building in Crop Improvement Programs

Institutional capacity building in crop improvement research impacts productivity and yield stability by adopting genetically improved varieties in regions where the crops of interest are essential for food security or income generation. Additionally, capacity building in NARS supports self-sufficiency to conduct plant breeding research to respond to emerging challenges in national food security. Institutional components of crop improvement programs contribute to realized genetic gain, impacting nutrition, profitability, social and environmental considerations to improve food security and reduce poverty.

<u>Discussion</u>

TCI measures the institutional capacity of NARS crop improvement programs before and after ILCI project implementation to determine the longitudinal impacts of TTM adoption on NARS capabilities to set priorities considering stakeholder input and achieve genetic gains. Although varietal release and farmer adoption are desirable outcomes of crop improvement programs, these long-term measurements are not feasible within the ILCI project's lifecycle. Moreover, varietal release is not an appropriate measure of NARS breeding program success, owing to the array of considerations pre-dating the official release of an improved crop.

Numerous variables are out of a breeding program's control, such as inefficiencies in release committees, insufficient registries of varieties, and complications associated with seed sector engagement (Walker, 2015). Hence, ILCI uses genetic gain in priority traits as the key indicator of built institutional capacity in NARS breeding programs. Genetic gain is an appropriate indicator of crop improvement capacity since it is a quantifiable estimate of progress typically documented, a fundamental goal in breeding programs, and precedes release and adoption. Genetic gain indicates the capacity of NARS to innovate and implement TTMs within crop improvement programs to improve varieties and conduct efficient research that responds to stakeholder preferences.

The literature review revealed that research conducted on institutional capacity of breeding programs is scarce, and comprehensive standards for established metrics are insufficient. However, compartmentalized into institutional components, some consensus exists regarding indicators of institutional capabilities in crop improvement programs, and can be consolidated to develop a framework. Furthermore, there is a need to establish metrics to assess institutional capacities of NARS breeding programs at a point in time for the repeated application to evaluate the progress of crop improvement. Tools and methodologies implemented to evaluate and diagnose breeding program capacities require expertise and resources from outside institutions. The framework TCI has created is a low-input, informative tool used in various breeding programs across institutional levels, especially NARS with limited resources to access external consultants.

Methodology in Development of the Tool

Existing Tools

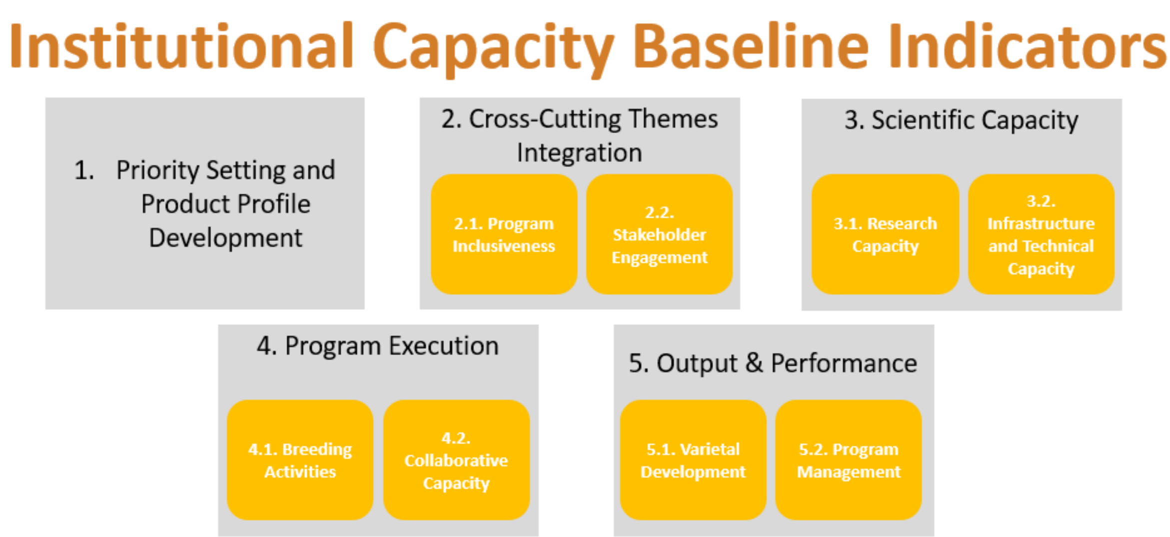
The Consultative Group for International Agricultural Research (CGIAR) developed a platform to facilitate modern plant breeding in developing countries, known as Excellence in Breeding (EiB). The mission is to influence food and nutritional security, climate change adaptation, and development by enhancing the rate of genetic gain to impact vulnerable farmers and consumers in low-income countries. The intention is to improve crop and animal breeding programs to deliver more productive, resilient, nutritious, and marketable traits. The tool takes a five-step approach to achieve genetic gain through 1) breeding program management, 2) optimizing breeding strategies, 3) genotyping/sequencing tools and facilities, 4) phenotyping tools and services, and 5) bioinformatics and data management tools and services. To optimize breeding schemes, the University of Queensland developed the Breeding Program Assessment Tool (BPAT) with support from the Bill & Melinda Gates Foundation to define standards for research management in CGIAR Centers by evaluating the effectiveness of breeding programs. BPAT appraises the strengths of capacity within breeding programs to present recommendations. The intended outcome is enhanced efficiencies of breeding programs to realize genetic gain in improved crops adopted by farmers. BPAT was adapted from the private sector to devise a framework to identify institutional concerns within breeding programs for diagnostic recommendations and comparisons (*Plant Breeding Assessment Tool)*.

BPAT is employed to generate scorecards for evaluation and strategize for capacity development. Long-term impacts and outcomes of plant breeding, such as the adoption of improved varieties, the performance of released varieties, seed sales and dissemination, variety turnover and age, and welfare benefits, are challenging to measure. A more informative indicator of performance is essential for donors to plan investment strategies. Genetic gain is a straightforward measurement representing an intermediate predictive indicator of performance determined by the number of crosses, plots, and trials conducted by the program, breeding cycle time, and quality of data management. BPAT evaluates management, organization, and capacity through a questionnaire followed by in-person site visits by experts to develop a scorecard and report, assessing the breeding program's strengths and areas that require improvement. Institutions leverage the tool to appeal to investors for resources and funding to acquire scientific expertise and coordination. BPAT evaluates nine components of capacity, including:

1. education and experience;
2. infrastructure;
3. program design;
4. crop development, release, and production;
5. product support;
6. program impact;
7. strategic planning and management;
8. budget and finance; and
9. performance management (*Plant Breeding Assessment Tool)*.

Drawing from BPAT, EiB, and literature, TCI has developed a survey tool to measure institutional capacity in NARS crop improvement programs. In contrast to BPAT, it is not a diagnostic and planning tool; instead is used to understand the present capacities in breeding programs. The expressed goal of this tool is to measure ILCI partnering NARS abilities at the beginning and end of the ILCI project to understand if the innovation and implementation of TTMs in AoIs and cross-cutting themes have an impact on institutional capacity. ILCI has predetermined TTMs that are assumed to lead to genetic gains. The goal of TCI is to measure the institutional components in the AoIs impacted by TTM innovation and adoption. In addition, the tool is a low-input method to assess institutional capacity at a particular time. It is less resource-intensive than BPAT and is, therefore, a practical and efficient way for breeding programs to track their ability to achieve genetic gains. The construction of the ILCI institutional capacity baseline survey is a substantial contribution, as there is currently no standardized method to track changes in breeding program capacity over time. The survey can be exploited by breeding programs to elicit funding streams and evaluate their programs without external resources and expertise. The tool takes the form of a survey that will generate an index to score the capacities of breeding programs in the five indicator components. TCI has adapted the BPAT capacity categories and questions to fit the context of NARS in participating ILCI partner countries to construct indicators of institutional capacity in NARS crop improvement programs (Figure 2).

Figure 2
Institutional Capacity Baseline Indicators



The Delphi Technique

After developing the survey instrument, the subsequent phase was to categorize questions into the AoIs of the ILCI project. The TCI team implemented the Delphi Technique to elicit expert opinions and reach a consensus around technical aspects of the questionnaire. The Delphi Technique was developed as an iterative exercise to obtain collective feedback while avoiding power dynamics and group pressures in meetings. The researcher controls feedback and conducts a quantitative analysis by categorizing results and searching for common themes. Questionnaires are presented to leaders in the field and ranked autonomously dependent on significance to a research question. The Delphi technique is applicable in circumstances where limited well-defined evidence exists regarding the question, enabling the experiences and knowledge of experts to build consensus (Thangaratinam & Redman, 2011). A network of experts identified

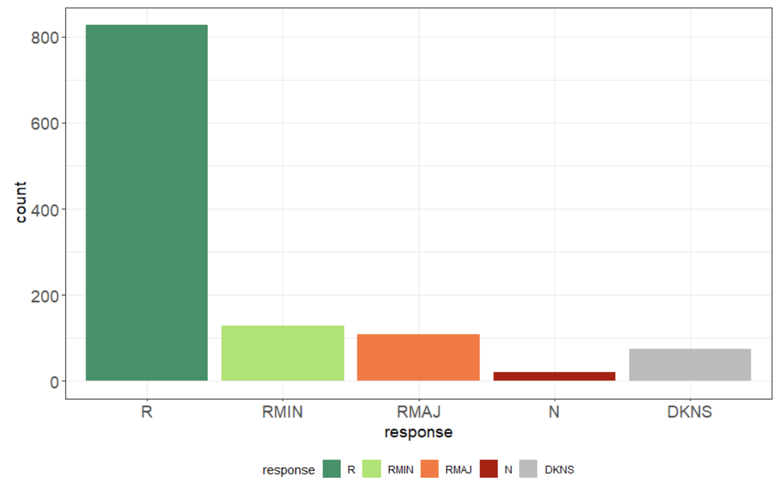
Table 3
Delphi Decision Criteria

<table>
<tr><td colspan="2">Categories
0: Not relevant
1: Relevant but requires major revisions
2: Relevant but requires minor revision
3: Relevant and requires no revision</td></tr>
<tr><td>Criteria</td><td>Decision</td></tr>
<tr><td>≥ 70% of experts agreed that the indicator was relevant</td><td>Include in final survey instrument</td></tr>
<tr><td>≤ 70% expert agreement</td><td>Revisit question and revise using comments from panelists</td></tr>
<tr><td>Category 2 + Category 3 ≥ 70%</td><td>Include in final survey instrument</td></tr>
<tr><td>Category 2 + Category 3 < 70% AND Category 1 + Category 2 > Category 0</td><td>Revisit question and revise using comments from panelists</td></tr>
<tr><td>≥ 50% agreement of category 0</td><td>Exclude</td></tr>
<tr><td>No consensus achieved on question</td><td>Exclude</td></tr>
</table>

in the AoIs and cross-cutting themes autonomously provided feedback and suggestions to the survey questionnaire. The intent was to generate a consensus on the validity of the indicators developed to measure a breeding program's institutional capacity and respond to technical challenges. Statistical representations are used to analyze panelist agreement and included qualitative feedback. The consensus-based methodology (**Table 3**) determined the validity of the indicator and criteria to evaluate inclusion or exclusion of each statement in the final survey instrument. The Delphi technique results confirmed that experts found the majority of questions relevant indicators to measure institutional capacity (**Figure 3 and 4**).

Figure 3

Delphi Total Responses



Key:

R = Relevant and no revisions needed
RMIN = Relevant but minor revision needed
RMAJ = Relevant but major revision needed
N = Not relevant
DKNS = Don't Know/Not Sure

Figure 4

Delphi Responses by Module

The TCI team reached out to experts for additional consultation to clarify the most appropriate questions to include in the final survey instrument to measure crop improvement program capacity in AoIs and cross-cutting themes.

Pilot Survey with ICRISAT

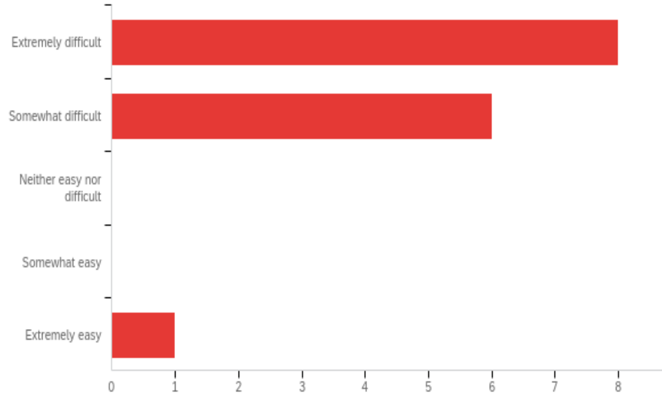
After integrating Delphi feedback, the TCI team administered an external pilot survey with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) crop improvement programs in Asia, East and South Africa, and West and Central Africa. The purpose of the pilot comprises two-part, first to test the functionality and technical features of the survey tool through Qualtrics software, and secondly, to receive feedback from crop improvement programs concerning the quality of the instrument. ICRISAT crop improvement programs were selected as target subjects because they support breeding programs in similar regions as ILCI partnering NARS, collaborate with NARS, and have target crops comparable to those in the ILCI project. Additionally, numerous ICRISAT breeding programs are familiar with the BPAT tool, representing knowledgeable respondents and meaningful resources to evaluate the validity of the selected indicators of institutional capacity. The pilot demonstrated a meaningful exercise with several lessons learned. The leading obstacle TCI encountered concerned technical challenges when multiple respondents within one program endeavored to complete the same survey on multiple devices concurrently. The complexity of the instrument requires multiple personnel to collaborate; however, responses will not transfer to other devices, exemplifying a barrier to collaboration. Uncovering technical issues signify a substantial outcome of the pilot survey that requires resolution before implementation by the ILCI project. TCI managed the situation by generating an offline copy of the questionnaire. ICRISAT personnel completed their respective sections individually and sent them to a delegated staff member to transcribe into the Qualtrics software. The initial technical issue exposed limitations of the software platform, allowing the TCI team to address the problem before final implementation.

After completing a module, ICRISAT provided feedback for each section, especially regarding clarity and redundancy concerns. At the end of the survey, key areas of feedback included;

1. Aspects of the survey that were the most challenging to complete with feedback on how to simplify the tool;
2. Amount of time required to complete the entire survey and the most time-intensive modules within the survey;
3. The number of breeding program personnel that were required to complete the survey;
4. How much information had to be collected from external documents to finish the survey;
5. Suggestions on how to reduce response time and respondent fatigue;
6. Recommendations on how to mitigate redundancies and improve clarity; and
7. Whether or not the tool represents an effective method to measure the institutional capacity of breeding programs (**Figure 6**).

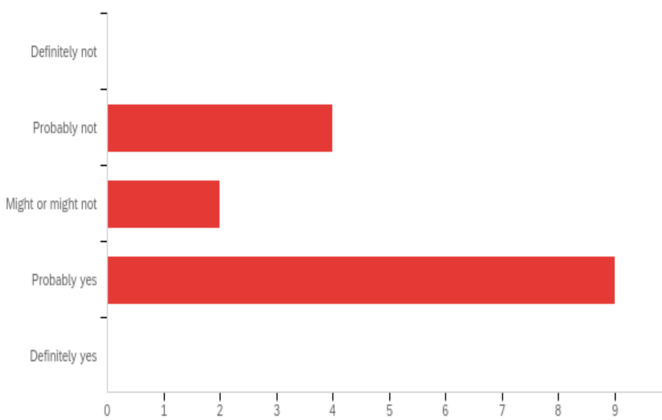
A total of 16 ICRISAT crop improvement programs completed the survey, and an overwhelming majority highlighted that the survey was lengthy and arduous (**Figure 5**). There were numerous redundancies and an expressed need to simplify the tool by reducing the extent to which documentation and personnel consultation were required to locate answers. ICRISAT crop improvement programs offered valuable feedback on which sections needed to be simplified, suggestions to reduce redundancies, and modules that lacked clarity. Valuable responses suggested reducing the entire tool to 50-60 questions from the initial 200 questions by concentrating on the capacity components required to construct an index. Other helpful insights included adding questions about financial resources and avoiding questions that require written response.

Figure 5
Responses to the question: Did you find the survey difficult to complete?



Incorporating ICRISAT's feedback, the TCI team revisited the survey instrument to significantly reduce the complexity and construct simple, concise questions critical in building an index to measure the institutional capacity of crop improvement programs. The TCI team

Figure 6
Responses to the question: Do you think this is an effective tool to measure institutional capacity in breeding programs?



reflected on the Delphi survey, noting that AoI experts offered excellent feedback to construct comprehensive and detailed capacity indicators. ILCI is a unique project that relies on multi-disciplinary experts to collaborate for impactful crop improvement research and development. The exponential growth and complexity of the survey tool's scope to capture indicators relevant to each AoI through the Delphi technique demonstrate the limitations of the approach. The diversity of expertise is insightful and meaningful. However, the role of the TCI team is to incorporate various inputs while avoiding the dilution of the total index through redundant and complicated questions. When revising the tool, the TCI team was predominately focused on simplifying questions to enable construction of the index to assess the institutional capacity of crop improvement programs. The team determined the information most representative of each indicator to construct a valid index (see next section). The challenge was to capture all the data crucial to construct the index by proposing just ten questions for each indicator. The team determined if each question was essential by considering responded fatigue and asking, how each response indicates the institutional capacity in crop improvement programs? And, how the information can be used to indicate the change in institutional capacity over time? After a week-long workshop, the final survey tool totaled 67 questions, and almost all questions were simplified to multiple-choice answers. The most recent iteration of the tool consists of thoroughly examined questions that captured data needed to construct the index (**see Appendix**).

Analysis of the Institutional Capacity Tool

The following section briefly defines the broad indicators of institutional capacity used in the survey tool. **Table 4** outlines the information required for each of the nine sub-indicators to construct a valid index, capturing the most relevant institutional components collected in a survey format. The questionnaire attached in the appendix was developed to obtain the basic information of institutional Capacity of NARS in the ILCI program.

1. Priority setting and Product Profile Development

The *Capacity to Specify Product Profiles* concerns the program's ability to package breeding objectives into specific plans for delivering products to markets and end users. Product profiles are ideally specific, evidence-based, and realistic given program contexts. This capacity also involves integrating diverse stakeholder inputs reflective of a specific market class and target populations focused on in crop improvement programs.

2. Scientific Capacity

Scientific capacity comprises of two sub-indicators; *Research Capacity* and *Infrastructure and Technical Capacity.* Research Capacity is the human capital and scientific expertise necessary to support breeding activities. Infrastructure and Technical Capacity assess the technological and facilities status necessary for effective breeding program operation, including breeding informatics software, germplasm availability, and genomic services accessible.

3. Program Execution

This module contains two sub-indicators; *Breeding Activities* and *Collaborative Activities.* Breeding Activities refers to the essential details regarding the activities and strategies currently employed by the breeding program. Collaboration refers to partnerships with institutions to share resources and information and to participate in technology transfer.

4. Output and Performance

This module contains two sub-indicators; *Varietal Development* and *Program Management*. Varietal Development is the program's generation of novel crosses and selections, leading to new, improved varieties. Program Management is the evaluation of the program and the impact of assessments and funding on breeding activities.

5. Cross-Cutting Themes Integration

This module contains two sub-indicators; *Program Inclusiveness* and *Stakeholder Engagement*. Program Inclusiveness is the program's procedure to accommodate diverse staff members and technical issues. Stakeholder engagement is the program's ability to collect, interpret, and utilize inputs from relevant stakeholder groups to set and achieve programs goals.

Table 4

Institutional Capacity Information for Index Development

Indicator	Data Needed for Index
Priority Setting and Product Profile Development	1. If a system is in place to develop product profiles; 2. If markets and end-user input inform product profiles; 3. The diversity of stakeholders involved in setting product profiles 4. Inclusivity of women; 5. The methods in which product profiles are set; 6. If product profiles are substantiated by scientific and demand-driven evidence; 7. If hypothesis testing is conducted; 8. If trait specialists are employed; 9. Diversity of scientific staff involved in setting breeding priorities, especially those with expertise for gender and youth inclusivity, nutrition, and climate resilience; 10. Perception of the breeding program’s ability to use product profiles to set breeding goals to meet food security needs
Research Capacity	1. Number of FTE scientists; 2. Core competencies of scientists; 3. Education of scientists represented by degree level; 4. Inclusivity of youth in scientific roles; 5. Inclusivity of female scientists;

	6. The output of research publications; 7. Perception of the available human capital to generate improved varieties to meet food security needs
Infrastructure and Technical Capacity	1. The amount of land available to the program; 2. The number of technical staff available to assist the program; 3. Availability of field machinery and equipment; 4. Sufficiency of laboratory facilities; 5. Availability of glasshouses; 6. Reliability of internet connectivity; 7. Sufficiency of data management hardware; 8. Efficiency in the production of seeds; 9. Breeding management software accessible by the program; 10. Accessibility of germplasm; 11. Number of breeding crosses made by the program; 12. Source of genetic materials for crosses made outside of the program; 13. Genotype utilization; 14. The ability of the program to employ molecular markers; 15. Accessibility of genomic services; 16. Perception of the breeding program's infrastructure and technical capacity to generate improve varieties
Breeding Activities	1. Diversity of breeding activities conducted within a breeding program; 2. The use of multi-locational trials; 3. Conducting multi-location trials on farmers' fields; 4. The degree to which lines are advanced each generation; 5. Methods used to reduce selection time; 6. The use of breeding management software and centralized databases for genotyping, phenotyping, and generating seeds; 7. The ability of the program to manage phenotypic data digitally; 8. The intensity in which traits are phenotyped; 9. How field plots are managed; 10. The perception of the programs ability to use phenomic and genomic services, and access to genetic resources
Collaborative Activities	1. Diversity of institutions that the breeding program collaborates with; 2. The number of institutions the program collaborates with; 3. The intensity and importance of the collaboration; 4. The nature of the collaboration and resources shared; 5. Perception of the breeding programs ability to maintain collaborations
Varietal Development	1. History of variety release; 2. The ability of the program to release varieties developed by the breeding program; 3. The ability of the program to release varieties using external crosses and selections; 4. Methods used by breeding programs to monitor adoption; 5. The adoption rate of improved varieties released by the program;

	6. The quality of adoption data; 7. Perception of the breeding program ability to deliver improved varieties to meet the country's food security needs
Program Management	1. The level at which evaluations are conducted internally and externally; 2. The frequency of evaluations; 3. If genetic gain is used as a method to evaluate program performance; 4. The amount and source of funding; 5. The percent of budget used for salaries and breeding operations; 6. The perception of the breeding program's funding sufficiency
Program Inclusivity	1. The ability of the program to accommodate children; 2. The official policies to ensure fair hiring processes; 3. The official policy for sexual harassment in the workplace; 4. The breeding program's perception of their inclusivity and diversity
Stakeholder Engagement	1. If varietal trials are conducted on farmer fields; 2. Diversity of communication platforms utilized by breeding programs to farmers and consumers; 3. The perception of the breeding programs effectiveness in implementing diverse stakeholder inputs

Next Steps

The revised survey was sent to ICRISAT for additional feedback concerning the ability of the simplified survey to capture valid indicators of the institutional capacity of a NARS crop improvement program at a point in time. Currently, the responses from the ICRISAT pilot surveys are being used to populate the newest iteration of the instrument. Additionally, the tool will be piloted with one ILCI partner NARS program, the National Institute for Innovation and Transfer of Agricultural Technology (INTA) in Costa Rica. The purpose of the pilot is to test the technical aspects of the instrument and ensure clarity with a representative institution of ILCI partners. Responses will be applied to index development testing to find a multivariate methodology that will simplify the various indicators of institutional capacity to a total final score of institutional capacity or for each indicator of institutional capacity. For example, the weighted scoring model requires the establishment of criteria for every question, assigning weights to denote the level of significance the data point has on the overall score. If, for example, the score is on a 1-3 scale, each question will be valued dependent on the degree to which the response indicates the capacity of the crop improvement program, 1 indicating low capacity, and 3 indicating the highest capacity. The value is multiplied by the assigned weight, and variables are summed to get a composite score.

Simplified variables from the Stakeholder Engagement sub-indicator in the cross-cutting themes section will demonstrate the weighted score methodology. Note that in practice, this particular indicator incorporates a broader set of variables from relevant questions incorporated across modules, in particularly from Priority Setting. There are 3 data points for this indicator:

1. If varietal trials are conducted on farmer fields, (50%)
2. The diversity of communication platforms facilitated from breeding programs to farmers and consumers, and (30%)
3. The perception of the breeding program's effectiveness in implementing diverse stakeholder inputs. (20%)

For this example, assume the first data point is the most critical indicator of the capacity of a breeding program to engage stakeholders and, therefore, will be assigned the highest weight. The weights are indicated in parenthesis next to each statement. Next, a score needs to be determined for each question relating to the degree of the program's capacity in each indicator, shown in parenthesis below. For instance,

1. Varietal trials are conducted on farmer fields
    1. YES (3)
    2. NO (1)
2. The diversity of communication platforms is facilitated from breeding programs to farmers and consumers

a. More than three communication platforms were selected (3)

b. At least one communication platform was selected (2)

c. No communication platform selected (1)

3. **Do you agree with the following statement?**

The breeding program effectively identifies, interprets, and utilizes stakeholder inputs when breeding for improved varieties to meet the country's food security needs.

a. Agree (3)

b. Neither agree nor disagree (2)

c. Disagree (1)

In this example, a NARS breeding program responds that they conduct varietal trials on farmer's fields, select one method of communicating with farmers, and disagree that their breeding program effectively incorporates input. The weighted scoring method would be calculated as follows: $3(0.5) + 2(0.3) + 1(0.2) = 2.3$ out of 3. The final number, 2.3, represents the capacity of the breeding program to engage stakeholders on a scale from 1-3. In practice, this method can be used to create an index for each indicator or sub-indicator and totaled to score the institutional capacity of NARS crop improvement programs in the ILCI project. Additional methods will be tested for index development, such as factor analysis by creating a composite index out of several variables measuring the same concept, in this case, institutional capacity.

The ICRISAT pilot surveys will also be converted into an index and compared to INTA. Validity will be assessed based on the assumptions that the capabilities of ICRISAT breeding programs are frequently more sophisticated than NARS. Therefore, the TCI team can confirm whether the tool effectively captures the differences in capacity when converted into an index. Finally, the survey tool will be implemented in all NARS crop improvement programs that participate in the ILCI project through Qualtrics software to gather essential information regarding institutional capacity within partner crop improvement programs. The tool will be implemented again at the end of the ILCI program, after TTM adoption, to measure the change in institutional capacity over time and assess the impacts of ILCI.

The ensuing literature review will continue to draw linkages between institutional capacity, genetic gains and adoption outcomes. This will be informative for the next stage of the ILCI project, qualitative data collection planning and TTM implementation capacity. The intention is to generate questions related to quality variables of institutional capacity that cannot be collected in an online survey format. In the second phase of the ILCI project, the breeding program's capacity to implement genetic-gain enhancing TTMs will be measured. Site visits allow for key informant and focus group discussions with TTM implementors from target breeding programs. Custom indicators of the capacity of breeding programs must be established for each TTM implemented. For example, indicators of capacity to implement genomic selection will differ from the ability of crop improvement programs to adopt PhenoApps. To better understand the TTMs being implemented in the ILCI project (Table 5), consultation with AoI leaders is required to develop indicators of the qualitative analysis.

Table 5

Overview of TTMs in each AoI

Areas of Inquiry (AoIs)	Tools, Technologies, and Methodologies (TTMs)
Priority Setting	**1.** Consumer preference studies **2.** Crop budget models **3.** Gender-responsive product profile tools **4.** Participatory priority setting methods
Trait Discovery	**1.** Goal-directed Hypothesis-driven (GoHy) web application **2.** Train scientists in the methods of hypothesis testing using the application **3.** Test priority traits identified in product profiles
Breeding Informatics	**1.** Set up informatic framework to deploy regional cloud computing hubs and web-based applications to support data management **2.** Integrate the breeding program with the framework to map the breeding process - Work with CoIs to streamline breeding process - Structure the plant breeding pipeline - Analyze historic processes - Introduce spatial correction to increase heritability, genetic gains, and reduce cycle time
Genomics	**1.** Enhance competence in decisions making about what genomic services are needed, where to get them, and use the results to make decisions and set up breeding genomic pipelines **2.** Train scientists and IT personnel to help design assays, manage data and technical processes **3.** Score genetic markers on plant breeding populations using practical haplotype graph (PHG)-based informatics
Phenomics	**1.** Work with collaborators to establish robust experimental designs and deploy fieldbooks such as PhenoApps interfacing with BreedBase database **2.** Train machine learning models for trait prediction and use Android PhenoApp to collect phenotypic data and determine trait predictions **3.** Use non-destructive methods to analyze nutritional traits, such as Fourier Transform Infrared (FTIR)

Conclusion

Studies measuring the institutional capacity of breeding programs are scarce, and the survey tool developed by the TCI team fills in the gap by establishing metrics to track the changes in capacity through technology diffusion and collaboration. The tool will be deployed in ILCI partner NARS across countries, institutions and crops, allowing for extensive testing of the validation of the instrument. This is a significant contribution to the ILCI project, to understand the ability of NARS to develop improved crop varieties in traits that are relevant to producers, consumers and markets to address food security. Through the improved institutional capacity and the generation of improved crop varieties NARS can impact income growth, nutrition and resilience of crops to climate change.

APPENDIX

ILCI Institutional Capacity Baseline Survey

Start of Block: Introduction

Thank you for taking the time to participate in this survey instrument to document the status of crop improvement programs. The Tata-Cornell Institute of Agriculture and Nutrition (TCI) as a partner in the Feed the Future Innovation Lab for Crop Improvement (ILCI) project, aims to document the change in institutional capacity within participating National Agricultural Research Institutes (NARIs) to understand the impact of ILCI on program participants. Our project seeks to understand how ILCI efforts to support institutional capacity in various NARI breeding programs assists breeding programs to deliver genetic gains.

Clarification of terms
In this study, we take institutional capacity to mean the ability of a breeding program to identify, set and achieve specific breeding goals leading to genetic gains. We include questions about current financial, infrastructure and staffing resources that are available to your breeding program.

What is the scope of "institutions" being considered?

- For our purposes, our aim is to assess the institutional capacity of a BREEDING PROGRAM for a single crop species. That is, the goals, tools, technologies, methodologies, and outcomes being considered correspond to breeding activities at the program-level.
- We acknowledge that breeding programs are situated within larger research institutions, which may be situated within even larger consortia/networks. In that regard, we are NOT evaluating the institutional capacities of the host institutions or the consortia/networks to which the BREEDING PROGRAM belongs. We are aware that many of the more complex indicators of institutional capacity **WILL NOT BE PRESENT IN THIS SURVEY**, because they require deeper investigation than can be accomplished in a self-administered questionnaire.

The survey includes eight modules and nine capacity thematic areas, outlined below.

1. Program Details: Basic identification and description of the breeding program, the host institution, the crop species, and the breeding approach.
2. Priority Setting and Product Profile Development: Characterization of the PROCESS of specifying product profiles.
3. Scientific Resources
3.1. Research Capacity: The human capital/scientific resources available to support breeding activities.
3.2. Infrastructure & Technical: Assessment of your program's access to the technological tools and facilities necessary for effective breeding program operation.
4. Program Execution
4.1. Breeding Activities: Basic details regarding the resources, activities and strategies currently employed by the breeding program.
4.2. Collaborative Activity: Characterization of your breeding program's engagement with external collaborating organizations to share resources and information, and to participate in

technology transfer.

5. Output & Performance

5.1. Varietal Development & Release: Information on finished varieties released by the program.

5.2. Program Management: Basic information about financial resources and breeding program performance evaluation.

6. Cross-Cutting Themes Integration

6.1. Program Inclusiveness: Basic information about the program’s procedures to accommodate diverse staff members.

6.2. Stakeholder Engagement: Activities to collect, interpret, and utilize inputs from relevant stakeholder groups to set and achieve program goals.

7. Trait Clusters: Information about the traits that are the focus of your breeding program.

8. Conjoint Analysis: Identification of priorities based on trade-offs across different crop improvements.

End of Block: Introduction

Start of Block: 1. Breeding Program Details

1. Breeding Program Details

1. **Respondent Name**
2. Respondent E-mail
3. **Center of Innovation**
    a. CACCIA (Haiti/Costa Rica)
    b. CIWA (Senegal/West Africa)
    c. CICI-ESA (Malawi/East Africa)
    d. CIFMS (Uganda/East Africa)
4. **Partner Institution**
5. **What year was the breeding program established?**
6. **Crop species focused on in the breeding program**
7. Which breeding system best describes your breeding program?
    a. Recurrent Selection
    b. Mass Selection
    c. Pedigree
    d. Hybrid
    e. Other
        i. Describe "Other" breeding system:

End of Block: 1. Breeding Program Details

Start of Block: 2. Priority Setting and Product Profile Development

2. Priority Setting and Product Profile Development
The Capacity to Set Priorities Generate Product Profiles concerns your program's ability to package breeding objectives into specific plans for delivering products to markets/end users. Product profiles are ideally specific, evidence-based, and realistic given program contexts. This capacity also involves the integration of diverse stakeholder inputs that are reflective of a specific market class/target population of interest to the program.

1. Does your breeding program use product profiles to determine breeding priorities?
2. **Did your program conduct formal interactions with any of the following key stakeholder groups in 2019?**
   Note: a "formal" interaction means an engagement that was planned in advance, that was advertised to stakeholders through relevant channels, and that was at least semi-structured (i.e., had an agenda, a key topic, and an objective)

	Formal Interactions:		If consulted, group was comprised of:					
	Did not consult	Consulted	Only Men	Mostly Men	Equal Men and Women	Mostly Women	All Women	NA
Farmer Groups	○	○	○	○	○	○	○	○
Consumers	○	○	○	○	○	○	○	○
Women's Groups	○	○	○	○	○	○	○	○
Private Traders	○	○	○	○	○	○	○	○
Processors	○	○	○	○	○	○	○	○
Private Grain Marketing	○	○	○	○	○	○	○	○
Private Seed Companies	○	○	○	○	○	○	○	○

3. When developing product profiles, which activities does your breeding program include to incorporate stakeholder input?
   Select all applicable.
   If no activities are currently used, please select "NA"
   a. Focus Groups
   b. Interviews
   c. Trait Prioritization
   d. Value Chain Mapping

e. Conjoint Analysis
f. Farmer Field Day
g. Participatory Trials
h. Trait Surveys
i. Release Trials
j. Other
    i. Please describe "Other" activities that your breeding program conducts to involve farmers/consumers:
k. NA

Page Break

4. **Provide the following details for each trait in your program's product profiles/breeding objectives:**

	Trait Name	Current Level Achieved (mean±SD if numeric)	Trait Goal (value you wish to achieve)	Reference Variety
Trait 1				
Trait 2				
Trait 3				
Trait 4				
Trait 5				

Page Break

5. **In your breeding program, how involved is each of the following stakeholder groups currently in specifying breeding product profiles?**

   In this context, specifying breeding product profiles refers to:
   1. Specifying new breeding product profiles
   2. Reviewing/Modifying existing breeding product profiles

   Rate the involvement of each group on a scale of 5 (0 = not involved, 5 = completely involved) by dragging the sliders to the appropriate position.

	Not Involved			Completely Involved		
	0	1	2	3	4	5
Trait Specialists (Pathologists, Agronomists, etc.)						
Value Chain Experts						
Economists						
Youth Specialists						
Nutritionists						
Gender Specialists						
Resilience Specialists						
Farmers						
Women's Groups						

6. Has the use of product profiles led to changes in your program's breeding objectives?
7. **Do you agree with the following statement?**
   The breeding program effectively uses product profiles to set and achieve breeding goals in line with the country's food security needs.
   a. Strongly disagree
   b. Somewhat disagree
   c. Neither agree nor disagree
   d. Somewhat agree
   e. Strongly agree

End of Block: 2. Priority Setting and Product Profile Development

Start of Block: 3. Scientific Capacity

3. Scientific Capacity
This module contains two sub-sections, *Research Capacity and Infrastructure and Technical Capacity*

3.1. Research Capacity
Research Capacity refers to the human capital/scientific resources available to support breeding activities.

1. **Program Personnel**
   Fill in the table for each scientific discipline, based on staff employed by your breeding program.

   "FTE" (Full-Time Equivalent) refers to the proportion of the scientist's time allocated to the specific crop in your breeding program
   Include in "Number of vacancies" the number of positions that are currently unfilled for budgetary or other reasons

	Number of scientists employed in each discipline	FTE	Number of scientists with PhD	Number of scientists with Master's degree	Number of scientists with Bachelor's degree	Number of female scientists	Number of scientists under the age of 35	Number of vacancies
Genetics/Breeding								
Molecular Biology								
Pathology and Virology								
Agronomy								
Entomology								
Physiology								
Breeding Informatics								
Economics								
Other Social Scientists								
Nutrition								
Other								

Please describe "Other" discipline expertise included in your breeding program:

2. How many publications did your breeding program produce between 2018-2020?

	Number of publications
Peer Reviewed Journals	
Book/Book Chapter	
Internal Reports, Technical Bulletins, and Other Publications	

3. **Do you agree with the following statement?**
   The breeding program has sufficient well-qualified scientific staff to generate improved varieties to meet the country's food security needs.
   a. Strongly disagree
   b. Somewhat disagree
   c. Neither agree nor disagree
   d. Somewhat agree
   e. Strongly agree

3.2. Infrastructure and Technical Capacity

Infrastructure and Technical Capacity is the assessment of the technology and facilities status necessary for effective breeding program operations. This capacity involves access to land, equipment, facilities, and germplasm resources necessary for implementing crop improvement goals.

Infrastructure and Facilities

1. **What is the total field space (in hectares) currently utilized by your breeding program?**
   Enter numeric value:
2. Please enter the number of technical field-staff (non-research staff) assisting your breeding program.
   Enter numeric value:
3. **Indicate the sufficiency of your program's current facilities.**

	Very Insufficient	Insufficient	Moderately Sufficient	Sufficient	Very Sufficient
Field machinery/equipment	○	○	○	○	○
Laboratory facilities	○	○	○	○	○
Glasshouse/controlled environment facilities	○	○	○	○	○

Internet connectivity	○	○	○	○	○
Computing and data management HARDWARE	○	○	○	○	○
Speed, quantity, and quality of seed production	○	○	○	○	○

Page Break

Breeding Informatics
Breeding Informatics Capacity involves the present computing and bioinformatics infrastructure available to the breeding program in support of breeding activities.

4. Which breeding management software(s) are CURRENTLY operation in your breeding program?
    a. Breeding Management System (BMS)
    b. GOBii
    c. BreedBase
    d. Other
        i. Describe "Other" breeding management software(s) currently operational:
    e. No breeding management software currently operational

Page Break

Germplasms & Genetic Resources

5. **How many unique germplasm accessions are CURRENTLY accessible to your breeding program?**
   accession is taken to mean a distinct and uniquely identifiable set of seeds representing a cultivar, breeding line, or population.
   Do not include inbred accessions or intermediate breeding crosses in this estimate.

   Enter a numeric value:
6. **How many breeding crosses were made in 2019?**
   Enter the number of crosses made:

Page Break

7. Out of (answer to #6) breeding crosses made in 2019, where did the parents come from?
   Please write the percentage for each source of parents

	Source of Parents			
	CGIAR Source	Other NARS	Universities	Own Genetic Resources
% of parents:				

8. **How many distinct lines/accessions were genotyped in 2019?**
Genotyping methods include: Genotyping-by-Sequencing (GBS), Whole-Genome Resequencing (WGR), Reduced Representation Sequencing (RRS), and SNP arrays
Enter numeric value:
9. Based on the genetic and phenotypic diversity of germplasm available in your program, how would you characterize the genetic base of your breeding population?
    a. Very narrow
    b. Somewhat narrow
    c. Neither narrow nor broad
    d. Somewhat broad
    e. Very broad

Page Break

Genomics Capacity

Genomics Capacity is the program's present access to genomics services.

10. For which traits of interest are molecular markers currently used for making breeding decisions?
    a. Trait #1 (from Q3 in Priority Setting)
    b. Trait #2 (from Q3 in Priority Setting)
    c. Trait #3 (from Q3 in Priority Setting)
    d. Trait #4 (from Q3 in Priority Setting)
    e. Trait #5 (from Q3 in Priority Setting)
11. **Select whether your breeding program has used genomic services either in-house (i.e., within your program or home institution/NARI) and/or contracted from external providers (i.e. OUTSIDE your program or home institution/NARI)?**
Genomic services include: Sanger Sequencing, Next-Generation Sequencing, Transcriptome Sequencing, Nucleic Acid (DNA & RNA) Extraction, Genotyping Arrays, Genomic Data Processing, Genomic Data Alignment and/or Annotation, Genomic Data Analysis, and Simple Sequence Repeats (SSR)

    a. The breeding program has used in-house genomic services
    b. The breeding program has used contracted genomic services from external providers
    c. The breeding program has not used genomic services

Page Break

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12. **Do you agree with the following statement?**
The breeding program has sufficient infrastructure and technical capacity to generate improved varieties to meet the country's food security needs.
    a. Strongly disagree
    b. Somewhat disagree
    c. Neither agree nor disagree
    d. Somewhat agree
    e. Strongly agree

End of Block: 3. Scientific Capacity

Start of Block: 4. Program Execution

4. Program Execution
This module contains two sub-sections, *Breeding Activities* and *Collaborative Activities*

4.1. Breeding Activities

1. **What breeding activities are CURRENTLY undertaken by the breeding program?**
    a. Breeding Crosses
    b. Yield/Trait Screening
    c. Varietal Evaluation
    d. Trait Science (pathology, agronomy, physiology, nutrition, etc.)
    e. Seed Production
    f. Other
        i. Describe "Other" breeding activities currently undertaken by the breeding program:
2. Are multi-locational trials performed?
    a. Multi-locational trials performed, none on farmer's fields
    b. Multi-locational trials performed, including on farmer's fields
    c. No multi-locational trials performed

Page Break

Advancement Process and Criteria

3. How many lines were advanced per generation (F1-F6) in your breeding program in 2019?

	F1	F2	F3	F4	F5	F6
2019						

4. What methods are CURRENTLY operational for reducing the time between selections?
    a. Genomic Selection
    b. Marker-Assisted Selection
    c. Single-Seed Descent
    d. Shuttle Breeding
    e. Double-Haploids
    f. Genetic Engineering/Transgenics
    g. High-Throughput Phenotyping
    h. Other
        i. Describe "Other" currently operational methods for reducing the time between selections:
    i. NA

5. Are you utilizing breeding management software and/or a centralized database to manage the following activities?

	Breeding management software	Centralized database	NA
Pedigree/Parentage Information	▢	▢	▢
Crossing Block Information	▢	▢	▢
Trial Designs/Layouts	▢	▢	▢
Phenotypic/Trait Data	▢	▢	▢
Genomic Data	▢	▢	▢
Seed Inventory	▢	▢	▢

Page Break

Selection Index

6. Do you use selection indices for breeding?
7. What type of selection index do you use? If you do not know the academic name or specific type of index you use, please write "NA".
8. Please describe the selection index you use. In the text box below, please describe your selection index by reporting the following information for each trait in your index:
   I) Trait description
   II) Index value and unit of measurement
   III) Scale or threshold (if applicable)
   IV) Weight (if applicable)
   Be as specific as you can and please write any comment that you think will help us understand the index you use and how you use it.

Page Break

Phenomics

Phenomics Capacity is the collection, management, and interpretation of trait data in your breeding program.

9. What percent of phenotypic data are entered digitally (smartphone, tablet, or computer) at the field level?
   If phenotypic data is not entered digitally, please write "0"

10. For each trait specified in your breeding product profile, what is the CURRENT phenotyping throughput, specifying the units (plants/day, plots/day, plants/season, plots/season, etc.)?

	Throughput Number	Units
Trait #1 (from Q3 in Priority Setting)		
Trait #2 (from Q3 in Priority Setting)		
Trait #3 (from Q3 in Priority Setting)		
Trait #4 (from Q3 in Priority Setting)		
Trait #5 (from Q3 in Priority Setting)		

11. For each trait specified in your breeding product profile, what methods are CURRENTLY used for field plot management/identification?

	Dropdown List
Trait #1 (from Q3 in Priority Setting)	
Trait #2 (from Q3 in Priority Setting)	a. Plot maps
Trait #3 (from Q3 in Priority Setting)	b. GPS
Trait #4 (from Q3 in Priority Setting)	c. Barcodes
Trait #5 (from Q3 in Priority Setting)	d. Other

Describe "Other" methods currently in use for field plot management/identification of the trait:
(If other is selection, insert trait name from Q11)

Page Break

12. **Do you agree with the following statement?**
The breeding program has sufficient capacity to effectively collect, manage, and interpret trait data to generate improved varieties to meet the country's food security needs.
    a. Strongly disagree
    b. Somewhat disagree
    c. Neither agree nor disagree

    d. Somewhat agree
    e. Strongly agree

13. **Do you agree with the following statement?**
    The breeding program has sufficient access to the germplasm needed to generate improved varieties to meet the country's food security needs.
    a. Strongly disagree
    b. Somewhat disagree
    c. Neither agree nor disagree
    d. Somewhat agree
    e. Strongly agree

14. **Do you agree with the following statement?**
    The breeding program has sufficient genomics expertise and capacity to generate improved varieties to meet the country's food security needs.
    a. Strongly disagree
    b. Somewhat disagree
    c. Neither agree nor disagree
    d. Somewhat agree
    e. Strongly agree

Page Break

4.2. Collaborative Activities

Collaboration refers to partnerships with institutions outside of your breeding program. Collaborations need not be equal (i.e., one partner can gain more than the other), and each partner can play different roles (i.e., one might do field studies while the other does data analysis).

1. Provide basic details for the top 6 CURRENTLY ACTIVE research collaborations between your breeding program and other institutions (CGIAR Centers, other labs, other NARS, universities, private sector, etc.)

	Name of Institution	**Type of Institution**	**Duration of Collaboration (# of years)**
		Dropdown List: a. CGIAR Centers b. National NARIs c. NARIs in other countries d. National Universities e. International Universities f. Private Sector g. Other	
Collaborator 1			
Collaborator 2			
Collaborator 3			
Collaborator 4			
Collaborator 5			
Collaborator 6			

2. If you have more than 6 institutions that you collaborate with, please enter the total number of additional collaborators (in addition to the top 6 named above) in your network

Page Break

3. **How important is each currently active collaboration to your breeding program?**

   Rate the level of contribution to achieving breeding objectives for each collaboration on a scale of 10 (0 = Not important, 10 = crucial to achieving breeding objectives) by dragging the sliders to the appropriate position.

	0	1	2	3	4	5	6	7	8	9	10
Name of Collaborator 1											
Name of Collaborator 2											
Name of Collaborator 3											
Name of Collaborator 4											
Name of Collaborator 5											
Name of Collaborator 6											

4. Identify the type of resource collaboration your breeding program shares with other institutions.

	Data Sharing	Germplasm Exchange	Training	Grant/Financial Support	Scientific Exchange	Technical Services
Breeding programs in other NARS institutions in your country	☐	☐	☐	☐	☐	☐
Breeding programs in other NARS institutions outside your country	☐	☐	☐	☐	☐	☐
CGIAR Centers	☐	☐	☐	☐	☐	☐
National Universities	☐	☐	☐	☐	☐	☐

International Universities	▢	▢	▢	▢	▢	▢
Private seed companies	▢	▢	▢	▢	▢	▢
Other	▢	▢	▢	▢	▢	▢

Describe "Other" collaborating institutions that have shared access to some or all of your program's centralized database:

5. **Do you agree with the following statement?**
   The breeding program is effective at developing and maintaining collaborations with other institutions needed to generate improved varieties to meet the country's food security needs.
   a. Strongly disagree
   b. Somewhat disagree
   c. Neither agree nor disagree
   d. Somewhat agree
   e. Strongly agree

End of Block: 4. Program Execution

Start of Block: 5. Output & Performance

5. Output & Performance
This module contains two sub-sections, *Varietal Development* and *Program Management*

5.1. Varietal Development
Varietal development is your program's activity in making novel crosses/selections leading to the release of new improved varieties.

1. **Does your breeding program release finished varieties?**

If "NO" is selected, SKIP to 5.2 Program Management

2. **Varietal Release History**
   Provide the following basic information about the recent history of varietal output in your breeding program.

	Number
Total varieties released by your program in the past THREE years	
Number of varieties released in the past THREE years that were developed from crosses/selections made originally by your program (i.e., not varieties developed in other programs)	
Number of varieties released in the past THREE years from screening varieties from crosses/selections made originally in OTHER programs	

Page Break

3. **Adoption of Released Varieties**

   Select all methods CURRENTLY used by your program to track/monitor adoption outcomes of released varieties:
   a. Farmer Surveys
   b. Seed Sales
   c. DNA Fingerprinting in Farmers' Fields
   d. Expert Elicitation
   e. Adoption Information Not Collected
   f. Other
      i. Describe "Other" method currently used for monitoring varietal adoption outcomes
   g. Adoption outcomes not monitored

4. What is the total adoption rate of varieties released by your breeding program? If unknown, please write "NA"
    a. Total hectares:
    b. Percentage of farmer adopting varieties released by your program:
5. In what year did your breeding program last collect adoption information?
6. **Do you agree with the following statement?**
   The breeding program delivers sufficient number and quality of improved varieties to meet the country's food security needs.
    a. Strongly disagree
    b. Somewhat disagree
    c. Neither agree nor disagree
    d. Somewhat agree
    e. Strongly agree

Page Break

5.2. Program Management

1. How is your breeding program evaluated?
    a. Evaluated internally at the whole institute level
    b. Evaluated externally at the whole institute level
    c. Evaluated internally at the breeding program level
    d. Evaluated externally at the breeding program level
    e. Internal individual performance reviews conducted
2. How frequently is your breeding program evaluated?

	Dropdown List
Internal Institute Level Evaluation	a. Quarterly
External Institute Level Evaluation	b. Annually
Internal Breeding Program Level Evaluation	c. Every 2-3 years
External Breeding Program Level Evaluation	d. Less than every 3 years e. More than every 3 years
Internal Individual Performance Reviews	f. No set protocol

3. **Does your breeding program compute genetic gain?**
4. **Program Financing**
   How many competitive grants did your program receive in the past 5 years?

	Number of Grants	Total Value of Grants
International competitive grants		
National competitive grants		

Sum of total competitive grants in the past 5 years		

5. What is the total annual budget of your breeding program?
    a. Personnel:
    b. Breeding Operations:
    c. Other:
    d. Total:
6. **Do you agree with the following statement?**
   The breeding program has sufficient funding to identify and carry out crop improvement activities to meet the country's food security needs.
    a. Strongly disagree
    b. Somewhat disagree
    c. Neither agree nor disagree
    d. Somewhat agree
    e. Strongly agree

End of Block: 5. Output & Performance

Start of Block: 6. Cross-Cutting Themes Integration

6. Cross-Cutting Themes Integration
This module contains two sub-sections, *Program Inclusiveness* and *Stakeholder Engagement*
6.1. Program Inclusiveness
Program Inclusiveness capacity is the program's procedures to accommodate diverse staff members and technical issues.

1. Proportion of program staff with maternity or paternity leave benefits in their employment agreement:
2. Does the main facility of your breeding program offer childcare services?
3. Is there a formal/official non-discrimination policy currently in place to ensure fair and just recruitment and hiring practices?
4. Is there a formal/official sexual harassment policy currently in place?
5. **Do you agree with the following statement?**
   The breeding program is inclusive, diverse, and provides equal opportunity for all people.
    a. Strongly disagree
    b. Somewhat disagree
    c. Neither agree nor disagree
    d. Somewhat agree
    e. Strongly agree

6.2. Stakeholder Engagement

1. Does your program conduct varietal trials in farmers' fields?
2. What communication platforms are CURRENTLY being used by the breeding program to disseminate trial results and recommendations to farmers and consumers?
    a. Farmer Meetings
    b. Extension Officers
    c. Online Submissions
    d. Mobile App
    e. Written letter
    f. Personal Communication with farmers and consumers
    g. Messaging System (e.g., WhatsApp)
    h. Other
        i. Please describe "Other" communication platforms used by the breeding program to disseminate trial results and recommendations to farmers and consumers:
    i. NA
3. **Do you agree with the following statement?**
   The breeding program is effective at identifying, interpreting, and utilizing stakeholder inputs when breeding for improved varieties to meet the country's food security needs.
    a. Strongly disagree
    b. Somewhat disagree
    c. Neither agree nor disagree
    d. Somewhat agree
    e. Strongly agree

End of Block: 6. Cross-Cutting Themes Integration

End of Survey

We thank you for your time spent taking this survey. Your responses have been recorded

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