Accelerating Genetic Gains in Maize and Wheat

AGG Maize Team's Action Taken Report/Responses to Maize Scientific and Technical Steering Committee (MSC) Recommendations

(March 2021)

Breeding scheme optimization opportunities/insights

1. Implement sparse testing strategy with testers as well as locations:

The Maize Scientific and Technical Steering Committee (MSC) noted that it is not necessary to test each sister line or full-sib on the same set of testers and that sparse testing across testers (not only locations) should be implemented in maize product profiles. In the last quarter of 2020, the maize team, together with biometrics team, did sparse phenotyping design for early stage (Stage 2) testing using Eastern Africa Maize Product profile 1 (EA-PP1) phenotypic data for 2018 Stage 2 trials (900 hybrids evaluated at 5 locations in Kenya) and genotypic data on 300 lines used in making the Stage 2 hybrids. Five different experimental layouts for sparse testing and four types of statistical analyses were used. These were: (a) Factor Analytic (FA); (b) FA plus coefficient of parentage (FAA); (c) FA + marker data (FAG); and (d) FA+ markers + CoP (FAGA). The results showed that there were no major differences among the different statistical models used in identifying the best hybrids that were selected through complete phenotyping. Among the different sparse designs, experimental designs 1, 4 and 2 consistently identified the best hybrids that were selected through complete phenotyping irrespective of the models used (**Figure 1**).

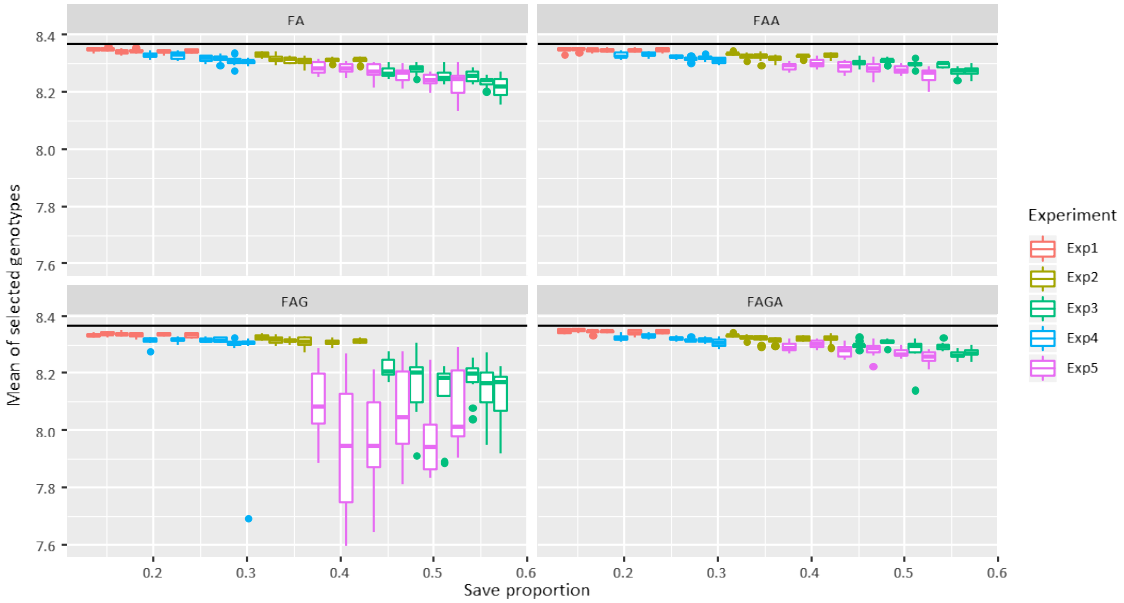

Figure 1. Comparison of the mean grain yield of the top 15% hybrids selected through complete phenotyping and sparse phenotyping in Stage 2 trials using four different models. The horizontal black line is the mean of the genotypes selected under complete phenotyping.

The results also showed that 20-30% the current phenotyping cost could be saved without significantly losing the precision of selecting best-performing hybrids (as 90% of the best hybrids were common between complete phenotyping vs sparse phenotyping) using sparse phenotyping.

We have also evaluated genomic-enabled prediction accuracy in different field sparse testing systems consisting of different ratios of non-overlapping/overlapping genotypes included in environments using two data sets from EA-PP1 (Jarquin et al., 2020). The results indicated that the genomic information (markers) by environment (GE) model provided higher prediction accuracy than the main effects models in the different allocation designs comprising different combinations of non-overlapping/overlapping genotypes in environments. Results indicated that substantial savings of testing resources could be achieved by optimizing the allocation design using genome-based models including GE interaction. For the given sizes of the trials included in this study, it is recommended (but not necessary) to have a small proportion of genotypes overlapping in all the environments while a large proportion of genotypes should be non-overlapping in the environments.

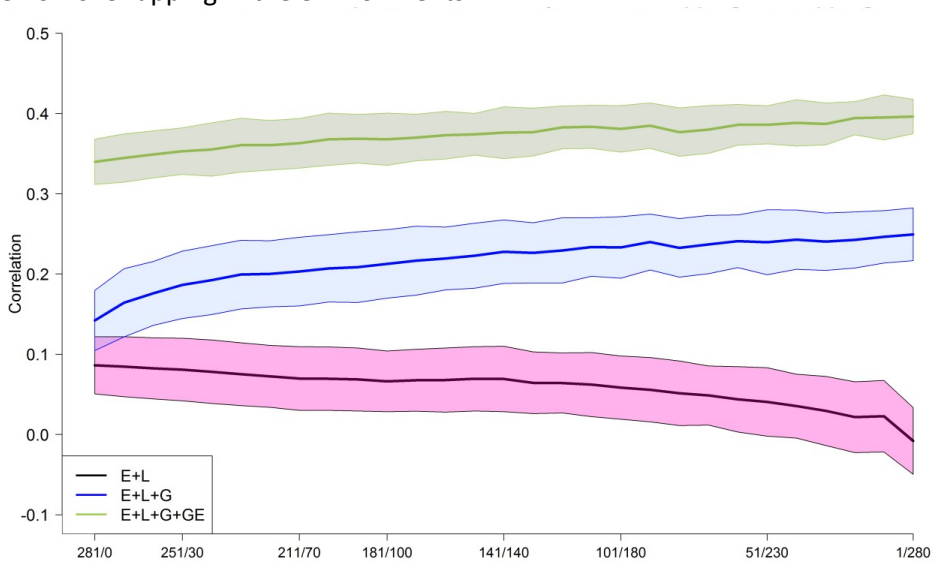

Figure 2. Average Pearson's correlation between the observed and predicted values of the maize genotypes for the three models **M1** (E+L) (Environment + Genotypes), **M2** (E+L+G) (G = genomic information markers), and **M3** (E+L+G+GE) (GE = interaction of markers x environments) for different composition of the non-overlapped/overlapped allocation designs. Shaded areas represent the interval of the mean plus minus one standard deviation. The x-axis the number of non-overlapping/overlapping genotypes (Jarquin et al., 2020).

Currently sparse testing across locations has been initiated in CIMMYT EA-PP1 and EA-PP2, and CIMMYT-Southern Africa Product Profile 1 (SA-PP1). Table 1 below is an example from Southern Africa showing the design arrangements and cost saving from using sparse phenotyping in for SA-PP1. The plan is to implement sparse testing in all maize product profiles by December 2021, including IITA's maize product profiles. We are exploring further optimization, including methodology for implementing sparse testing for the testers.

Table 1. Sparse phenotyping and augmented design – Case 1 for Stage 2 hybrids in SA-PP1, 2020/21 season. This is a multi-environment trial of 522 hybrids (from 117 lines and 5 testers) under 6 management conditions (3 at 2 sites, and 3 at one site).

Mangement	Sites	Design	Tested in 2 environments	Tested in 1 environment	Checks	With 2 replicates	Total genotypes without checks
Optimum	2	Sparse phenotyping	300	111	5	832	416
Optimum	2	Sparse phenotyping	300	111	5	832	416
Random stress	2	Sparse phenotyping	300	111	5	832	416
Random stress	2	Sparse phenotyping	300	111	5	832	416
High Density	2	Sparse phenotyping	300	111	5	832	416
High Density	2	Sparse phenotyping	300	111	5	832	416
			2 replicates	1 replicate			
Managed drought stress	1	Augmented design	322	200	5	854	522
Managed heat stress	1	Augmented design	322	200	5	854	522
Managed low N stress	1	Augmented design	322	200	5	854	522
					Total plots	7554	
					% of complete design	79%	
					Saving	21.1%	

Finally, we have demonstrated that the use of algorithms which use genomic information to optimally assign selection candidates to different testing environments and/or to either the training or testing set (in a scheme where not all selection candidates are phenotyped) can effectively improve prediction accuracy (Atanda et al., 2020). By genotyping all individuals of a populations ahead of time, algorithms which use genomic information to balance representation of alleles between testing and training sets or among testing environments can improve prediction accuracy.

2. Use of selection indices:

The MSC recommended that selection indices must be used in CIMMYT/IITA maize breeding pipelines. In this context, it is critical to address the challenging question – how do we put appropriate economic weights on different traits targeted in breeding pipelines? Currently selection indices are being implemented in various formats (e.g., independent culling) in different CIMMYT/IITA maize product profiles and the approaches need to be standardized. CIMMYT maize team, together with the EiB, are using retrospective data analysis of selection decisions to develop selection index based approaches to automate the trait weights used by breeders during selection. If the selection differentials represent the breeder's goal, then the weights determine the merit of individuals selected. Weights were calculated back as b=P-S (Table 2).

Table 2. Example of weights calculated through retrospective analysis.

Weight (b)	
GCA_GY.opt	**3.1584**

GCA_AD.opt	-0.099
GCA_ASI.opt	-0.361
GCA_EAR.ASP.opt	-0.533
GCA_BHC.opt	0.0172
GCA_ER.opt	0.0446
GCA_MOI.opt	0.2154
GCA_GY.drt	**2.9024**
GCA_AD.drt	0.1224
GCA_ASI.drt	-0.085

GCA, general combining ability; GY, grain yield; AD, anthesis date; ASI, anthesis-silking interval; EAR.ASP, ear aspect; BHC, bad husk cover; ER, ear rot; MOI, moisture content; opt, optimal conditions; drt, drought.

The index was calculated among-families and then within-family; the comparison is given in **Figure 3**.

Figure 3. Comparison of current selection differentials our maize breeders are using (red bars) vs selection index (blue bar) for recycling lines after Stage 2 (using EA-PP1 as a pilot).

The retrospective analysis method will be useful for understanding trait weights currently being applied by breeders and will enable establishment of systems of calculation and presentation within decision support software. At the current time, the retrospective selection index method does not account for economic weights defined by resource constrained smallholder maize farmers; however, the system for displaying and using selection index output will be useful for future selection indices weighted to match end user needs.

In 2021, the breeding team will also be working with socio-economists to make preliminary economic weight estimates for traits prioritized within selected ESA product profiles, and once optimized, the methodology will be extended to other Product Profiles in both ESA and WA.

3. Separating parental selection from selection of products:

The MSC recommended that not all parents need to hit all the thresholds in the product profile and the selection for choosing parents for recycling should be separated from selection of products for advancement. Before the initiation of AGG, selection of parents for recycling was done by the CIMMYT

team at Stage 3 using different forms of selection indices. Since the beginning of AGG, breeders have shifted towards selection of parents with target traits at Stage1 and Stage 2 of the breeding pipeline. In partnership with the EiB team, simulations were undertaken on datasets from EA-PP1 breeding pipeline. The analysis showed that recycling parents after Stage 1 or 2 would increase genetic gain by 17 and 9%, respectively, compared to recycling at Stage 3 (**Figure 4**).

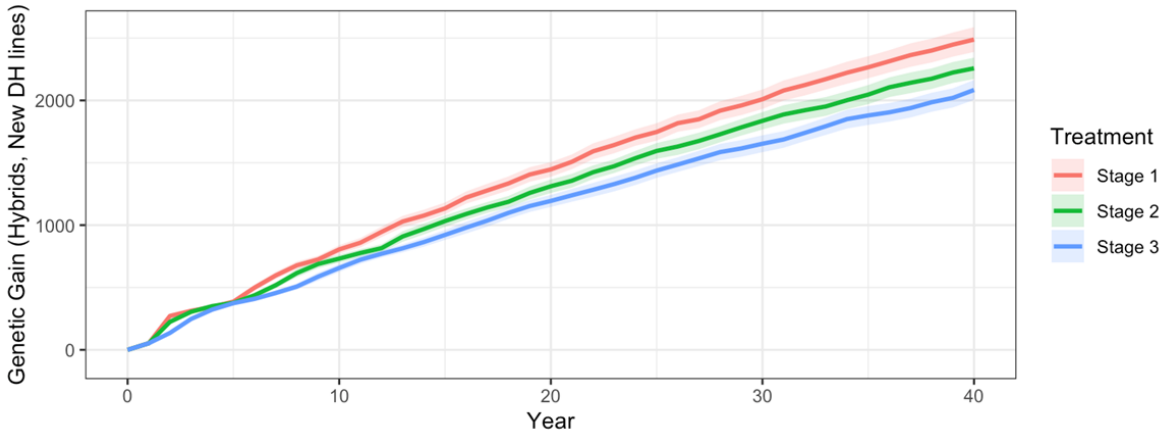

Figure 4. Simulations results comparing the current recycling at Stage 3 vs recycling after Stage 1 and 2 testing using data from EA-PP1. Recycling after Stage 1 or Stage 2 could deliver more genetic gain than the current baseline (Stage 3).

Based on these results, recycling lines after Stage 2 testing is being implemented in EA-PP1, SA-PP2 and in all WA product profiles; hence, reducing the breeding cycle from the earlier 5 years to 4 years is already in progress. Selection of parents after Stage 2 will be implemented in other product profiles during 2021. To recycle lines after Stage 1 testing, further research (e.g., determining optimal number of sites to be used for Stage 1 testing to sample target population of environments or TPEs, the number of testers to use at Stage 1) will be required. Using historical data and GEBVs, parental selection after Stage 1 is presently being piloted in EA-PP1, which will then be further expanded to other product profiles of CIMMYT and IITA by the end of 2021.

In our breeding pipelines, selection of products is already undertaken separately from selection of parents for recycling (**Figure 5**). Selection of products follows a well-defined stage-gate advancement of products from Stages 1 and 2 by line development breeders, followed by selection of the best products by the regional team for advancement through Stages 3 and 4 (Regional On-station Trials) and Stage 5 (Regional On-farm Trials).

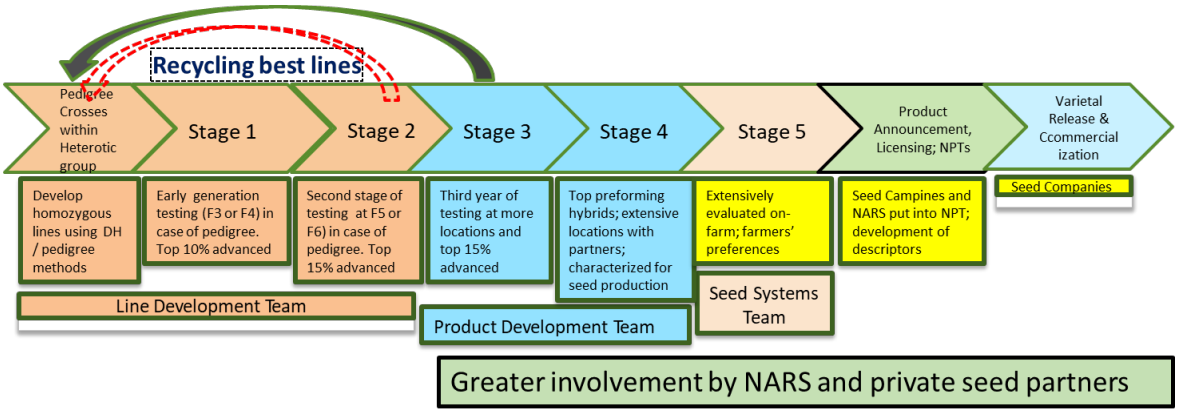

Figure 5. Stage-gate advancement process currently undertaken by CIMMYT in ESA. Lines advanced to Stage 3 with high GCA and desirable attributes are recycled to form new breeding starts (pre-2020, green solid line) and lines recycled after Stage 2 being implemented under AGG (dotted line).

4. Need to move toward driving genetic gains in source populations, and reduce focus on product identification which needs to happen in the NARS and private companies:

The main focus of CIMMYT/IITA maize breeding pipelines has been improvement of source populations through recurrent selection and rapid recycling of elite lines for continual generation of more robust new inbred lines to increase genetic gains in products developed and shared with partners. New lines are filtered through three stages to identify the most promising lines for use by partners to form new hybrids, extensively test them in multiple locations, and identify promising products for their target production zones. Furthermore, engagement of the NARS and private seed companies in product advancement meetings facilitates the selection of promising hybrids that are preferred by partners. In 2021, CIMMYT and IITA have planned to further strengthen complementary population improvement activities to supply improved populations to the NARS partners as sources of divergent maize inbred lines for optimizing heterosis in hybrids. Additionally, we will begin to implement rapid-cycle genomic selection (RCGS) for East Africa Product Profiles in 2021 and will then extend this to other product profiles in southern and West Africa in coming years once adequate training data exists.

Effective engagement with partners and capacity development in the times of COVID-19

1. Develop a capacity development strategy:

Under AGG PO4, an array of virtual capacity building activities (including eight Training Webinars on several relevant topics) have been implemented in 2020, while coping with Covid19-related restrictions. The Webinars included: 1) Increasing maize varietal turnover in sub-Saharan Africa; 2) Statistical analysis (3 sessions); 3) Enhancing and measuring genetic gain; 4) Genomics-assisted maize breeding; 5) Breeding program continuous improvement; and 6) Improving phenotyping accuracy and throughput in maize (**Table 3**).

In addition to knowledge sharing webinars, in collaboration with EiB, we are developing customized improvement plans for each AGG-Maize NARS partner. This is a comprehensive process involving significant time investment from the NARS, AGG and EiB scientists to document in detail the current state of each NARS program and develop a robust plan for modernization commensurate with budget and human resources available. The process and tier-rating methodology are shown in **Figure 6** and **Table 4,** respectively.

In 2020, the maize programs at KALRO (Kenya), NARO (Uganda) and DR&SS (Zimbabwe) have been assessed and modernization plans finalized. Support to access genotyping, digitization equipment, adoption of data management systems, breeding scheme optimization are already underway for these programs. We are working towards this customized model of NARS capacity development to drive tangible and meaningful change at NARS programs rather than relying on blanket, generic training. In 2021, we will begin intensive engagement with TARI (Tanzania), ZARI (Zambia) and CSIR (Ghana) to develop the second wave of modernization plans for NARS partners.

We recognize the need to develop a concise and crisp capacity development strategy to cater to the needs of different target audiences, including field technicians, early career breeders, senior breeders, seed technologists, post-degree training. In 2021, jointly with EiB, the project will undertake a virtual survey of the partners to assess their needs for capacity development and will develop a baseline and critical gap assessment. The project will also engage with an external consultant having a strong understanding of our partner landscape to formulate a suitable capacity development strategy for the Project.

Table 3. Details of Training Webinars conducted by the AGG maize team in 2020.

Date	Topic	Who were Trained[9]	Number Trained[10]		
			Male	Female	Total
August 12, 2020 (Virtual)	Genomics-assisted Maize Breeding	NARS and SME scientists (maize breeders, pathologists, entomologists, physiologists, biometricians, and post-graduate students) from Africa, Asia, and Latin America, including from the 13 AGG maize target countries	171	62	233
August 14, 2020 (Virtual)	Improving Phenotyping Accuracy and Throughput in Maize	NARS and SME scientists (maize breeders, phenotyping specialists, and post-graduate students) from Africa, Asia, and Latin America, including the 13 AGG maize target countries	136	45	181
November 19, 2020 (Virtual)	Enhancing and Measuring Genetic Gains	NARS and SME scientists (maize breeders, biometricians, and post-graduate students) from Africa, Asia, ad Latin America. including the 13 AGG maize target countries	70	31	101
October 23, 26 & 29, 2020 (Virtual)	Statistical Analysis for Plant Breeders	NARS and SME scientists (maize breeders, pathologists, entomologists, physiologists, biometricians, and postgraduate students) from Africa, Asia, and Latin America, including the 13 AGG maize target countries	80	23	103
July 27, 2020 (Virtual)	Increasing Maize Varietal Turnover in sub-Saharan Africa	NARS and SME scientists (seed technologists, maize breeders, pathologists, entomologists, physiologists, biometricians, socio-economists and post-graduate students) from Africa, Asia, and Latin America, including the 13 AGG maize target countries	54	19	73
October 6, 2020 (Virtual)	Continuous Improvement of Breeding Programs	NARS and SME scientists (maize breeders, pathologists, entomologists, physiologists, biometricians, and postgraduate students) from Africa, Asia, and Latin America, including the 13 AGG maize target countries	54	8	62

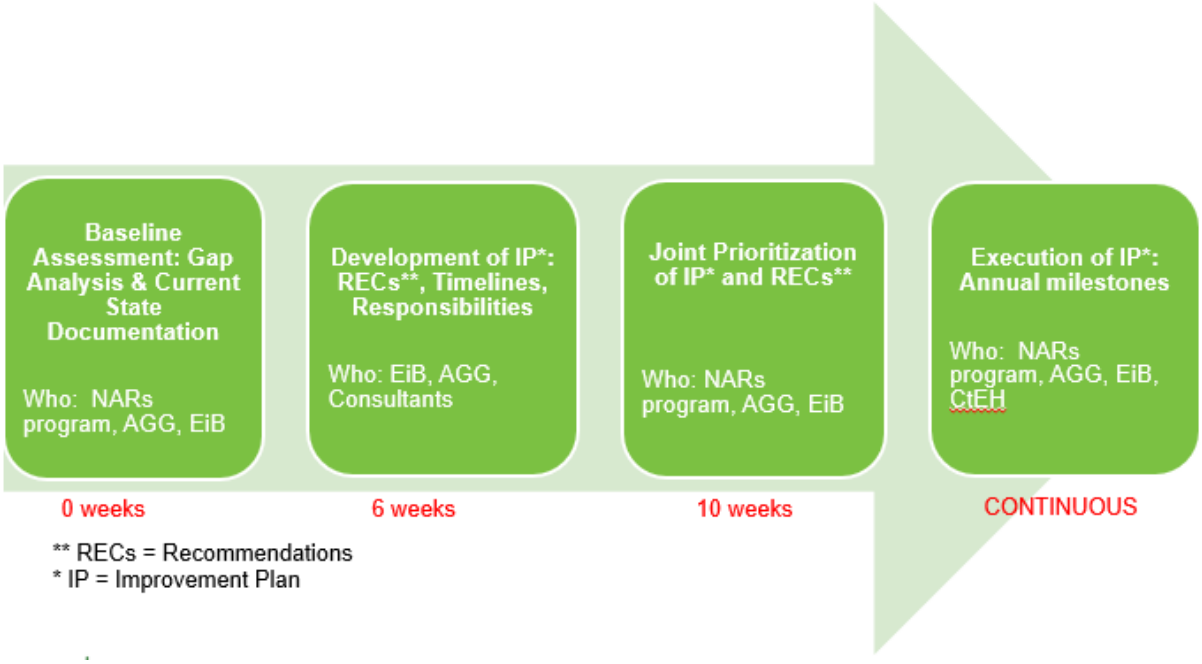

Figure 6. Process flow for used jointly by AGG and EiB to assess NARS breeding programs and to develop customized breeding program improvement and modernization programs.

Table 4. Tier rating system and criteria used by AGG and EiB teams to facilitate development of customized improvement and modernization of NARS breeding programs.

Tier	Tier Type	Breeding program Description
Tier 5	Dormant	No germplasm dev activity, some opportunistic testing of products from CG led networks/external partners but not consistent. No breeding expertise or internal germplasm.
Tier 4	Testing & Trait Based	Routine testing of products from CG led networks/external partners with occasional release. Internal breeding capacity limited and predominantly trait focused.
Tier 3	0.25x program	Routine testing and release of products from CG led networks. Some internal germplasm dev effort focused on a defined product profile but pipeline is not continuous and underfunded. Germplasm base is predominantly CG.
Tier 2	0.5x program	Continuous pipeline that consistently develops new germplasm but pipeline is undersized relative to market size and needs. Some release of internal germplasm but majority of releases are from CG led networks.
Tier 1	1x program	Mature pipeline, well-budgeted and well-aligned to market size and needs that regularly develops internal germplasm that is competitive with germplasm from CG led networks. Regular release of varieties with clear path to scale.

2. Use appropriate training modalities for each PO:

Due to the Covid-19 restrictions no face-to-face training activities were conducted in 2020 and only virtual training Webinars were carried out as reported above. In addition to continuing with virtual training webinars, in 2021, we will explore and implement virtual product tours and technical video trainings for

small groups where appropriate and make the trainings more interactive. As recommended by the MSC, training events will be tailored to differentiate online capacity development events (i) training/workshops designed to teach, and (ii) science meetings with presentations designed to share results, experience, and recommendations. Under the current Covid19 scenario, Webinars will continue to introduce concepts and practical options on improving maize breeding efficiency, especially with the NARS partners (e.g., Product profile-based maize breeding; Breeding costing; Crossing list review, Stage-gate advancement, etc.,).

If the Covid-19 situation improves in 2021 significantly, the project may consider hands-on training of selected NARS breeders with CIMMYT/IITA teams for 3-6 months. Where some specialized skills exist outside the AGG and EiB teams (e.g., with industry and advanced research institutions), the project will consider outsourcing some of the capacity development events, in addition to jointly developing training modules, and using resource persons to elaborate innovations in maize breeding and seed systems.

3. Explore various opportunities to enhance partner engagement in addition to capacity development:

In 2020, under the AGG project, NARS partners were engaged in regional product advancement meetings of CIMMYT in ESA and IITA in WA. In the stage gate-advancement meetings in ESA, results from Stage 4 regional trials (along with instructions on how to vote on different hybrids based on well-defined trait metrics) were shared with the partners three weeks before the advancement date. Partners returned their votes on the hybrids, and during the meeting the process of selecting hybrids to advance to Stage 5 was explained and an opportunity was given to partners to provide their feedback. In 2021, Stage-gate advancement meetings involving partners will be extended to Stages 3 and 4 trials in ESA and Stage 4 trials in WA. Plans are also under way in 2021 to survey partners for feedback on experience during the Product Advancement Meetings that were held in 2020/2021.

As previously indicated, in collaboration with EiB, the AGG PO4 team has completed breeding program assessments of DR&SS (Zimbabwe), KALRO (Kenya) and NARO (Uganda) in 2020 which has led to the development of customized Improvement Plans. Plans are under way to assess at least 6 more NARS programs in 2021 covering both ESA as well as West Africa. The one-on-one engagement with the 3 NARS partners in 2020 has led to a deeper understanding of the needs of the NARS partners, and will help the CIMMYT and EiB scientists develop capacity development initiatives with a real need in NARS programs that will lead to tangible change.

Another important engagement we had with partners in 2020 was through the formation and implementation of “Regional Collaborative Maize Breeding and Seed Systems Networks” in EA, SA and WA, with defined code of operations and collaboration. The formal launch of these regional collaborative networks in ESA took place in August 2020 while the one for West Africa was launched in May 2020. Following the formation of regional networks, individual AGG Country-specific Maize Workplan Development Meetings were held in ESA in September-October 2020. In 2021, annual review meetings will be conducted in all three AGG maize target regions.

Clearly defining roles and responsibilities amongst the CGIAR, NARS and SMEs in the AGG maize breeding networks will be a priority for the project in 2021/22. Given the CGIAR’s comparative advantage in upstream areas of research such as trait discovery and introgression, population improvement, provision of centralized services and rapid cycling, the CIMMYT and IITA maize programs would lead these areas with a clear mandate to drive genetic gain in source population through the adoption of best practice and available technology. NARS and SMEs that are running active breeding programs will receive technical backstopping from the CGIAR centers and will be provided an opportunity to include material developed from these efforts in joint AGG testing networks. The vision for this network is presented in **Figure 7** below.

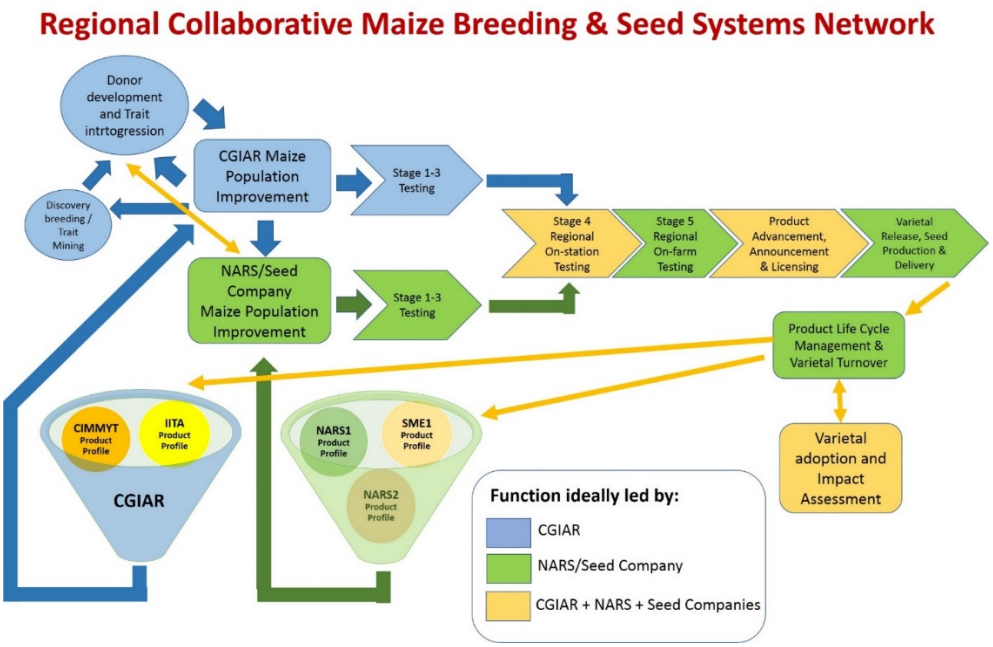

Figure 7. Implementation of "Regional Collaborative Maize Breeding and Seed Systems Networks" in EA, SA and WA, with defined code of operations and collaboration.

NARS and SME partners have a clear comparative advantage in the downstream, customer facing components of the breeding network and are being encouraged to lead these activities particularly with regard to gathering country level market intelligence and leading the final stages of variety selection and release. A combination of webinars and one on one support is planned in 2021 to support NARS and SMEs to understand the concepts of market segmentation, product profiling and presenting this critical information in a formalized way to CGIAR regional breeding programs who will aggregate product profiles on a regional level based on country specific requirements.

NARS and SMEs will also be supported to take on a more proactive role in variety identification and advancement through participation in advancement meetings in 2021. In addition to presenting market intelligence and country specific trends at regional pipeline advancement meetings, NARS and SMEs will be supported to take the lead in making final stage advancements into the release process and will eventually become accountable for ensuring release criteria, QA/QC and maintenance of basic seed. Whilst the CGIAR centers will be the primary engine for driving genetic gains through their rapid cycle population improvement schemes, NARS and SMEs will be the driving force behind variety turnover and adoption.

4. Provide after-training support to NARS partners:

While we recognize that currently the AGG project has no streamlined process for after-training support, in 2021 the project will strive to create a virtual platform (with focal points from different POs) for providing dedicated and dynamic support to partners after training. This will be done in collaboration with the Communications and Knowledge Management Teams in CIMMYT and IITA, an Online Platform will be established for providing after-training support to the AGG partners.

Seed systems and gender intentionality

1. Need to develop an effective Regional On-farm Trial (ROFT) strategy:

Starting in 2020, a revised Regional On-Farm Trial (ROFT) strategy which combines inputs from biophysical and socio-economic scientists has been drafted and is being implemented (**Annex 1**). The revised ROFT strategy includes a change in the experimental design, a scaling plan for wider testing, greater involvement of NARS, NGOs (including AGRA), and seed companies, and harmonization of the ROFT approach between CIMMYT and IITA. The revised ROFT will also be a platform to gather socio-economic and gender-disaggregated data. **Table 5** presents the current partnership of on-farm trials in Eastern and Southern Africa for the 2020 and 2020/21 seasons, respectively.

Table 5. AGG regional maize on-farm trial network partners in ESA.

Countries	Partners
Zimbabwe	NARS (Agritex) Seed Companies (Seed Co, Valley Seeds) ARDA
Zambia	NARS (ZARI, SCCI)
Malawi	DeSIRA project (CIMMYT) NGOs (AGRA, AFAP) Seed Companies (Global Seeds)
Mozambique	NARS (IIAM)
South Africa	NARS (ARC) Seed Companies (Quality Seed, Vuna Seed, Imbewu)
Tanzania	NARS (TARI)
Kenya	NARS (KALRO) NGOs (AGRA) Seed Companies (Western Seeds, East African Seeds, Kenya Seed Co, Advanta)
Uganda	NARS (NARO) Seed Companies (NASECO, FICA)

Work has already been initiated on the harmonization of regional on-farm trial strategy across AGG maize target regions in ESA and WA.

2. Need to better understand overall market conditions (and options for market segmentation) to help guide investments by seed companies:

The MSC noted that in ESA the seed companies have relatively higher capacity and more potential for innovation in seed marketing, while in many countries in West Africa (WA) formal maize seed market development is still in early stages (exceptions include Nigeria and Ghana) with several bottlenecks, including limited capacity of seed companies, limited breeding capacity, challenges for reaching hinterland etc. The MSC recommended that options should be explored to adjust work plans to respond to the differences in context (current plans are very similar, focused on seed marketing primarily).

Various efforts are now underway by CIMMYT and IITA to better understand marketing conditions:

- Currently the CIMMYT PO3 team is conducting experiments in EA on smallholder variety selection and trait valuation while in WA the IITA team is looking to estimate improved seed demand using experimental auctions. Research findings will be communicated to seed companies and other partners in the course of 2021 (as discussed below).
- Interviews with seed companies were conducted in Nov-Dec 2020 on their current access to market information and related market intelligence needs in ESA and WA, of which a report being written for sharing with relevant audience.
- In EA the CIMMYT team is designing a pilot research effort in 2021 to collect seed market information in Kenya at the retail level across market segments (with eventual rollout to other targeted countries in 2022). Discussions are on-going for carrying out similar work in WA. Additional resources are likely to be required. We are discussing with EiB on this.
- The PO3 team developed, tested and validated a standardized survey instrument to collect baseline seed market data, including seed prices, seed availability, seed production, consumer/farmer demand, seed marketing, and others. Working with NARS partners in Benin, Ghana, Mali, and Nigeria, data were collected by administering the standardized survey questionnaires to more than 35 seed companies in Nigeria, 5 seed companies in Mali, 3 seed companies in Ghana, and 54 small seed entrepreneurs in Benin. The data is currently being processed to develop baseline information on seed market performance indicators. These indicators will be used to monitor and track the performance of the maize seed market in each country in terms of improved maize seed availability, accessibility, affordability and quality in WA.
- By July 2021, we will complete on-going data collection in WA and will generate a publication plus a summary document with information on overall market conditions for stress tolerant maize.
- As deliverables, by mid-July 2021, we aim to generate two market intelligence reports and conduct two webinars on trait preferences (one each by CIMMYT and IITA) to provide estimates of seed demand across different market segments and/or varietal traits.

3. Engage with seed companies over evidence on farmers' preferences and consumer behavior, as input for seed companies' marketing strategies:

The MSC noted that a) there is potential to better inform seed companies, retailers, and others on the market for stress -tolerant maize seed, and b) under STMA project, information was generated on women-owned seed businesses and some learnings thereof. The MSC further suggested that AGG should not plan to reengage on this topic; rather, much more is needed to ensure broader gender intentional seed delivery.

In 2019 and 2020 analysis of agro-dealers' influence on maize varietal selection was undertaken in EA, and more work on farmers' seed purchase decision process is planned for 2021. We are discussing options for replication of these studies in WA. However, given the differences in context (e.g., the issue in WA is more about increasing use of hybrids, while the issue in ESA is more about getting farmers to switch to newer maize varieties), options are yet to be identified. We will continue discussions based on CIMMYT's experiences in EA, as well as IITA experiences in WA, based on the work on estimating farmer seed demand.

We will pilot a farmer-managed on-farm "modified Tricot trial" for collecting robust data on varietal performance and farmers' preferences in Kenya, with a focus on engaging women and poorer farmers. This research is ambitious and will take a couple of years of piloting before full implementation. We will explore design challenges and options for replication in other contents, as well as engage external partners as needed.

The PO3 team conducted literature review on gender-specific trait preferences for improved maize varieties and used the information to develop a sex-disaggregated survey tool to collect key trait preference information during participatory field/variety evaluations by farmers in Benin, Ghana, Mali, and Nigeria. In collaboration with the NARS partners in these countries, field days were organized for 10 men and 10 women farmers per site (more than 600 in total across Benin, Ghana, Mali, and Nigeria) at flowering and harvest stages where on-farm variety trials and demonstrations were conducted and detailed socio-economic (including credit, market information, and land-related factors) and trait preference information were collected. Focus Group Discussion (FGD) involving selected men and women farmers were also conducted across several locations in Nigeria, Ghana, Benin and Mali. Through the FGD, detailed information about the main constraints both men and women farmers face in maize farming, the relative importance of key production, consumption, processing and market-related traits for maize variety selection decision, and the wish-list of key variety traits were collected for consideration in future breeding programs. The collected data are being analyzed to develop a comprehensive synthesis report highlighting the most preferred maize variety traits among men and women farmers.

We recognize that effectively responding to the MSC's recommendation also means deeper engagement with seed companies and other project partners on their marketing strategies. Given the Covid19 situation, we will need to rely on Webinars at least for a major part of 2021. Our socio-economists at CIMMYT and IITA will conduct the following webinars:

- Report on research conducted in 2019 and 2020 on gender-based farmers' preferences (IITA and CIMMYT)
- Report on seed demand and current marketing strategies and gaps in WA (IITA)
- State of the maize seed retail market in Kenya (CIMMYT)
- Results from "out-of-stock" experiment (CIMMYT)

4. Be cautious about using seed production data instead of seed sales data to estimate variety uptake:

The MSC suggested that we might be overestimating seed uptake since there can be substantial differences between seed production and sales in some years, when some companies have substantive carryover stocks. They recommended instead to use seed sales data (rather than seed production) to estimate variety uptake. However, we do not agree with this suggestion as it is not practical to collate on an annual basis the confidential/market-sensitive commercial seed sales information from all the seed company partners in the target countries in Africa. Certified seed production data by country and by stress-tolerant maize variety (with germplasm relationship to CIMMYT/IITA) is presently obtained systematically from seed company partners on a confidential basis. The certified seed production-commercialization data for the project is presented as meta-data (aggregated country-wise) with no specific reference to seed companies or specific varieties to protect the market-sensitive data. Although carryover commercial stock may cause some discrepancy in estimates, we do not believe it is a major issue; even if this happens with seed companies in some countries, it is expected to be largely neutralized by the commercialization of carryover seed from a previous year.

5. Need to see gender in the context of the larger household strategy:

The MSC noted that questions remain about how to increase women's engagement in decision making around and use of improved seed. Engagement with women-led seed companies could offer insights on how to reach women farmers, but these companies are very few and have a small share in the seed market in sub-Saharan Africa. Questions also remain on how women farmers' views are gathered in Regional On-farm Trials, whether those views are being appropriately considered in product development and advancement, and to what extent women's stated preferences are reflective of their ability to productively use the technologies.

The PO3 team, led by CIMMYT and IITA gender specialists, is currently reviewing the existing literature on gender relations and preferences. The review, which will be completed by mid-2021, will provide a framework for future engagement by CIMMYT and IITA in this area. CIMMYT and IITA gender specialists will be involved not only in the Regional On-farm Trials, but also in planning mixed methods research exploring farmers' preferences, needs, and constraints; intra-household dynamics; and seed purchasing behaviors influencing improved maize varietal adoption and decision-making in the project areas. Qualitative research to build a working understanding of gendered market segments will be completed by mid-2021 in Kenya and will inform a large-scale segmentation survey to be completed by end of 2021. The CIMMYT and IITA gender specialists in collaboration with EiB will review the existing tools for assessing gender-based improved maize seed preferences drawing on tools such as Gplus (developed by CRP RTB).

The PO3 team members at IITA conducted a literature review on major gaps/bottlenecks in the current seed marketing strategies to develop the research protocol for an in-depth study to identify current maize seed marketing strategies in Nigeria. Also, survey tools were developed, tested and validated to collect additional information on the current stage of marketing strategies around the 4Ps (Product, Price, Place and Promotion) and to identify innovative marketing strategies that could improve the delivery of improved maize seed to both men and women farmers. The survey was conducted in Kaduna and Niger, two important maize producing states in Nigeria, to assess and draw lessons on how the marketing channels work in competitive market conditions (Kaduna state) and in areas where there is limited competitiveness and presence of seed companies (Niger state). Data were collected from 9 community surveys, 306 rural households, 32 agro-dealers, and 14 seed companies, besides detailed gender-related information related to seed marketing behavior, to identify gender-responsive marketing strategies.