Enhancing Agricultural Resilience: The Impact of Regional Shared Breeding Pipelines for Dryland Crops in Sub-Saharan Africa

This is the full unedited version of Shared breeding pipelines improve dryland crops in sub-Saharan Africa. This is for informational and research purposes only – contact the author if you require clarification: m.aluoch@cgiar.org

By Marion Aluoch

CIMMYT, through the Dryland Crops Program (DCP), has pioneered an innovative regional shared breeding program for dryland crops. This program aims to improve the cultivation and commercial viability of new crop varieties in Eastern and Southern Africa (ESA) and West and Central Africa (WCA). The approach is based on a participatory design where key stakeholders such as breeders, farmer representatives, pathologists, agronomists, socio-economists, seed systems specialists, nutritionists, gender specialists, and seed industry representatives come together to develop unified crop improvement teams for sorghum, pearl millet, finger millet, groundnut, chickpea and pigeon pea in sub-Saharan Africa. These teams are pivotal in identifying market demands and setting breeding priorities that align with regional needs.

Traditionally, most public sector breeding programs are breeder centric, with breeders having significant decision-making power on breeding targets. However, breeders have a limited perspective on a discipline that is becoming increasingly collaborative and integrative. Today's breeding programs should have the framework and processes necessary to quickly develop varieties that meet the rapidly changing market demands and climatic conditions. Market segments in traditional breeding programs were not clearly defined and prioritized to optimize resources for larger impact. Value chain actors had minimal inputs to clearly define products required by the market. Programs also operated independently of each other, and multidisciplinary approaches were not actively sought.

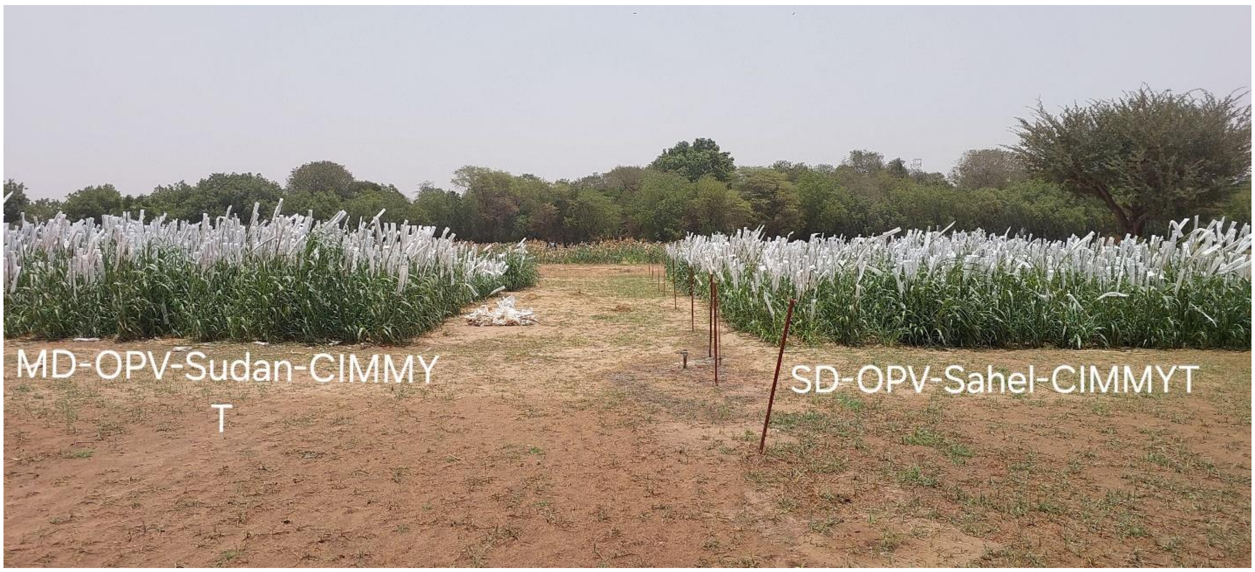
The regional shared breeding pipeline model transforms this traditional framework by linking breeding activities with market needs and environmental challenges. "Understanding both the farmer's needs and market demands allows us to tailor our breeding objectives more precisely, which significantly enhances the adoption, adaptation, and impact of new varieties," says Dr. Biswanath Das, the National Agricultural Research System (NARES) Coordinator.

This ensures that new crop varieties are not only bred using the latest and most efficient technologies with minimal environmental footprint but also resonate with consumer preferences, nutritional requirements, regional market demands, and environmental conditions, thereby enhancing their commercial success and societal impact.

The shared breeding pipeline approach

The shared breeding pipeline is a comprehensive strategy that entails a collaborative approach to co-designing, co-developing, and co-implementing a shared research agenda that leverages the complementary strengths of NARES and CGIAR partner institutions of African Dryland Crop Improvement Network (ADCIN).

"This approach is built on the principle that collective effort and shared knowledge lead to greater innovation and impact," says Dr. Harish Gandhi, Associate Program Director for DCP and chair of the ADCIN -WCA steering committee. "By combining our expertise and resources, we ensure that new crop varieties are scientifically advanced and aligned with regional market demands and environmental conditions.



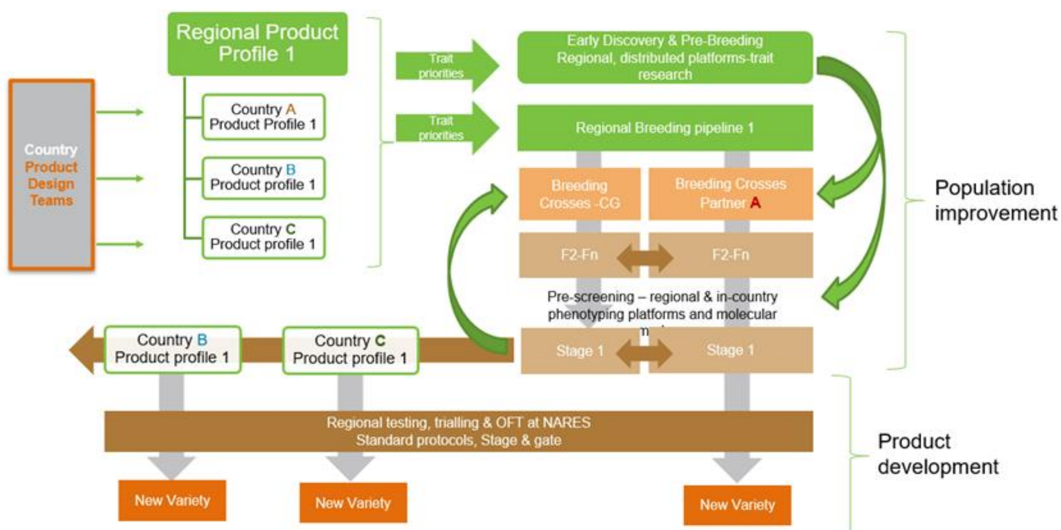
Pipeline showing short-duration OPV for Sahel zones (SD-OPV-Sahel-1) and medium-duration OPV (MD-OPV-Sudan-1) at the crossing block managed by CIMMYT, Bambey station. This block represents 50% of the total crossing. Photo: Drabo Inoussa/CIMMYT

The approach begins with establishing regional crop improvement work groups and subsequently defining shared research priorities for each region and crop. Regional meetings are organized to establish regional crop improvement work groups for each crop. In these meetings, crop improvement network vision and strategy are discussed, and the next steps of the implementation are agreed upon. Also, regional priority traits that need investments in phenotyping and pre-breeding capacity are identified; country product design teams (PDTs) are formed for each crop. These PDTs include key experts and stakeholders such as breeders, nutritionists, gender specialists, crop health specialists, seed systems specialists, peer NARES, CGIAR representatives, farmer representatives, government representative, and industry representatives like processors, aggregators, millers, and seed companies. PDTs provide guidance to the plant breeder on current market needs and trends by actively sharing their knowledge. PDT meetings were conducted in each country in 2022- 2023 to define market segments and develop the corresponding target product profiles for each crop.

The breeding program in each participating country is then assessed by peers using the Excellence in Breeding (EiB) Breeding Assessment Tool to evaluate its current capacity and complementary strengths. This assessment helps determine their tier status as recommended by Accelerated Breeding Initiative (ABI) Transform and develop an improvement plan to enhance the capacity and efficiency of each program.

Following the country PDT meetings and program assessments, regional meetings were organized in Mali and Tanzania for the crop improvement work groups. The meetings brought stakeholders together to agree on prioritized regional market segments and responsibilities for each segment. Responsibilities were given based on each partner's current and projected capacity, partner needs, and aspirations.

Shared breeding pipeline of network partners: Example schematic for one breeding pipeline



The final step in the process involves the implementation of regional breeding pipelines. In this phase, a dedicated regional breeding pipeline is built for each prioritized market segment, with lead centers identified to coordinate activities. Partners in charge of these pipelines identify ADCIN-Population Development Centers where breeding will take place. The PDTs also identify testing locations for each pipeline based on the importance of market segments in the individual countries and prioritize them. This structure ensures that the breeding activities are strategically aligned with specific market demands and are led by centers that specialize in the necessary areas of expertise.

"The structure of our pipeline is designed to ensure that every stage of the breeding process is informed by collective intelligence. From setting priorities to testing and deployment, each step reflects shared knowledge and joint effort, says Dr. Gandhi.

Pipeline showing a short-duration OPV (Open Pollinated Variety) for Sahel zones, labeled SD-OPV-Sahel-2, at Kamboinse station managed by INERA. This block represents 25% of the total crossing effort. Photo: Armel Rouamba/INERA

This approach not only accelerates the breeding cycle and enhances the genetic diversity of crop varieties but also fosters a sense of ownership and commitment among stakeholders, ensuring rapid adoption of the varieties within the communities they aim to serve. Optimized breeding schemes for each pipeline are defined in consultation with quantitative geneticists. Parent selection for population development is jointly made based on data from genotyping and phenotyping of potential parents.

Some of shifts to modern plant breeding that address the components of genetic gain include:

- Breeding program size are typically 50-400 individuals, but network programs are shifting to >1,500 individuals, impacting selection intensity
- Recycling parents earlier from Stage 1 or using eventually genomic predictions to reduce cycle time to 2-4 years, compared to conventional practice of using released varieties and landraces (gene bank germplasm and old cultivars) in crossing block every year which resulted to a cycle time of 15 years. Reducing the cycle time is the lowest hanging fruit and easiest to implement.
- Optimizing the total number of families and number of lines per family to adequately sample the variation.
- Optimizing field nursery operations for better efficiency such as shortening growth duration of plants to rapidly advance generations in the field

The use of genomic tools plays a critical role in population development within the shared breeding pipeline approach. Low, mid, and high-density marker systems are available to facilitate this process. Specifically, working collections of target crops for ADCIN are genotyped using mid-density SNP (Single Nucleotide Polymorphis) panels. This genotyping helps assess the diversity of germplasm and select potential parents, including the development of heterotic groups for hybrid breeding programs. To ensure the genetic integrity of the breeding efforts, quality assurance/control markers are utilized to verify the purity of parental lines and confirm the hybridity of filial generation1 (F1) populations. This step significantly enhances the accuracy of the breeding process, allowing only true F1 hybrids to advance to the next generation, therefore reducing phenotyping costs. Additionally, the process of sampling and submitting samples for genotyping to achieve a quick turnaround in results has been streamlined. This efficiency enables faster decision-making for advancing breeding stages. For instance, seed chipping is used for genotyping F1 seeds in groundnut, ensuring that only true F1 seeds are planted. Ongoing efforts are also dedicated to developing and validating markers for traits currently lacking specific trait-linked markers, further enhancing our breeding capabilities and ensuring robust agricultural advancements.

The development of plant populations is focused on addressing key biotic traits such as anthracnose, stem borer, midge, and striga in sorghum; downy mildew, head miner, and striga in pearl millet; leaf spots, rosette, and rust in groundnut; Ascochyta blight and stem borer in chickpea; and fusarium wilt and pod borer in pigeon pea. The main abiotic trait is developing drought resistance, for all dryland cereals and legumes. Also, enhancing grain quality is prioritized, with focus on increasing the iron and zinc content in sorghum and millet, and the oil and oleic acid content in groundnut. To support these goals, work groups have identified representative phenotyping sites capable of implementing advanced techniques such as artificial inoculation, dirty plot/sick plot screening, and hotspot screening for these priority traits. Investments are being made to enhance the capabilities of these sites to function as ADCIN screening hubs. These include mechanization tools such as planters and harvesters, improved irrigation systems, screen houses, and digital tools like handheld data loggers and barcodes. Additional enhancements include well-equipped pathology and entomology labs, seed processing facilities with seed counters, weighing scales, moisture meters, and both short- and medium-term cold seed storage units. Furthermore, analytical equipment for assessing grain quality, such as NIRS (Near-Infrared Spectroscopy) and XRF (X-ray-fluorescence), are also being installed at locations in both WCA (e.g., Senegal) and ESA (e.g., Kenya, Tanzania, Uganda).

The development of plant populations is supported by a well-thought-out pre-breeding strategy. At Kiboko, Kenya, a specialized facility known as the “backcrossing factory” has been established to integrate key traits into elite lines using rapid genomic-assisted backcrossing. Traits and parents (recurrent and donor) have been identified and prioritized by each crop work group. Elite lines from the backcrossing program will be incorporated as parent lines in the development of plant populations.

Example of implementation: the ADCIN pearl millet WCA workgroup

The ADCIN pearl millet WCA workgroup, which was established in September 2022, is an example of this approach in action. This group focuses on a regional approach tailored to the needs identified across several countries in WCA, with the aim of enhancing the genetic diversity and adaptive capacity of pearl millet varieties.

"The implementation of the new approach for regional population development, specifically focusing on medium-maturing open-pollinated varieties (OPVs) of millet, marks a significant achievement for both my program and the institute at large. This approach addresses the need for medium-maturing millet populations in WCA. It involves a collaborative effort of co-designing and co-implementing with colleagues from NARES and CIMMYT, leveraging the unique capacities and strengths of each partner. This collaboration aims to deliver precise and impactful results. Overall, this achievement underscores our commitment to innovation and collaboration in addressing regional agricultural challenges," says Dr Maryam Dawud, a Pearl Millet Breeder at Lake Chad Research Institute (LCRI) in Nigeria and a member of the pearl millet WCA workgroup and finance secretary in the ADCIN steering committee.

The workgroup, coordinated by CIMMYT, has made remarkable progress in its first 15 months:

- Conducted comprehensive peer-to-peer assessments to optimize breeding capacities.
- Partner institutions agreed on responsibilities to lead regional breeding pipelines
- Developed workplans based on the role of each institution and budgeted accordingly.
- Developed and genotyped over 750 pear millet inbred lines to initiate heterotic grouping for hybrid breeding program.
- Regional trials of 50 pearl millet open-pollinated varieties (OPVs) were conducted across 8 countries and 24 locations (12 in Sahel zones and 12 in Sudan zones) in 2023.
- 10 founder lines selected for short duration and 10 others for medium duration OPV pipelines.
- Developed OPV and hybrid breeding plans and agreed upon protocols for key pests and disease management.
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We appreciate the contributions we are making in collaboration with CIMMYT towards the development of short-duration OPVs for the Sahel zone," says Dr Oumar Diack, pearl millet breeder at Institut Sénégalais de Recherches Agricoles (ISRA), Senegal "This approach is highly relevant in terms of pooling and optimizing the use of available resources for the entire region. The new crossbreeding schemes are less random—they are now more precise, more representative of the parent genotypes, and based more on real data than on general knowledge of the parents. I believe that, in this way, we'll achieve faster genetic gains and reach our targets more quickly."

Shared Breeding Pipeline for prioritized pearl millet market segment in West and Central Africa

Breeding Pipeline Short Name	Breeding Pipeline Long Name	Pearl Millet WCA ADCIN-Population Development Centers							
		CIMMYT/Senegal		INERA/Burkina Faso		LCRI/Nigeria		ISRA/Senegal	
		% Effort towards 1X pipeline	location	% Effort towards 1X pipeline	Location	% Effort towards 1X pipeline	location	% Effort towards 1X pipeline	location
Short Duration Pearl Millet OPV	Short duration dual purpose pearl millet OPVs adapted to Sahelian zone for food and food processing	50%	Bambey	25%	Kamboinse			25%	Bambey
Medium Duration Pearl Millet OPV	Medium Duration purpose Pearl Millet OPVs adapted to Sudanian zone for food and food processing	50%	Bambey			50%	Maiduguri		
Medium Duration Pearl Millet Hybrid	Medium Duration Pearl Millet Hybrids for Sudanian Zone for food and food processing	75%	Bambey	25%	Kamboinse				
Expectation from ADCIN-Population Development Centers in 2024		1- 20 Crosses for OPV Early 2- 20 crosses for OPV medium 3- 15 crosses RxR 4- 15 crosses BxB 5- 1076 Crossing for Heterotic grouping 6- 19 BxB and 12 RxR 7- Field trial of F1 crosses		1- 10 Crosses for OPV Early 2- Evaluation in observation trial/screening for downy mildew of 250 F1 OPV progenies 3- QA/QC and F2 of 30 RxR and 15 BxB 4- Field trial of F1 crosses (het grouping)		1- 20 crosses for OPV Medium 2- Evaluation in observation trial/screening for downy mildew of 500 F1 OPV progenies 3- Field trial of F1 crosses (het grouping)		1- 10 Crosses for OPV Early 2- Evaluation in observation trial/screening for downy mildew of 250 F1 OPV progenies 3- Field trial of F1 crosses (het grouping)	

The working group is currently witnessing significant improvement in capacity development, which aligns with the evolving needs of breeding programs. This involves having access to innovative technologies that are essential for advancing the methodologies and outcomes. Additionally, the distribution of shared responsibilities has significantly improved the modernization of NARES programs. This modernization effort not only improves the technical capabilities but also strengthens the collaborative relationship.

Additionally, the connection to a global network has been invaluable, enabling the working group to interact with experts across various fields. This interaction has resulted in a rich exchange of knowledge and innovative practices, hence increasing effectiveness and reach.

There has also been a notable increase in funding for NARES programs. This increase in resources is tailored to each program's role within the network, ensuring that funding is strategic and impactful, and allowing for more robust and well-supported research initiatives.

Impact and moving ahead

The implications of the DCP crop work groups efforts are profound. New varieties will boost yields, improve nutritional value, and increase resilience to environmental challenges, thereby ensuring more reliable food sources and increased incomes for small-scale farmers.

By involving a wider range of stakeholders and focusing on shared goals, the shared breeding program strengthens agricultural communities to meet the challenges of climate, gender inequality and market changes.

The shared breeding pipeline approach provides a model for other crops and regions in a CGIAR-NARES crop improvement approach. It demonstrates that with the right collaboration, it is possible to make significant advancements in crop development, even under the most difficult conditions.

"This strategy is effective because it enables all the programs within the network to benefit from the advantages such as the availability of equipment and experience, under regional coordination. Previously, each program managed independently, developing its own varieties. This often led to a variation in breeding schemes at the regional level, which sometimes caused confusion. The significant improvement with this new approach is that it is based on an analysis that includes selection indices for preferred traits, which were absent in the previous strategy," remarks Dr Armel Rouamba from INERA, Burkina Faso.

Pipeline showing a short-duration OPV for Sahel zones (SD-OPV-Sudan-2) at the crossing block managed by the Lake Chad Research Institute, Maiduguri, Nigeria. This block represents 50% of the total crossing. Photo: Maryam Dawud/ the Lake Chad Research Institute

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