Adapting agriculture to climate change: collecting, protecting and preparing crop wild relatives

Crop Wild Relatives Project

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(Crop Wild Relatives Project)

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Any opinions and conclusions expressed in the report are those of the consultant team and do not necessarily reflect the views the Global Crop Diversity Trust, Millennium Seed Bank, Kew Royal Botanical Gardens, their partners and donor in the Crop Wild Relatives Project

https://www.cwrdiversity.org/

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Executive summary

Collecting and processing

"Adapting Agriculture to Climate Change: Collecting, Protecting and Preparing Crop Wild Relatives" – the CWR Project – has as its first objectives to collect important species of crop wild relatives and to ensure their long-term conservation. Key partners of the Global Crop Diversity Trust - Crop Trust - in collecting and conservation are the Millennium Seed Bank (MSB) of Royal Botanic Gardens, Kew and national genebanks in 25 countries. Together, they were largely successful in collecting and processing the CWR target taxa; with thousands of unique new accessions now conserved and safely duplicated in national and international genebanks worldwide. MSB through the CWR Project enhanced the technical and institutional capacity of the national genebanks, but also bolstered their engagement with local partners and government institutions in this work. For the future, building upon and consolidating this early effort, most national genebanks will remain dependent upon global initiatives to support further collecting, conservation and use of these genetic resources.

Pre-breeding

The third objective of the CWR Project is to facilitate the use of CWR in breeding new, improved crop varieties. It is the first major investment supporting the use of CWR across multiple genepools to generate knowledge and materials contributing to adaptation to climate change, and the first ever to capitalise on previous experience to develop pre-breeding CWR-introgressed materials. Its nineteen pre-breeding projects have produced very impressive results regarding pre-breeding material, knowledge, and partnerships, and especially in developing material tolerant to abiotic stresses. A key asset is the partnerships of CGIAR Centers and advanced research centres with national breeding programmes across the world; we recommend that these partnerships continue in future initiatives. Project agreements stipulate that the produced materials and information become accessible in the multilateral system (MLS), to emphasise the importance of availability of germplasm materials and associated information from pre-breeding projects for end-users. Projects that have already concluded have made advanced materials available to genebanks for maintenance and future use. Most projects are yet to be concluded. We recommend Crop Trust reinforces this position on sharing materials and information and ensure on this commitment. To promote global awareness on the newly available materials and information, we recommend Crop Trust and partners prepare a special issue of a reputable scientific journal on CWR pre-breeding for climate change adaptation and organise meetings for pre-breeders and breeders to exchange their experience in working with CWR species.

Information management

Assessments and upgrades have been implemented in the Information Management Component of the CWR Project in a straightforward fashion and have enhanced the basic information management infrastructure of a significant group of national genebanks. Given that national genebanks prioritised information management as critical for the institutional development of their organisation and responding to the effective implementation by Crop Trust, we consider this component impactful and highly relevant, and recommend its continuation and embedding in future initiatives.

Capacity development

Capacity development is a cross-cutting activity across the technical components of the CWR Project; consequently, it had no dedicated capacity development staff or budget. Capacity development was implemented through the technical components, for example through training workshops, and coaching by project leaders; these have been relevant and impactful to global goals.

A key capacity development activity within the Pre-Breeding Component are the 12 Postdocs and more than 50 post-graduate (PhD and MSc) students. Through their research they increased the efficiency of the pre-breeding projects. These students plan to continue working in plant breeding and associated research; this illustrates the project's contribution to sustainability in terms of human resources for

pre-breeding. We recommended to continue supporting and training post-graduate students as part of future pre-breeding activities.

We observe a distinction between capacity development contributing to the global goals and capacity development being tailored to partners' demands, in turn, with the embedding of capacity development in the global frame, such tailoring results in a limited relevance to national partners. For future initiatives of the Crop Trust, we recommend including a specific capacity development strategy and component, with dedicated staff and budget. In its activities from the onset, we recommend it assesses in a systematic manner the capacities of partners, and subsequently engages with partners in a tailored approach of strengthening human, technical and institutional capacities relevant to the agreed global goals, but also national aspirations.

A proposed intervention for future initiatives is to promote peer-to-peer linkages, as separate from project management interactions, driven by partners demands and interests. Another way for Crop Trust to promote such interactions is to establish communities of practice, which could operate as virtual global and regional platforms; efficiency in this sharing and learning can be gained by making use of modern digital applications. Such communities of practice could also serve as global platforms for interactions between partners working on similar highly technical topics. They would foster efficiency, progress and subsequently impact in the assembly of individual projects into the global initiative and its global goals.

Collaboration

In managing the CWR Project, the Crop Trust developed strong relationships with a large group of globally and nationally operating stakeholders in collecting, pre-breeding, and genebank information management, it developed insights in capabilities of partners and implementers, while also obtaining intelligence on specific country and institutional frameworks and challenges. The partnership of the Crop Trust with MSB has been effective, applying its globally recognised expertise and established network for collecting and conserving wild plants to the field of CWR collecting and conservation. Partners considered their interactions with the Crop Trust team as highly professional, flexible, and willing to help whenever requested. The CWR Project's efficient leadership and collaboration at global and national levels has been crucial to the effective delivery of the partners' agreed outputs.

CWR Project in the context of the multilateral system

The CWR Project, through the partnership with national genebanks, provided a standardised process of scientifically sound and internationally accepted methods of CWR collecting, taxonomic identification, documentation, seed processing, *ex situ* conservation in national genebanks, and its safety duplication in international genebanks using the standard material transfer agreement (SMTA) for formalized access and benefit sharing through the MLS. Crop Trust and its partners have been effective and reached impact in terms of collecting and conservation of CWR accessions. We consider that perhaps the greatest - but least recognized - achievement of the CWR Project is the opportunity it provides for the partner countries to participate in and contribute to the MLS and thereby secure the long-term conservation of these materials by depositing them in multiple genebanks within the system. While the recognition and eventual monetary and non-monetary benefits of their contributions may not become apparent until later, the fact that these genebanks have now actively and purposefully contributed in the MLS, is an important threshold event from a policy standpoint and a significant national achievement. As a global organisation contributing to and being embedded in the MLS, we recommend that the Crop Trust reallocates some of the CWR Project's communications resources toward the national partner institutions and staff, continuously informing and raising their awareness about the project's goals and methods, in both the national and global contexts.

Future directions

For the project to have lasting impact, it is essential to raise awareness among national policy and decision makers and to start seriously considering CWR as essential in the conservation of plant genetic resources for food and agriculture (PGRFA). We consider that Crop Trust, with its insights and intelligence, coupled with its admirable communication capabilities, plays and should continue to play a constructive and supportive role in this space. Realistically, limited financial resources are available for this work in most countries; this provides a justification for continued global investments in conjunction with the MLS.

The exploration of CWR taxa through pre-breeding is new, implementing a structured approach combining a broad range of CWR species and abiotic stresses in a setting of climate change adaptation is even newer. As a result, Crop Trust and its partners today have a good knowledge about the opportunities and limitations of such an effort. Looking forward, we recommend the Crop Trust to continue its dialogue with donors, CGIAR Centers, advanced research centres, national genebanks and breeding programme; together they should identify and assess capacity in human resources, knowledge and facilities available, and assess partners' institutional commitment to continue implementing the CWR Projects' achievements in pre-breeding. A critical feature that supports the design of a next initiative including pre-breeding, is that Crop Trust and partners assess the continuum in which pre-breeding operates, the arrangement of genebanks, pre-breeding, breeding, including other disciplines, and seed systems, to select and prioritize investments. The assessment should examine the workplans and budgets for pre-breeding as well as business plans including pre-breeding within larger frameworks of crop improvement and seed systems. We conclude that the CWR Project has developed an initial and firm basis in its contribution through pre-breeding, which requires continuation and further support to result in practical outcomes—seed of adapted varieties including traits sourced from CWR—that will allow farmers to benefit from the globally available CWR. This will support farmers to counter the climate change challenges they are facing with newly adapted varieties.

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Acknowledgement

Conducting a review of a project the size of the Crop Wild Relatives Project in a participatory and inclusive manner is a complex exercise, as we actively listened and sought to give voice to partners in more than 50 countries. Moreover, we engaged in an interactive learning process with staff of the Global Crop Diversity Trust – Crop Trust - in Bonn, Germany and Millennium Seed Bank – MSB - of Key Royal Botanical Gardens, Wakehurst, UK. We appreciate the commitment to the process, patience and professionalism of Hannes Dempewolf, Nelissa Jamora, Benjamin Kilian, Matija Obreza, Beri Bonglim, Nora Castañeda-Álvarez, Luigi Guarino, Dagny Poser and colleagues at Crop Trust, and Ruth Eastwood, Christopher Cockel and colleagues at MSB on this journey. We consulted the partners of the CWR Project through a total of seven e-surveys; some partners even responded to two or more of these surveys; the time and perspectives they shared contributed significantly to the insights generated. Various partners engaged in phone and video conference conversations. During country visits to 10 countries, partners in the CWR Project received review team members with hospitality and openly shared their stories, insights and lessons learnt, they engaged in interactive workshops and showed us their facilities. We would like to thank staff of the following organizations for receiving us: Agricultural Plant Genetic Resources Conservation and Research Center (APGRC), Wad Medani, Sudan; Departamento Nacional de Recursos Fitogenéticos (DENAREF), Instituto Nacional de Investigaciones Agropecuarias (INIAP), Quito; Genetic Resources Research Institute (GeRRI), Kenya Agriculture, and Livestock Research Organization (KALRO), Nairobi, Kenya; Instituto de Investigaciones Agropecuarias (INIA), National Genetic Resources Programme, INIA-La Platina, Santiago; and INIA-Intihuasi Base Genebank (BBS), Vicuña, Chile; International Center for Agricultural Research in Dry Areas (ICARDA, Rabat, Morocco; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, and Nairobi, Kenya; International Institute for Tropical Agriculture (IITA), Kano, Nigeria; International Potato Center (CIP), Lima, Peru; Kenya Agriculture, and Livestock Research Organization (KALRO), Food and Crops Research Institute, Kisii, Kenya; Maseno University, Maseno, Kenya; National Agricultural Genetic Resource Centre (NAGRC), Kathmandu; National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan; Plant Genetic Resource Programme (PGRP), Bio-resources Conservation Institute (BCI), Islamabad, Pakistan; Plant Genetic Resources Centre (PGRC), National Agricultural Research Organisation (NARO), Entebbe, Uganda; United States Department of Agriculture, USDA, Madison, USA; Universitat Politècnica de València, València, Spain and University of Sargodha, Sargodha, Pakistan. We hope that the constructive and thoughtful contributions shared are reflected in the report, that it will be adequate to inform the Crop Trust, MSB and its donor on the effectiveness, efficiency, impact, relevance and sustainability of the project, and will assist them in better shaping future work in the field of plant genetic resources, crop wild relatives and climate change adaptation.

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Acronyms

BPAT	Breeding Programme Assessment Tool
CGIAR	Consultative Group on International Agricultural Research
CIP	International Potato Center
CoP	Community of Practice
Crop Trust	Global Crop Diversity Trust
CRP	CGIAR Research Programme
CWR	Crop Wild Relatives
EMBRAPA	Brazilian Enterprise for Agricultural Research
FGD	Focus Group Discussion
GOAL	Genebank Operations and Advanced Learning
GOM	General Operational Manuals
GPA	Global Plan of Action
GRIN	Germplasm Resource Information Network
ICARDA	International Center for Agricultural Research in Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute for Tropical Agriculture
IT	Information Technology
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
MLS	Multilateral System
MSB	Millennium Seed Bank
PGRFA	Plant Genetic Resources for Food and Agriculture
RGB	Royal Botanic Gardens
SMTA	Standard Material Transfer Agreement
SOP	Standard Operational Plans
USDA	United States Department for Agriculture

1. Introduction

1.1 The CWR Project

The objectives of the "Adapting Agriculture to Climate Change: Collecting, Protecting and Preparing Crop Wild Relatives" - CWR Project - are to collect important species of crop wild relatives, ensure their long-term conservation, and facilitate their use in breeding new, improved crops. This 10-year project was launched in 2011 with US$50 million in funding from the Government of Norway. The project is managed by the Global Crop Diversity Trust - Crop Trust – in collaboration with the Millennium Seed Bank (MSB) at Royal Botanic Gardens, Kew. The CWR Project is implemented in partnership with national and international genebanks and plant breeding programmes around the world.

The structure of the CWR Project is visualized in Figure 1 and has the following technical components:

- Prioritisation of CWR: Crop Trust and partners developed a global CWR inventory, an occurrence dataset, and gap analyses detailing where CWR species have not been collected before. This initial step identified and prioritised which CWR to collect and where to collect, based on a global dataset of past collections and expert evaluations; it further includes information on ease of use in breeding for each species.
- Collecting and conserving of CWR: national partners, e.g. national genebanks, organized the collecting of priority CWR in their country. The collected CWR are conserved in *ex situ* collections to safeguard their genetic diversity from extinction and to ensure their continued availability for breeding. All CWR collected are conserved in the national collections of the country of origin, the Millennium Seed Bank, the appropriate CGIAR international collection, and/or the Svalbard Global Seed Vault.
- Pre-breeding using CWR: a wide range of activities are implemented that aim to isolate desired genetic traits (e.g. tolerance to drought, heat and salinity; resistance to pests and diseases) in CWR species and introduce them into breeding lines that are more readily crossable with crop varieties.
- Information Management: data about the material needs to be of as high quality, and as easily accessible, as the seeds and breeding material themselves; the project is working to build information systems to help manage and search crop collections globally.

In the component for the collecting and conservation, Crop Trust and MSB work closely together. The collecting is conducted by the appropriate national institution(s) which, in most cases, is the national genebank. The seed samples collected are cleaned, dried and stored in the national genebank. As stipulated under the collecting agreement, a portion of each sample is transferred under a Standard Material Transfer Agreement (SMTA) to MSB for safety duplication storage and distribution to pre-breeding programmes and other genebanks and users. At the MSB, the seed samples are verified for the species identification and documented for quality and quantity. Table 1 shares the 25 countries in which collection activities have taken place and the associated crops for which CWRs were identified and targeted for collection.

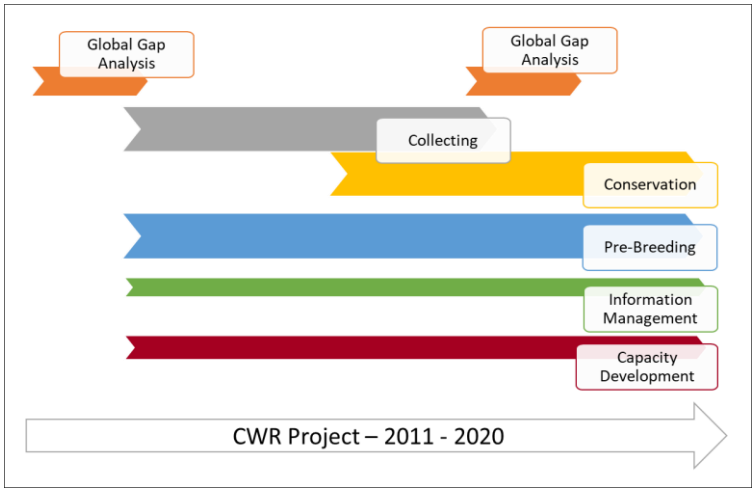

Figure 1: CWR Project and its components

Table 1: Summary of collection activities in the CWR Project

Country	Crops / genepools
Armenia	alfalfa, apple, barley, carrot, grass pea, oat, pearl millet, pea, rye, sorghum, vetch, wheat
Azerbaijan	alfalfa, apple, barley, carrot, grass pea, lentil, oat, pea, pearl millet, rye, sorghum, vetch, wheat
Brazil	finger millet, potato, rice, sweet potato
Chile	alfalfa, barley, finger millet, potato
Costa Rica	common bean, lima bean, potato, rice
Cyprus	alfalfa, barley, carrot, faba bean, grass pea, lentil, oat, vetch, wheat
Ecuador	eggplant, lima bean, potato, rice, sweet potato
El Salvador	common bean
Ethiopia	cowpea, eggplant, finger millet, lentil, oats, pea, pearl millet, sorghum, vetch
Georgia	alfalfa, apple, carrot, barley, grass pea, lentil, oat, pea vetch, wheat
Ghana	eggplant, pearl millet, finger millet, sorghum, rice, cow pea and sweet potato
Guatemala	barley, common bean, eggplant, rice, potato, sweet potato,
Italy	alfalfa, carrot, barley, grass pea, pea, oat, vetch, wheat
Kenya	eggplant, finger millet, rice, pearl millet, sweet potato, vetch
Lebanon	alfalfa, barley, chickpea, grass pea, lentil, oat, pea, rye, vetch, wheat
Malaysia	banana, eggplant, pigeon pea, potato, rice, sorghum
Nepal	apple, banana, barley, alfalfa, carrot, cowpea, chickpea, eggplant, finger millet, grass pea, oat, pearl millet, pigeonpea, rice, sweet potato, vetch,
Nigeria	Bambara groundnut, eggplant, cowpea, finger millet, pearl millet, rice, sorghum, sweet potato
Pakistan	alfalfa, apple, barley, carrot, chickpea, eggplant, faba bean, finger millet, grass pea, lentil, oat, pearl millet, pigeon pea, rice, rye, sorghum, sweet potato, wheat
Peru	potato
Portugal	apple, alfalfa, barley, carrot, faba bean, grass pea, garden pea, lentil, oat, vetch
Spain	alfalfa, barley, bread wheat, faba bean, garden pea, grass pea, lentil, oat, rye
Sudan	cowpea, eggplant, finger millet, pearl millet, rice, sorghum
Uganda	cowpea, eggplant, finger millet, lentil, pearl millet, rice, sorghum, sweet potato, vetch
Vietnam	apple, aubergine, banana, cowpea, pigeonpea, rice, sweet potato

In 2015, Crop Trust started with partners in pre-breeding project for 19 crops. Each projects focuses on assessing CWR for traits especially relevant to climate change adaptation including resistance to biotic factors (diseases and pests) and tolerance to abiotic stress factors (e.g. drought, heat, salinity), and transferring these trait components into breeding materials. Subsequently, advanced materials with those new trait components from CWR are being tested and evaluated. The projects always involve a lead partner in a CGIAR Center or an advanced research organisation as subcontracting partners. The pre-breeding projects being supported by CWR Project are presented in Table 2.

The CWR Project engages in information management activities in support of national genebanks. It has assessed a total of 32 genebanks using the genebank IT assessment tool. Based on the assessments concluded, the CWR Project provided 21 genebanks with targeted support to improve their data management (Table 3). This component further engages in support to genebanks to transition to GRIN-Global, a genebank management and documentation system, and support the use of Genesys, a portal for genebanks to share their passport information on PGR, including CWR, with prospective users. A final activity in this component is the training of genebank staff in aspects of quality management through GOAL workshops.

Crop Trust thus works in the CWR Project in many different activities and with a wide range of partners in a total of 56 countries across all continents. At the heart of the practical and technical activities, primarily in low- and middle-income countries, is training and capacity building for partners on collecting and conserving CWR, the use of this diversity for crop improvement, and managing information on CWR. Capacity development activities are embedded within each of these components, thus, they are approached as a transversal component as illustrated in Figure 1.

Table 2: Overview of pre-breeding projects in the CWR Project

Crop	Project lead countries*	Subcontracting partner countries	Focus traits
alfalfa	Australia	Chile, China, Kazakhstan	drought tolerance
banana	Bioversity (Belgium)	IITA (Tanzania), Papua New Guinea	drought tolerance
barley	ICARDA (Morocco)	Germany, Morocco	drought, heat tolerance, disease and pest resistance
carrot	USA	Bangladesh, Pakistan	heat, salt and drought tolerance
chickpea	USA	Turkey	drought tolerance
cowpea	IITA (Nigeria)	Burkina Faso, Niger, Nigeria	drought and heat tolerance
common bean	CIAT (Colombia)	Colombia, Honduras	heat, drought, waterlogging and root rot resistance
eggplant	Spain	Cote d'Ivoire, Sri Lanka	Drought, waterlogging, heat tolerance, bacterial wilt resistance
finger millet	ICRISAT (Kenya)	Kenya	drought tolerance, resistance to blast and striga
grass pea	ICARDA (Morocco)	Morocco	heat tolerance, low toxicity, broomrape (Orobanche), powdery mildew
lentil	Canada	Spain	drought tolerance, Orobanche and *Stemphylium*-blight resistance
pearl millet	ICRISAT (India; Niger)	India, Niger	heat and terminal drought tolerance, blast resistance
pigeonpea	ICRISAT (India)	India	salinity tolerance, *Phytophthora* blight, and pod borer resistance, yield-related traits
potato	CIP (Peru)	Brazil, Peru, Uruguay	heat and drought tolerance, late blight and bacterial wilt resistance
rice	IRRI (the Philippines), USA		yield-related traits under drought
sorghum	Australia	Ethiopia	heat tolerance, water-use efficiency, rust, anthracnose, grain mold and downy mildew resistance
sunflower	Canada	Uganda	drought tolerance, early flowering, yield related traits
sweet potato	USA	Peru	heat tolerance
wheat (durum)	UK	Mexico, Morocco, India	yield potential, heat tolerance and drought tolerance, disease resistance

* In case of a CGIAR Center being the lead, it is indicated.

Table 3: Geographic distribution of information management activities in the CWR Project

Information management activity	Asia-Pacific	North Africa, Near East & Central Asia	Latin America	Sub-Saharan Africa	#
Assessment	CePaCT (Fiji)*, Malaysia, Philippines, Vietnam	Azerbaijan, Egypt, Lebanon, Morocco, Jordan, Tunisia, Turkey (Izmir & Ankara)	Bolivia, Chile, Colombia, CATIE (Costa Rica) *, Cuba, Ecuador, Guatemala, Mexico, Peru, Uruguay	Kenya, Nigeria, Rwanda, SPGRC (Zambia) *, Sudan, Uganda, Zambia	32
IT upgrade	CePaCT (Fiji)*, Philippines, Vietnam	Azerbaijan, Lebanon, Morocco, Jordan, Tunisia	Bolivia, Chile, Colombia, CATIE (Costa Rica) *, Cuba, Ecuador, Guatemala, Peru	Kenya, Nigeria, Rwanda, SPGRC (Zambia)*, Sudan, Uganda	21

* Regional genebanks: CePaCT: Centre for Pacific Crops and Trees of the South Pacific Community; CATIE: Centro Agronómico Tropical de Investigación y Enseñanza; SPGRC: SADC Plant Genetic Resources Centre

1.2 Results framework

The primary goal of the CWR Project is to contribute to climate change adaptation and enhance food and nutrition security; it aims to realise this through improved breeding processes and through farmers' use of improved varieties. These will result in increased productivity, increased farm incomes, and enhanced resilience to production shocks from climate change. The results framework with impact, outcomes, outputs, activities and partners is presented in Figure 2.

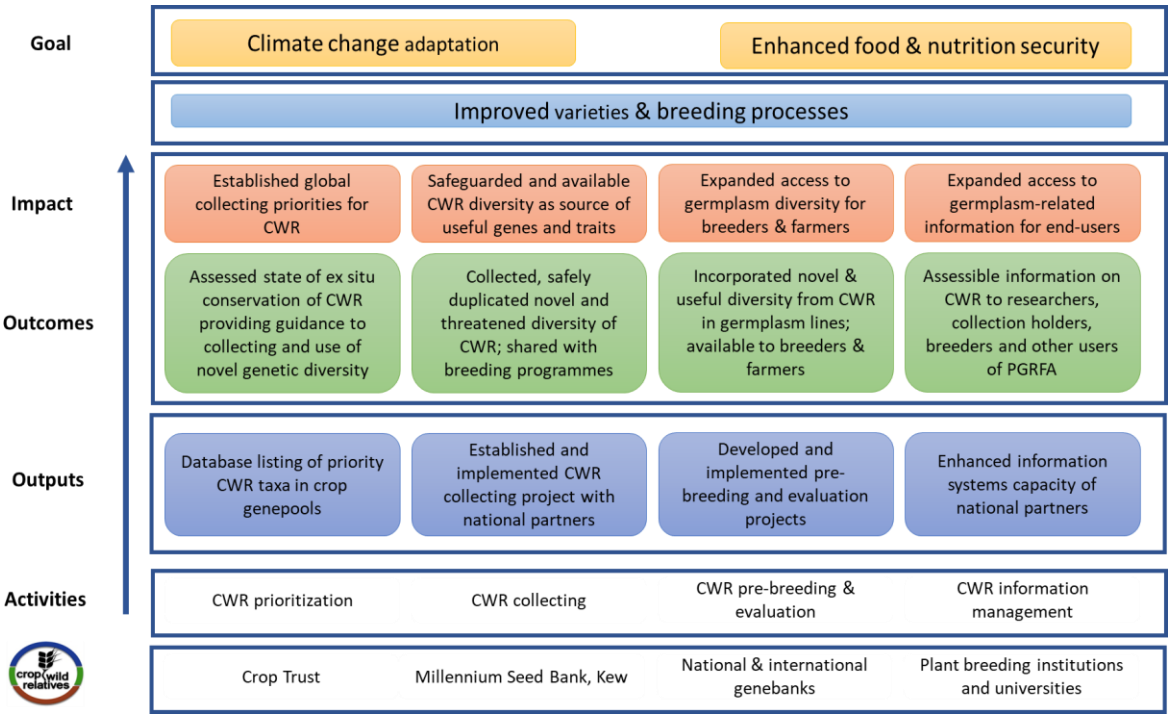

Figure 2: CWR Project Result Framework

2. Review methodology and process

The Crop Trust and its donor commissioned an external review of the activities of the CWR Project that have been implemented since the last project review in 2014. The main objective of CWR Project Review is to provide the CWR Project stakeholders with an independent assessment of the effectiveness, efficiency, impact, relevance and sustainability in the implementation of project activities. It focused on the project's collecting and processing, pre-breeding, capacity development, and information management activities.

The CWR Project review is guided in its method and structure by a globally well-recognized publication[1] that provides strategic and methodological standards and guidelines for structuring an evaluation in a manner that is participatory and inclusive. The method takes a 'learning approach'; consequently, we implemented the review not only in a reactive manner, looking at how activities in the past have resulted in impact, but we also took a proactive perspective, looking at improvements that can be made in the framework of the current or possible future project(s). The approach is participatory in a manner that the project team at the Crop Trust and MSB, but also a diversity of partners in the CWR Project, actively participated and contributed to the review process. Consequently, we have been able to reflect on the activities in the project but are also able to address strategic and operation topics

[1] Kusters, C., with S. van Vugt, S. Wigboldus, B. Williams and J. Woodhill (2011). Making evaluations matter: a practical guide for evaluators. Centre for Development Innovation, Wageningen http://www.mspguide.org/sites/default/files/resource/2011_guide_memguide.pdf

relevant to the way the Crop Trust, MSB and partners have implemented so far and are implementing the project. This approach allows us also to reflect on the way that the Crop Trust and its partners in the CWR Project operate in larger frameworks for the conservation and use of plant genetic resources for food and agriculture (PGRFA), crop wild relatives (CWR), and crop improvement for climate change adaptation. More details on the methodology, structure and steps are presented in Annex 1 and visualized in Annex 2.

The review was structured in five components, being: (a) collecting and processing; (b) pre-breeding; (c) information management; (d) capacity development in collecting and processing; and (e) capacity development in pre-breeding. Linked with the review's objective, five review questions have guided our work: (i) effectiveness: Is the CWR Project doing things right? (ii) efficiency: Is the CWR Project worthwhile? (iii) impact: What changes have resulted from the CWR Project? (iv) relevance: Is the CWR Project doing the right things? and (v) sustainability: What changes that resulted from the CWR Project will last?

For the collection of information and data, we developed and implemented seven tailored e-surveys for partners in collecting and processing, pre-breeding and information management. The surveys were sent to a total of more than 400 respondents. We received 230 responses. For all of them, we succeeded in getting are presentative coverage of countries and crops.

We visited Chile, Ecuador, Kenya, Morocco, India, Nepal, Nigeria, Pakistan, Peru and Spain, where we interacted with leadership of the partners organizations, project leaders, teams and their partners involved in the collecting, pre-breeding and information management activities, and visited genebanks, fields and laboratories. We interacted with partners in Sudan and Uganda as well via online communication channels.

We produced 7 e-survey briefs and 12 country briefs and used those as inputs for interpretation workshops. In a collaborative manner with the project team, we discussed observations and responses to each of the five review components. We produced five synthesis documents in which we elaborated narratives for each of the responses with references to information and resources gathered; the narratives with observations, achievements and recommendations are supported in evidence by our observations during country visits but also the insights gained through the e-surveys. Annex 3 presents the matrix with individual responses to the five research questions for each of the five components reviewed.

In an interpretation workshop with the project team, we transformed the collection of responses to the review questions into a framework of five groups review outcomes that provided us with the structure for the narrative that is presented in chapter 3 of this document. Annex 4 presents the structure including references to the components and research questions. For each of review outcomes, we elaborated gained informed insights on the achievements of the CWR Project and its challenges in the implementation; they also informed us in the formulation of recommendations for future actions.

3. CWR Project Review

A. Enhanced capacity in CWR conservation & use

3.1 Enhanced technical and institutional capacity

The capacity development activities in collecting and processing CWR have supported national genebanks with the resources and equipment essential for collecting taxa agreed upon and identified through the global gap analysis. MSB prepared for each country a collecting guide, which demonstrate to be a critical resource. The blue drum kit, which most genebanks received, included items that were considered useful in the collecting work.

MSB also provided expert technical information, tools, and training to partners for the identification, location, collection, preparation, documentation, and conservation of CWR. MSB further coordinated and processed shipments of CWR materials for further processing, testing, documentation, and ultimate conservation in MSB storage facilities. As recognized world authority in the field of plant taxonomy Royal Botanic Gardens (RGB), Kew, has been responsible in the CWR Project for providing taxonomic support. We consider that the responsibility of providing global technical taxonomic colleting support to a widespread group of national partners with widely differing strengths and weaknesses to be challenging. We realized that partners in some countries have enjoyed a longstanding collaboration with MSB that has strengthened their technical capacity and allowed them to be technically capable partners. Genebanks in other countries, which lacked such in-house capacity and did not have or avail themselves of MSB assistance, were less efficient and hampered in their collecting and reporting efforts. Several partners sought, and received, guidance and assistance from a taxonomist at their national herbarium. However, the local experts in several cases were not able to fully provide the level of taxonomic expertise required; this diminished the effectiveness of their collecting efforts. Nevertheless, the examples of challenges among some partners, we conclude that most of the partners have been largely successful in collecting and processing the CWR target taxa, and they consider their collective capacity to continue this work enhanced.

To ensure seed quality was retained in the shipment process, national partners conducted upon collecting materials, initial cleaning and drying of materials as per MSB training and instruction. MSB staff indicated that this was essential, and partners in most cases were successful in sending viable and quality seed samples to MSB. Even though MSB training addressed technical aspects of seed processing, that there is room for improved in terms of the capacity of some partner genebanks for processing and regeneration. Upon receipt at the materials, MSB further tested and processed the seed until it could be included in its seedbank and transferred for conservation to other genebanks. We conclude that the sum of the technical and institutional capacity development activities has been instrumental to reach the goal of collecting and processing of CWR accessions. Project partners in several countries visited expressed that this capacity turned from a previous weakness into a current and new strength, and we conclude that capacity development in collecting contributed to the logic and sequence of the project and responded to the demands of national partners.

The Pre-Breeding Component is structured in crop-based projects that each are coordinated by a project leader who is either based in a CGIAR center or advanced research organization. Project leaders collaborate with a range of (national) partners, often in middle- or low-income countries within National Agricultural Research Systems (NARS) or universities. The assumption underlying capacity development is that the project leaders enhance the capacity of the national partners in pre-breeding. We observed much variation in the ways that project leaders have assumed this responsibility; this depends on existing relationships in which they operate and, above all, on the capacities of national partners in pre-breeding and breeding. Power dynamics between the project leaders that mostly

operate in resource-richer organizations when compared with the conditions of their partners, influence this collaboration. We conclude that the assumed capacity development role of the project leaders is pertinent with these dynamics and relationships. We understand that the Crop Trust did not provide specific guidance to project leaders on the type of capacity development activities other than engaging in collaboration. We consider it therefore hard to assess the efficiency of this collaboration in terms of capacity development. Nevertheless, the CWR Project has strengthened and fostered regional and global partnerships in pre-breeding relevant to a wide diversity of crops and abiotic stresses. These partnerships should be considered an impact in the development of institutional capacity in the use of CWR in pre-breeding. The new exposure especially among national partners on the use of CWR in pre-breeding targeting abiotic stresses is considered highly relevant, but the capacity in this work among most is still fragile.

In the larger structure of the CWR Project, the Information Management Component was relatively small. The Crop Trust assessed the status of information management within national genebanks, supported genebanks through information technology (IT) upgrades, and co-organized and co-financed several regional training workshops on quality management of genebanks (GOAL workshops). We consider that the assessments and upgrades have been implemented in a straightforward fashion and have enhanced the basic information management infrastructure. We observed a majority of genebanks are aware, in the process to start or have started transitioning their genebank management and information management systems to the one provided by GRIN-Global. This is however a complex process, requiring sophisticated inputs in technical capacity and institutional development. We consider that the role that Crop Trust played through the CWR Project - and can continue to play in supporting this process - is impactful and highly relevant.

3.2 Enhanced human capacity

MSB organized training events that served the purpose of enhancing the capacity of national partners in CWR collecting and processing. National teams got experience within a relatively short time to plan and implement the collecting work. Project leaders took up and gained expertise in leadership roles; where appropriate, they were coached by MSB staff. The participation of the national genebanks have provided them with relevant experiences and insights. The collecting and processing activities in most of the countries were well managed, the collecting activities had national geographic coverage, produced good results, and generated the required technical reports. In some cases, partner genebanks elected to significantly extend the list of target taxa and species identified in the global gap analysis. The Crop Trust as leading partner of the CWR Project, even though indicating that budget disbursements are conditional to progress and achievement of milestones defined in project agreements, in our view, proved in our view to be constrained to intervene in a decisive manner, for example, by putting stricter resource-based repercussions to the partial contribution of outcomes. Genebanks and their germplasm collection are important within the MLS, and Crop Trust through its global position needs to have a long-term relationship with these genebanks. We learnt that Crop Trust needs to be delicate in managing this relationship, and therefore is challenged in its project management responsibility. Nevertheless, we realize that these challenges were few, most genebank teams made a great and largely successful effort to meet the project's collecting and processing goals. We realize that they were successful despite engaging in this type of work for a first time and confronting several daunting institutional challenges. In every case, however, the skills and experience acquired by the national partners has enhanced their technical and project management capacity and positions them for participation in future global initiatives involving CWR and/or PGRFA conservation.

The CWR Project includes more than thirty PhD students that through their research contribute to the pre-breeding projects. The CWR Project has financed, in a varying degree, their projects and/or grants. During the virtual focus group discussions (FGDs) part of the review, students shared an understanding

of the complexity of pre-breeding for abiotic stress factors. They shared their concerns about climate change; they provided both optimistic and pessimistic perspectives in ways that breeding will be able to contribute to global food security in the face of this challenge. We consider that the graduate students made significant contributions, particularly increasing the effectiveness and efficiency of the pre-breeding projects. During the FGDs, participants expressed that they consider themselves working in plant breeding and associated research. This aspiration illustrates that this type of activity significantly contributes to impact and sustainability in the field of human resources for pre-breeding. If future global projects are considered, we highly recommended to embed likewise PhD programmes.

3.3 Boundaries and approach to capacity development

By capacity development being positioned as instrumental to the goals, a linear and perceived top-down approach was taken. This approach also results from being positioned as cross-cutting activity across the other components within the CWR Project (see figure 1). Consequently, no dedicated or specialized capacity development and staff, budget and activities were available. Communication staff and budget were available, these were used for external communication, we observed that these to support or implement the cross-cutting component of capacity development. We observed that primarily technical staff, that were not necessarily professionals in communication and capacity development, implemented the capacity development activities.

Professional trainers were responsible for the series of trainings on CWR collecting and processing. The coaching activities offered by MSB staff for collecting and processing, and by project-leaders at CGIAR centres or advanced research organizations for pre-breeding, were embedded in project management activities. This mixing of capacity development and project management in our view may have jeopardized the relevance in terms of capacity development to the demands of national partners. Most of the partners were successful in collecting CWR and achieved their contributions to the pre-breeding work. We conclude that capacity development activities were implemented in a manner that was relevant and effective to the larger design and thus impact of the CWR Project.

The opportunity to promote and facilitate peer-to-peer linkages between country partners was present as staff from several countries participated in global or regional MSB training workshops. We consider that the design of the CWR Project was not structured to facilitating such linkages, MSB operated at global and central node within the project's framework, as such linkages between peers did not necessary contribute to the larger goal of collecting CWR materials. Likewise, and at national level, the design of the budget did not encourage partners to engage in capacity development activities. The genebank in Nepal organized training of partners in collecting CWR, and surprisingly this effort is unique in the CWR Project. In the Pre-Breeding Component, for reaching more effectiveness in capacity development, the Crop Trust, through its global role interacting with project leaders could have supported and facilitated interactions between projects creating more opportunities for interactions among pre-breeding projects. In the design of this component, Crop Trust operated as central node and positioned the project leaders in a likewise central position. We consider that these features of the design of the CWR Project, have influenced and limited the peer-to-peer or joint capacity development opportunities. Capacity development activities contributed to project goals as fostered by MSB, Crop Trust and pre-breeding project leaders, but we consider that there was no clear focus which resulted in a limited effectiveness and efficiency in capacity development. These observations illustrate the absence of a capacity development strategy within the CWR Project.

Based on these observations, we recommend to structure in future programmes the support to national partners through targeted regional capacity development platforms, and not only through central communication between central nodes (Crop Trust, MSB or project leaders) and partners in collecting and pre-breeding. Rather we encourage to include peer-to-peer or lateral linkages within

the design. Capacity development platforms can facilitate peer-to-peer coaching services in the field of genebank management, information management, quality management, and pre-breeding. Opportunities for such did emerge in the MSB training and GOAL workshops, though neither MSB nor Crop Trust grasped the opportunity to promote and facilitate such interactions. Taking a more proactive role should be considered part of Crop Trust's future capacity development strategies. Communities of Practice as capacity development instruments can increase effectiveness and efficiency making use of the currently available digital applications, e.g. WhatsApp, MS Teams, Twistapp or Slack. With an increased entry of young professionals among its partners, these applications will reach more easily as assumed their potential, while also make genebank and associated work more contemporary and thus attractive to this new generation of professionals.

B. Increased knowledge and understanding of CWR

3.3 Enhanced knowledge and understanding among partners

Through the participation in training workshops and experience in CWR collecting, genebank staff in participating countries enhanced their awareness unquestionably increased their understanding of the current status and threats of CWR. Almost all project leaders and senior members participating in an e-survey, expressed their concern that CWR species are significantly threatened or endangered in their natural habitats. We consider that the CWR Project succeeded in putting CWR as well as their threats "on the map" of national PGRFA research and conservation agendas.

One of the first steps in pre-breeding is to study and understand genetic diversity. Project leaders of pre-breeding projects indicated in the e-survey that there is a reasonable basis of information regarding the genetic diversity of the CWR species they are working with. Partners indicated that it is essential to increase their knowledge about the genepool distribution and the genetic diversity of the CWR. During country visits, we got an understanding of the impact of the individual projects.

- At ICRISAT, the project leaders and partners mentioned that to them this is the first systematic effort to utilize CWR for pre-breeding of pearl millet, finger millet and pigeon pea. The implementation of the projects allowed increased understanding of the genetic variability in CWR for those crops; consequently, this strengthened the development of CWR introgressed lines with higher level of tolerance to abiotic and resistance to biotic stresses.
- The Universitat Politècnica de València broadened the genetic base of the eggplant while it increased the understanding diversity through the development of lines with traits introgressed from CWR. These lines are the first ones in the world and thereby become global reference material for pre-breeding.
- The main impact of the sweet potato pre-breeding project managed in a collaboration between CIP, University of North Carolina and national partners in various countries is the understanding of the crossability pattern of the CWR species. It is the first time ever that such a complete study was executed for sweet potato relatives; more than 19,800 crosses were made involving nine of the 14 species selected for the CWR Project.

We consider enhancement of the understanding of the genetic diversity present in the CWR species a major impact of the Pre-Breeding Component. To the best of our knowledge, this is the first time ever a global initiative focussed for a wide diversity of major and minor food crops on the use of CWR species targeting abiotic and biotic stresses. A question Crop Trust should consider in the continuation of this type of programmes is how much understanding and support is needed to contribute to an efficient and effective use of CWR species in pre-breeding for tolerance to drought, heat, flooding and/or salinity and/or resistance for pest and diseases among crops in agricultural systems affected by climate change.

The focus of pre-breeding is to identify and transfer useful traits from CWR that could contribute to the development future varieties that are adapted climate change. In order to achieve that, pre-

breeders and breeders need to be convinced about this opportunity. Some projects we visited provide clear evidence.

- In India, data on pigeon pea are showing that CWR introgressed lines have acceptable agronomic traits, salinity tolerance and *Phytophthora* blight resistance; national partners are starting to use these lines in their breeding programmes.
- In Peru, the NGO Yanapai evaluated CWR introgressed potato clones and selected five for further evaluation.

Based on these visits, we learnt that a lot of information is just coming out of the experiments being carried out; but this information is not necessarily being shared with the larger community of breeders or published yet. As the CWR Project reaches its conclusion, we recommend Crop Trust and partners prepare a special issue of an international reputable and widely read scientific journal on CWR pre-breeding for climate change adaptation; this special issue should share understanding CWR genetic diversity, pre-breeding experiences, data and materials. To raise breeders' awareness on CWR and availability of materials and data, we recommend that within the remaining time of the project, resources permitting, Crop Trust organizes meetings for pre-breeders and breeders to exchange their experience in working with CWR species.

Most partners in pre-breeding projects highlighted that using CWR and pre-breeding for tolerance to abiotic stress factors was a new experience for them. In the e-survey, almost all partners indicated that pre-breeding using CWR became more important in their organization because of the CWR Project. Initial exposure among national partners can be considered highly relevant, enhancing awareness and developing capacity for using CWR in breeding. They confirmed the pre-competitive nature of the pre-breeding work. With pre-competitive we mean that the activities by default are implemented by public research organizations; no private and therefore conditional investments are made in the space; the results of the research are now made available under specific arrangement (licenses) to few private seed companies. In the projects visited for the review, only one case was observed where private sector involvement was encountered. In the case of pearl millet in India, three private seed companies demonstrated an interest in materials with resistance to a biotic stress that is important in an area with more intensive and commercial pearl millet production, e.g. where the companies sell their hybrids. This is not an area with smallholder farmers and vulnerable to climate change. For other projects, we interacted with partners where pre-breeding takes place in a context of food crops with hardly any private seed companies investing in plant breeding (e.g. cowpea, pigeon pea, barley, finger millet and sweet potato). Thus, breeding of these crops by default happens in public organizations. In two cases where we visited partners engaged in pre-breeding of vegetable crops (carrot and eggplant), using CWR for addressing abiotic stress factors is undertaken as pre-competitive research activity respectively by United States Department of Agriculture (USDA)-Madison and Universitat Politècnica de València (Spain); advanced materials become available both to public (including NARS) and also private sector during the evaluation of more advanced materials. We conclude that by including the Pre-Breeding Component in the CWR Project and structuring this component in multiple crop-based projects, Crop Trust has raised awareness, fostered collaboration and enhanced capacity in pre-breeding using CWR.

An achievement of the GOAL workshops part of the Information Management Component is an initial awareness among national genebank staff in especially Asian countries on the development and use of Standard Operational Plans (SOPs) and General Operational Manuals (GOMs). We consider that this knowledge and understanding is preliminary; for quality management to become practice and routine, we recommend a more structured process in capacity development of and engagement with national genebanks. We consider that GOAL workshops would be better structured and resulting in more impact if embedded in a strategy for capacity development in genebank management. Despite the limited size of the Information Management Component, genebank teams identified during interactive

workshops information management as strategic in enhancing their capacity in the conservation and use of CWR, which justifies the current engagement and supports continuation and future investments in this field.

3.5 Awareness among decision-makers, policy-makers and the general public

By engaging partners in a pioneering effort to collect and conserve crop wild relatives, the CWR Project not only enhanced the countries' technical and institutional capacity to study and conserve these unique genetic resources, but also to engage and inform their local partners, governments and the general public about their existence and importance. The CWR Project generated excitement and enthusiasm amongst national partners; this contributed significantly to their dedication, effectiveness, ownership and persistence in the implementation of the collecting and processing activities.

- In Chile, this enthusiasm spilled over into scientific publications and presentations at professional meetings as well as awareness-raising talks to popular audiences in rural communities near where the collecting activities were taking place.
- The genebank in Pakistan organized a national gathering involving scientists, conservation professionals and local government representatives raising the awareness on the value CWR conservation and use.
- In Uganda, numerous workshops were organized in rural communities to teach local villagers about CWR as part of the country's prior informed consent requirements for collection.

The increased number and enhanced capacity of national partners working with CWR, together with the publicity and public interest that the CWR Project generated at national and global levels, have introduced the importance and value of CWRs into the public perception. The incipient recognition of CWR at the national level, including conservationists and their public and private organizations, represents the foundation of more widespread awareness and interest that will eventually culminate in national support for this work. However, at this early stage of national CWR research, many partners still depend upon global actions to support further collecting, conservation and public awareness of these unique genetic resources.

During country visits, we learnt that there are opportunities to influence the CWR conservation at different levels of decision making, including higher-level national authorities. It is a pity that the collecting and processing projects have been concluded, as the Crop Trust and the Project's strength in communication could have created support to national genebanks in the design and implementation of communication strategies targeting decision makers to invest in CWR conservation. As reflected in the e-survey, among those most knowledgeable about CWR in the partner countries, i.e., CWR Project leaders and genebank managers, their overwhelming majority agreed that CWRs should be publicized and more widely recognized as national treasures worth conserving; and believed that CWRs provide significant opportunities for national plant breeders to develop new, improved crop varieties that are better adapted and more resilient to climate change.

When we consulted the senior leaders of participating CGIAR Centers, we learnt about the effect of the CWR Project at the institutional level. To highlight the importance of pre-breeding, the DG of one of the Centres shared he included a sub-programme on pre-breeding in the Center's working program structure. Senior leadership of another Center emphasized that the CWR species provide critical and alternative inputs to develop new varieties adapted to the effects of climate change. Leadership in both CGIAR Centers are motivated to make the case for the CGIAR Research Programs (CRPs) to pay attention to this subject and allocate resources for its implementation within the CGIAR system.

The knowledge, data, and materials generated through the implementation of the different CWR Projects are available to the Crop Trust and partners. We recommend for Crop Trust, using its communication assets and voice as global institution, beyond its communication through the CWR-

website, to support in a targeted manner its pre-breeding partners in the concluding years of the CWR Project to design and implement communication strategies informing and convincing decision makers to invest in CWR pre-breeding. The efforts dedicated to this activity need to be targeted at both institutional and national levels, where opportunities seem to be present to influence decision makers, including higher-level national authorities.

C. Enhanced collaboration in conservation & use of CWR

3.6 Enhanced collaboration in CWR collecting

Through the CWR Project, genebanks have established or reinforced partnerships with national or university herbaria; their taxonomists have participated in collecting missions and have taken up responsibility in the verification of species in the field and post-mission in the laboratories. During all country visits, we learnt from the genebank teams that these partnerships were new to most of them and are highly appreciated. The teams indicated the development of partnerships with various research, forestry, nature conservation, local government and community bodies, e.g. community seed banks, as critical for their CWR collection work.

The Global Gap Analysis Component of the CWR Project informed the selection of countries and the definition and prioritization of target taxa to be collected in each country. In their interactions with us, some of the national partners, particularly those involved in the collecting activities, questioned the selection of the target taxa and indicated that they were not consulted in that process. Those same partners felt that the country-specific collecting guides prepared for them by MSB (using the Global Gap Analysis database) likewise lacked occurrence data pertinent to their country and obliged them to compile supplemental datasets and produce their own, more accurate occurrence and probability maps to guide their collecting efforts. The comments about the Global Gap Analysis received from those partners, which were corroborated by the responses to global e-survey, made it clear that significant differences exist between the Global Gap Analysis and what we would like to call a “National Gap Reality”. While recognizing that the Crop Trust did in fact involve the national partners in the development of their sub-grant Project Agreements, including the selection of the target species, we conclude that the persistent perception amongst some of the partners that the project’s collecting goals and target taxa were imposed rather than mutually developed must derive from a communication problem. Perhaps the sub-grants were negotiated with senior managers of project’s national partners who did not necessarily consult, involve, or adequately inform the technical staff who would be implementing and eventually reporting on the project’s activities. This apparent breakdown in communication between the global CWR Project’s managers and its national implementers could be the source of some partners’ discomfort with what they perceive as a top-down execution of a global agenda with little regard for, or understanding of, national needs and priorities. Although this unfortunate perception is certainly not shared by the majority of national partners, we believe that it nonetheless merits the attention of the project team. We recommend that the Crop Trust and MSB be more strategic in their communication with partners, involve them more actively in the planning of gap analysis-based activities that will take place in their countries, and direct some of the Crop Trust’s ample communications talents toward the national partner institutions, continuously informing and raising their awareness about the project’s goals and methods, in both the national and global contexts. These critical observations notwithstanding, we conclude that the vast majority of the national partners demonstrated a strong interest in, commitment to, and enthusiasm for the CWR Project and they delivered the results expected.

During the country visits, partners shared that the well-known divergent global policy positions between Ministry of Agriculture (based on the ITPGRFA) and Ministry of Environment (based on the Convention on Biological Diversity) often jeopardised their collecting and conservation efforts, at both national and local levels. On the topic of access and benefit sharing, some partners reiterated their

concerns about the deficiency of tangible benefit-sharing in the MLS. We understand that, in the logic of the project, partner countries collect and make available their CWR, and then wonder "Where are the pre-breeding opportunities for us? Where is the benefit sharing through the MLS?" There appears to be little or no connection between those responsible for collecting and those engaged in pre-breeding activities, and this has been confusing to the partners of both components. The CWR Project has inevitably created some expectations in this regard, and these concerns continue to create challenges for the national and international transfer of materials. In more than one instance, we observed that those lingering concerns have hampered or even stymied the effectiveness of the CWR Project.

We recognize that it is problematic for a globally operating body to intervene in project-relevant but sensitive domestic affairs especially when access is concerned. The Crop Trust has, where appropriate, supported sharing information and resources with national partners in addressing divergent perspectives to access. As a global organisation contributing to and being embedded in the MLS, Crop Trust could provide information and resources to national partners and decision-makers to communicate the design and context of the MLS and inform them about what their benefits through MLS participation are. More explicitly, Crop Trust could use its strength in communication to share and articulate these ongoing concerns and benefits globally or even nationally, if requested.

3.7 Collaboration in pre-breeding for climate change adaptation using CWR

Crop Trust opted in the design of the Pre-Breeding Component for a wide diversity of crops. This design is consistent with the global nature of the CWR Project and its embedding within the MLS. With this choice, Crop Trust created opportunities for pre-breeding investments in both major and minor food crops, embedded either in CGIAR crop improvement programmes or in advanced research organizations working with vegetables, fruit, fodder, leguminous and oilseed crops. This approach has resulted in an awareness, initial capacity and fostered collaboration for 19 different crops in pre-breeding to tackle aspects of climate change adaptation using CWR, while operating in a diversity of institutional settings and networks of partners. This achievement can be considered a foundation in the global adaptation effort.

An operational breeding programme effectively uses the available plant genetic resources when linkages among genebank managers, pre-breeders, breeders, and other disciplines are strong and the development of improved materials is a continuum. We observed during the visits that several CWR pre-breeding projects did not forge this continuum; the reasons for these vary from crop to crop and institution to institution. As they house all functions, when CGIAR Centers were leading pre-breeding projects, we observed the involvement and active participation of genebank managers, pre-breeders and breeders, and other disciplines, which increased the effectiveness and potential impact of the pre-breeding projects. In the case of advanced research organisations, and universities leading the projects, such a continuum requires more attention. The degree to which pre-breeding projects are linked with breeding programmes and have a functional delivery channel, e.g. linkage with seed companies or other seed system stakeholders, depends largely on the crop, the economics of the crop, and the structure and functioning of its seed system. Considering future investments, the Crop Trust should consider the relevance of having such a continuum in-house or in-partnerships to select collaborators and to ensure effectiveness of the CWR type of pre-breeding projects.

One of the best ways to sustain the results of this project is through the involvement of public and private partners as early as possible in the pre-breeding work. For the public partners, pre-breeding is a logical process, but to interest the private sector requires a well-designed and convincing strategy, which relies on achievements, e.g. improved materials that are attractive and will turn profitable.

Table 4: Provisional outlook on the results of collecting and processing work completed by partners in the eight countries focused on during the CWR Project review, 2018/2019 [a]

Country & targeted genepools	Collected genepools	Targeted species by country	Collected species by country	Targeted populations	Collected populations	Populations received at MSB
Chile alfalfa, barley, finger millet, potato	all	18	16	180	154	156
Ecuador [b] eggplant, lima bean, potato, rice, sweet potato	all	18	17	320	164	pending processing
Kenya eggplant, finger millet, rice, pearl millet, sweet potato, vetch, banana (Ensete), sorghum	all, adding cowpea	48	50	111	97	67
Nepal alfalfa, apple, banana, barley, carrot, cowpea, chickpea, eggplant, finger millet, grasspea, oat, pearl millet, pigeonpea, rice, sweet potato, vetch,	all	33	25	110	90	20
Nigeria Bambara groundnut, eggplant, cowpea, finger millet, pearl millet, rice, sorghum, sweet potato	all adding Bambara groundnut	20	25	148	206	196
Pakistan alfalfa, apple, barley, carrot, chickpea, eggplant, faba bean, finger millet, grasspea, lentil, oat, pearl millet, pigeon pea, rice, rye, sorghum, sweet potato, wheat	all except grasspea	37	30	273	203	203
Sudan cowpea, eggplant, finger millet, pearl millet, rice, sorghum	all except finger millet	16	9	89	290	288
Uganda cowpea, eggplant, finger millet, lentil, pearl millet, rice, sorghum, sweet potato, vetch	all except cowpea, lentil & sweet potato	19	16	138	90	26
Totals		**209** [c]	**188** [c]	**1369**	**1294**	**956**

[a] Source of data Crop Trust and MSB, March 2019;

[b] Shipment from Ecuador has been received by MSB, but not processed yet;

[c] Several CWR target species occur and were collected in more than one country. Totals reflect the sum of species targeted and collected in each country.

During our visits we observed examples on how it can be done. We use the three pre-breeding projects hosted by ICRISAT as examples.

- The pearl millet pre-breeding project in India has called the attention of the private sector´s breeders, even though it is in the initial stage of the development of the materials. Breeders from multinational companies are evaluating segregating pre-breeding materials in their testing sites and providing information to project leader and partners on their performance.
- Pigeon pea has a more limited commercial appeal in India, ICRISAT works solely in partnerships with national breeding programmes and universities. The main sign for sustainability was given by

the public partners, which decided to nominate a couple of CWR introgressed lines to their regional and national variety trials for preliminary evaluations.

- In East Africa, finger millet is an important but minor crop in some countries. By ICRISAT hosting a regional breeding programme, it can later share the data and materials of the pre-breeding projects that it generates with its partners in Kenya with breeding programmes in Uganda and Ethiopia, that each subsequently engage in strategies for the delivery of varieties, primarily through informal seed systems.

During interactive workshops with genebanks in Nepal, Nigeria, Kenya and Pakistan, the attention for pre-breeding was identified as a weakness, which illustrates that in the current structure of the CWR Project, collecting and processing and pre-breeding have been operating in parallel. In two countries visited, we learnt that during the CWR Project no direct collaboration happened between the genebank and the research group or university participating in a pre-breeding project. This opens opportunities for better linking genebanks and pre-breeding programmes at national and regional levels within their national context, while also considering the role that CGIAR Centers play. We recommend towards the conclusion of the CWR Project, that national level linkages between genebanks and organisations participating in pre-breeding projects are strengthened. We propose that they share outcomes, but also jointly assess the national status and capabilities in the conservation of CWR and pre-breeding using CWR, while also exploring the development of a national framework of collaboration and follow up to the CWR Project.

D. Enhanced access to and benefit sharing from PGRFA/CWR

3.8 Safely conserved CWR germplasm

For the purpose of maximising the viability and sustainability of the CWR materials collected, the partners were required to process a robust sample of fresh, clean, viable seeds (ca. 10,000) from each accession. 1/3 of the sample is to be deposited in the national genebank; 1/3 is sent for safety duplication to MSB; another 1/3 is shared to MSB to be forwarded to an international genebank for further conservation, use, distribution and safety-duplication, e.g. the Svalbard Global Seed Vault. Each of these transfers and deposits are conducted using an SMTA under the terms of the MLS. In this way, the viability of the material and its protection from accidental or catastrophic loss will be best secured over the long-term. We consider this structure to be critical within the global design of the project; it ensures the participation of a wide diversity of countries. Above all, the project facilitated countries where globally important CWR can be found, e.g. identified through a global gap analysis, to contribute CWR germplasm to the MLS and secure the long-term conservation of these materials by depositing them in three genebanks operating within the system.

Table 4 provides a representative synthesis of preliminary achievements of the collecting and processing work of partners in the eight countries that we focused on during the CWR Project review. It should be noted that for some countries materials is still being shipped to MSB, while for others the materials have not yet been verified taxonomically and tested for viability before being accessioned in the MSB seedbank and prepared for shipment to the third genebank. This overview illustrates that the national teams have been successful in collecting populations from nearly all of the targeted genepools and species. It should be understood that the targeted species may occur in two or more countries, therefore the totals of targeted and collected species in the table do not represent the number of species per se, but rather the sum of the numbers of species targeted and collected in the eight countries. These totals provide an insight into the overall fulfilment of the project's collecting goals. Once the seed samples from all countries have been received, processed and accessioned at MSB, a finer dissection of the individual country and collective collecting achievements can then be compiled. Based on the data presented from the eight countries focused on in the review, we can conclude that the Collecting and Processing Component of the CWR Project has, overall, been very successful.

3.9 Available advanced CWR pre-breeding materials

The work with CWR species in pre-breeding is very challenging because it is complex and there is limited knowledge on how to do it; this statement applies for understanding abiotic stresses, too. Pre-breeding projects under the CWR Project combine these two levels of complexity. Below we share some examples on the impact achieved among some of the crop projects.

- One of the main results produced by the eggplant project at Universitat Politècnica de València was the development of a collection of CWR introgressed lines in every chromosome of the cultivated species and introgression lines for all 12 chromosomes of the eggplant, all of them tolerant to drought stress and showing good agronomic performance.
- With INIA-Uruguay, the potato project at CIP generated pre-breeding materials with resistance to bacterial wilt. In the partnership with Embrapa-Brazil, this project resulted in pre-breeding materials tolerant to drought.
- A large amount of crossability data was generated by the sweet potato CWR Project at CIP and University of North Carolina. According to the experts this is the most comprehensive crossing study among flowering plants ever done.
- For the first time ever, it was possible to obtain viable plants from interspecific crosses between *L. sativus* and accessions of *L. cicera* and *L. ochrus* at the pre-breeding project at ICARDA in Morocco; the BC_1 generation went to the greenhouse for further crossing and the development of populations with genes from CWR and cultivated materials combined.

A critical goal of the CWR Project is that advanced materials become available in public and globally accessible collections. The project leaders and partners have committed themselves to this goal, and thus will make these accessible to breeders irrespective of their country or organisation. By making the material available to genebanks, they maintain potentially valuable advanced materials and make these available for future use; ensuring investment is captured and not lost.

3.10 Available data on CWR germplasm in genebanks

The CWR Project developed and provided online resources in support of the collecting work, these include: (a) The Harlan and de Wet - Crop Wild Relative inventory; (b) CWR Global Atlas; and (c) CWR occurrence database. Collecting partners shared that they frequently access the CWR Project website for using these online resources, especially for the CWR occurrence database. They confirmed the relevance of the maps and information in their collecting work. Much of the materials are still being processed at MSB before being shared, conserved and becoming legally available to potential users, and it is still too early to draw any conclusions on availability of data of collected CWR germplasm. A relevant output of the CWR Project refers to “expanding access to germplasm information”. This directly refers to Genesys as an online platform where its users can find information about PGRFA conserved in genebanks worldwide. Crop Trust, beyond the CWR Project, is supporting genebanks making information available in Genesys, and thereby making information on their accessions accessible to the global audience.

3.11 Available data on advanced pre-breeding materials

In the pre-breeding e-surveys, project leaders and partners shared divergent perspectives in relation to making data available on CWR and enhanced germplasm with CWR derived traits. Some partners in pre-breeding projects (sub-contractors) did not know whether pre-breeding data (passport, genotypic, phenotypic data) on the most promising newly generated material are shared publicly, even though this is a clear provision in the contractual agreement between the lead partner and Crop Trust. More than 70% of project leaders have shared or are planning to make their data publicly available through the generic plant genetic resources database, Germinate 3, which is run in collaboration with the James Hutton Institute. The remaining group has committed themselves to the same. However, questions in e-surveys on this topic show divergent perspectives to whom data and information on germplasm resulting from pre-breeding projects belongs and how these should be made available. About 50% of

partner respondents (subcontractors) indicated that sharing the information on materials is an option, which illustrates that a stronger awareness and commitment is required amongst them to support globally sharing data on CWR. We therefore recommend that Crop Trust in the remaining period raises awareness and reinforces positions among project leaders and partners in pre-breeding projects on this topic. Furthermore, we recommend Crop Trust to work with both genebanks and breeders that if pre-breeding material is shared and conserved in genebanks or breeders' collections, they need to have a minimum level of data available that accompany them in order to stimulate use. Such data could include tolerance or resistance to the target biotic or abiotic stresses they were pre-bred for.

3.12 Legally available collected CWR germplasm

Perhaps one of the greatest - but perhaps least recognized - benefits of the CWR Project is the opportunity it provides for partner countries to participate in and contribute to the MLS. While the recognition and eventual monetary or non-monetary benefits of their contributions may not become apparent until later, the fact that genebanks have now actively contributed in the MLS, some for the first time, is an important threshold event from a policy standpoint and a significant national achievement for their participation in a global community that facilitates the exchange of crop genetic resources and the sharing of associated benefits.

The CWR Project has established and strengthened global coordination and international collaborative relationships in CWR collection, conservation, and utilisation in pre-breeding and crop improvement. For example, teams in Chile, Ecuador, Nepal, Nigeria and Pakistan each conducted more than 20 collecting missions, in which project-supported technicians did much of the collecting work. In the case of one of the countries visited, we understand that sending the seed samples and herbarium specimens to MSB, is a landmark achievement. These, and other successful implementations of the project by national partners, are concrete manifestations of their trust in the ITPGRFA and their active membership in the MLS.

We learnt, however, during country visit conversations with several partners, that the continuing perceived deficiency of actual benefit sharing in the MLS persists and thus creates challenges for genebanks and authorities responsible for providing access to materials, e.g. the decision to transfer collected CWR materials under an SMTA to MSB and thereby placing it in the MLS. Of course, this is a sovereign decision that falls to the national authorities who, in many countries, pertain to the Ministry of Environment, not Agriculture. We consider that Crop Trust can play an enabling role in this context by providing partners with information resources illustrating how, in the CWR Project and thus in the MLS, and through global efforts such as pre-breeding, real benefit sharing can be effectuated. More explicitly, Crop Trust could also use its voice and leadership role, strengthened through this project, to share and articulate the experiences and concerns expressed by national partners regarding different countries' contributions to and the benefits received through participation in the global benefit-sharing structure of the MLS which operates under the international legal umbrella of the ITPGRFA.

3.13 Publicly available advanced materials

The concern on benefit sharing relates directly to one of the core values of the CWR Project, values that have direct implications on the pre-breeding projects. This relates to the availability of the materials developed in pre-breeding projects to end-users. This value has been translated in project agreements of Crop Trust with project leaders; it stipulates that pre-breeding projects should make the produced advanced materials available in the MLS, while it does not specify the mechanism. Based on dialogues with partners in pre-breeding projects, we understand that it will take a few steps for them to have developed materials that can be shared, this is in line with the early steps in pre-breeding in which the many projects are. For some crops, the projects upon evaluation will be able to have

materials available. This is an area where the Crop Trust should strengthen the dialogue with project leaders to ensure conformity with the value for making benefit sharing work.

Most project leaders in pre-breeding shared their interest and willingness to make available relevant CWR introgressed materials to breeders and researchers. However, we observed that no agreement exists among partners about what products of the pre-breeding project should and should not go into a genebank. Genebank managers stressed during visits the difficulties related to conserving pre-breeding materials. An issue is that pre-breeders and breeders, considering the genetic contribution of the CWR to the materials, have to be able to make decisions on what goes and what does not go to the genebank. Another issue is related to the capacity of the genebank to conserve, multiply, and distribute the materials stored in it. It is well known the costs associated to genebank activities, thus increasing the number of materials in the genebank is directly associated to an increase in running costs. Bringing new materials to the genebank means adding maintenance costs, which cannot be afforded by most of the national genebanks that we visited. A final issue, which is not completely sorted out yet by many of the pre-breeding projects, is linked to the promising materials that are still part of the breeding process. Most project leaders are asking the pre-breeders and breeders to conserve these CWR introgressed materials in their pre-breeding and breeding working collections and share them also using the SMTA with anyone who requests them. The limitation of this mechanism is that information about the existence of such materials is not globally available. Most project leaders are planning to make the information available through Germinate 3 or otherwise, but we understand this is also a matter shared responsibility between project leaders and partners, but also a matter of timing as the pre-breeding projects are moving to their concluding phase. Given these issues, we recommend the Crop Trust to remain articulate about aspects and to ensure partners' commitment of sharing products and information of CWR pre-breeding and advanced materials.

E. Global frameworks for CWR conservation & use and climate change adaptation

3.14 Global prioritization

The ITPGRFA in its Article 6 emphasizes the importance for countries to get involved in "broadening the genetic base of crops and increasing the range of genetic diversity available to farmers". The priority activity 10 of the Global Plan of Action (GPA) talks about pre-breeding, e.g. "increasing genetic enhancement and base-broadening efforts", which is directly linked to the role of the CWR in contributing to broadening the genetic base of the varieties made available to farmers. The CWR Project is a major example of its donor's commitment to supporting country's investments in collecting of CWR and using CWR in pre-breeding. We however also consider the participation of the diversity of international and national partners as expressions of their commitments to both ITPGRFA and GPA. Several of the visited institutions brought ITPGRFA to our attention, none mentioned GPA, which we consider sign of the necessity of Crop Trust communications efforts to link the project to their contributions to this important global framework.

In almost all countries visited partners discussed about what crops should be emphasized in future pre-breeding activities. The GPA on its priority activity 12 "Promoting development and commercialization of underutilized crops and species" mentions major and minor crops as relevant for food and agriculture, but it does not give orientation regarding which one should be priority. In the design of the CWR Project, the Crop Trust, in consultation with its donor, has used Annex 1 list of crops of ITPGRFA in its prioritization. This choice has informed the global gap analysis directing the collection and breeding activities. With this choice, Crop Trust has made a strategic decision to limit the financial resources available for the individual projects. It also created a framework to work with both major and minor crops in its Pre-Breeding Component. It has become evident working with research and breeding groups working with minor crops, that a lot still can be achieved working with them from, for example, the use of landraces and initial steps in crop improvement, rather than focusing on pre-

breeding and use of CWR. But that these crops require attention is more than evident and Crop Trust may want to inform donors on this consideration.

On the other hand, the large coverage of crops created opportunities for pre-breeding investments in both major and minor food crops, including vegetables, fruits, fodder, leguminous and oilseed crops. To our knowledge few global funding or supportive multi-crop mechanisms are in place that support and finance pre-breeding and the use of CWR. With this diversity of crops, the focus on CWR and pre-breeding, and the focus on abiotic stress factors, the effort is unprecedented and unique; moreover, it shapes a foundation for contributing to climate change adaptation in different corners of the world.

This foundation puts major responsibilities to Crop Trust and its partners relevant for the continuity and thus sustainability of the work. Pre-breeding is considered a priority to most of the organisations engaged as partners in the project. However, it is alarming that most project leaders indicated that given the limited financial resources available in their breeding and research programmes, they are unable to continue the pre-breeding work upon the conclusion of the project. We recommend Crop Trust to engage in advocacy to promote funding for pre-breeding. The experience and gained global position require Crop Trust to continue its global awareness and advocacy role within global crop improvement and climate change adaptation frameworks complementary to its more evident position in PGRFA frameworks. Understanding the reality and priorities of national and regional budgets for crop improvement, we recommend follow-up pre-breeding programmes by the Crop Trust and its donor(s).

3.15 Project management and structure

The project leadership at global, pre-breeding project and national levels has been crucial to the efficient and effective delivery of the agreed outputs. Crop Trust has identified strong leaders to coordinate the implementation of the projects toward delivering the proposed results. The project leaders and partners considered the leadership role assumed by Crop Trust relevant to implementing the project in an efficient and effective manner. Based on the conversations that we had with partners in more than 12 countries, and further endorsed by insights obtained in the series of e-surveys with partners, the relationship between the Crop Trust team and the implementing partners in the three components was considered exceptional and professional. Partners shared that Crop Trust was always available, flexible, and willing to help when requested. There is no doubt that this relationship positively contributed to the delivery of quality outputs.

In the Collecting and Processing Component, the partnership with MSB has been effective, bringing its unique and globally recognised expertise and network in collecting, processing and conservation of wild plants to the field of CWR. Where MSB assumed primarily a technical role in the component, Crop Trust assumed a more institutional position in the coordination and linkage with national genebanks.

The achievement for the Pre-Breeding Component in prospecting and managing projects leaders and partners across multiple crops can be considered a significant capacity and unique acumen within both the MLS and global framework for climate change adaptation. As Crop Trust engaged with these partners in pre-breeding, but also with genebanks in the collecting and processing, and information management, it has developed strong relationships with a large group of globally and nationally operating stakeholders. Herewith, Crop Trust has developed insights in capabilities of partners, project managers, and implementers, while also obtaining intelligence on oftentimes specific country and institutional frameworks, including the challenges, in which these partners are working.

The activities in the information management component further enforced Crop Trust's relationship with national genebanks, this small component was highly appreciated and valued by national

partners. Given the prioritisation of information management by several of the national genebanks in their development, we consider that it has been the right choice to embed an information management component within the CWR Project.

We perceived each component, and country and crop "sub-project" within the CWR Project operating in its own world. The assembly of partners can be considered a global platform or even a Community of Practice of an unprecedented magnitude. This is applicable to genebanks engaging in the collecting and processing of CWR, but we consider many of them are already linked in one or another way. Where the world of genebanks is relatively small, we think a different situation exists for Crop Trust's partners in pre-breeding. They are working with different crops and each group operates in a distinct professional network. What unites them in the CWR Project is that they engage in pre-breeding, use CWR, target mostly abiotic stress factors (drought, heat and salinity) and work in a context of climate change adaptation. Yet, they mostly engage in groups of related crops (e.g. *Solanaceae*; legumes; cereals); commonalities at least in understanding physiological and other aspects relevant to pre-breeding for abiotic stresses are assumed. Crop Trust is well positioned to link the various partners, researchers and students in Communities of Practice (CoPs). We consider that facilitating and catalysing CoPs on topics such as Pre-Breeding for Climate Change Adaptation, on using CWR and for example breeding for specific abiotic stresses, would foster efficiency and progress in this complex field of work. With currently available digital communication applications, running such CoPs no longer take large financial investments. We conclude that particularly for the Pre-Breeding Component, a more articulate communication strategy including the use of contemporary tools, is a missed opportunity. This observation confirms the limitation of the CWR Project in addressing and facilitating communication within a larger capacity development strategy.

3.16 Facilitating global efforts in MLS/PGRFA and climate adaptation

The CWR Project constitutes a global effort to actively promote and strengthen the conservation and use of CWR with a key role for national genebanks and supported by globally operating organisations such as Crop Trust, MSB and the international genebanks of the CGIAR. As a prerequisite for participation, the project requires that the CWR materials collected and processed by the national partners be shared through the MLS. In this way, the CWR Project has furnished a global structure for collecting, processing and conserving CWR that has proven successful. Within this structure, partner countries are cumulatively sharing thousands of novel and newly collected CWR materials and in-bred lines through the MLS. In the cases of countries that we visited, being Chile, Ecuador, Kenya, Nepal, Nigeria and Pakistan, the CWR Project has effectively provided both the incentive and opportunity for the country's active participation in the MLS, which is a significant landmark for each country and a substantial achievement for the project.

The CWR Project, through the partnership with national genebanks in 25 countries has provided a standardised process of scientifically sound and internationally accepted methods of CWR collecting, taxonomic identification, documentation, seed processing, *ex situ* conservation of the germplasm in national genebanks, and its safety duplication in international genebanks using the SMTA for formalized access and benefit sharing through the MLS. With regard to its crucial role in establishing a global process for the identification, occurrence, collection and long-term conservation of CWR, including the requisite compliance with relevant national and international policies, the CWR Project has certainly been effective in achieving its principal objective. Achieving this, the Crop Trust itself has gained the capacity, assumed a position and global responsibility to manage and implement global projects as it has done so since its foundation. It has effectively marshalled the necessary technical and financial resources for an ambitious 10-year project involving more than 25 countries in what is undoubtedly the world's largest CWR collecting and conservation initiative.

The Pre-Breeding component, with its 19 projects with multiple partners organised in group by crops, and the information management component upgrading genebanks' capacity in this field are somewhat independent and disarticulated from the CWR collecting and processing activities but contribute to the larger agenda of GPA promoting best practices in PGR conservation, management and use.

We consider it an achievement that Crop Trust has been able to prospect research leaders and groups across multiple crops. The Crop Trust in consultation with its donor has structured the Pre-Breeding Component to cover a wide diversity of crops as guided by the Annex 1 of the ITPGRFA. For each of the crops considered, a relationship was established between Crop Trust with a leader with experience in or potential to engage in pre-breeding. With the strong relationships developed with these leaders, Crop Trust has developed insights in their capabilities to be effective partners, project managers, and implementers. This capacity and unique intelligence can be considered one of Crop Trust's new assets as a critical node and catalyst within the MLS. Together with its research partners, Crop Trust has shaped a platform that is instrumental in the use of CWR for combating climate change. We realize that no other organization has assumed such a global role. The Crop Trust has gained an evident and recognized global position and profile in fostering the use of CWR and pre-breeding contributing to climate change adaptation in agriculture.

F. Next steps for CWR conservation and use for climate change adaptation

3.17 Collection and conservation of CWR

A major goal of the project was the collecting and processing of CWR that had been identified through a global gap analysis. To achieve this, Crop Trust, in partnership with MSB, was able to support collecting work by national genebanks in 25 countries. It raised capacity and fostered collaboration to collect and process the seed samples of identified crop genepools and target taxa. The relationship of genebanks with MSB focused on technical aspects in the collecting, the taxonomic verification and seed processing at its seed laboratory. Each project leader in a country partnering in the project worked with a counterpart at MSB addressing technical aspects of collecting and processing, but also working on the shipment of materials to MSB. The data in the e-survey illustrates that this relationship with MSB was new to a large majority of the genebanks. We conclude that the logic of the project, driven by the global gap analysis, created a relationship between Crop Trust, MSB and national genebanks in 25 countries. We consider this collaborative framework for the collection of a wide diversity of species a major achievement.

The project achieved significant results for reaching sustainability of the technical and institutional capacity, but this work is by far not done. The gap analysis identified other countries where CWR collection remains urgent and collection activities in the current project, even though significant, are not exhaustive in terms of covering taxa, species and collection areas. In the currently participating countries where collecting work did take place, we realize that the budgetary limitations of most national genebanks translate into their near-total dependence on external resources. We recognize that in a global system, such as the MLS, such dependence is not necessarily a challenge. However, at national levels, CWR collecting and conservation are mostly regarded as "non-essential", and therefore do not usually fall under genebanks' core budgets. The budgetary restrictions at national genebanks, such as those we observed during our visits to the genebanks in six countries, do not permit CWR activities to continue unless external support is provided. This dire funding situation was confirmed in the e-survey by 20 out of 22 project leaders and genebank managers who reported they do not have the financial resources to continue the CWR collecting work. For the project to have lasting impact, a need emerges to raise awareness among national policy and decision makers and start considering CWR as essential in PGRFA conservation. We consider that Crop Trust with its insights and intelligence in the topic, coupled with its admirable communication capabilities, plays and should continue to play

a constructive and supportive role in this space. However, we remain realistic and consider that the limited financial resources available in most partner countries provides a justification for continued globally structured investments, especially if the CWR are collected and shared within the MLS. Crop Trust's leadership and its proven capabilities in managing in an effective and efficient manner a global project, creates a foundation and provides proven mechanisms to successfully implement such globally structured investments.

3.18 Pre-breeding for climate change adaptation using CWR

Around the world there are experiences in pre-breeding using CWR species targeting biotic and abiotic stresses. However, there is none, which has been working in a structured way combining a broad range of CWR species and abiotic stresses. The CWR Project tried to capitalize on these limited experiences, and after almost ten years of experience, Crop Trust has a good knowledge about the opportunities and limitations of such an effort. Looking forward, Crop Trust has the opportunity to dialogue with donors, CGIAR Centers, advanced research centres and national breeding programmes to identify where human resources, knowledge, facilities, and partners are at the highest level to continue implementing the results of the Pre-Breeding Component of CWR Project.

Within the larger structure of the CWR Project, pre-breeding projects had as partners in their implementation NARS and universities of low and middle-income countries. The design of the Pre-Breeding Component was that these partners enhanced their capacity to use CWR species while working hand-in-hand and exchanging knowledge and experiences with institutions with expertise in pre-breeding. Examples of the observed capacity enhancing come from the partnerships between Universitat Politècnica de València in the eggplant project and the breeding programmes of Sri Lanka and Ivory Coast; USDA-Madison in the carrot project with universities in Pakistan and Bangladesh; CIP in the potato project and INIA-Uruguay and Embrapa-Brazil, ICARDA in the barley project with the national programme INRA-Morocco, and ICRISAT (Nairobi) in the finger millet project with a university and NARS in Kenya. Breeders and researchers in NARS and universities engaged in the various steps and components of screening CWR, identifying and getting an understanding of the traits, making crosses between CWR and cultivated varieties, and further evaluation and development of advanced materials. The project leaders indicated the need for more and better capacity among their partners to run pre-breeding programmes. Responding to this point, we recommend Crop Trust to become more strategic on ways to develop capacity in pre-breeding, thus not only assume that project leaders engage in capacity development but move beyond that. Partners in the pre-breeding projects were initially identified in a discussion with the Crop Trust from existing networks of project-leaders. We recommend Crop Trust if engaging in a next phase to become more strategic in identifying partner NARS and universities and take a more structural approach to capacity development. We do not mean its selection of project leaders which proved to be successful. We propose in the selection an assessment of partners to use an adapted version of the now widely used Breeding Programme Assessment Tool (BPAT). This assessment tool facilitates a structured review of key technical, capacity and management components of plant breeding programs to help design improvements that increase their efficiency and achieve higher rates of genetic gain. The tool should be adapted to the focus on pre-breeding capabilities and identify those partners with a potential in pre-breeding. Such an assessment could be part of the design phase of a new activity and given the reference in chapter 6 of the ITPGRFA to pre-breeding, Crop Trust could involve in addition to its donors the ITPGRFA secretariat in such an effort. Partners with such a potential could be identified; based on the assessment engaged in a process of targeted capacity development in human capacity, but improvement processes and upgrades in infrastructure relevant to pre-breeding. We consider that the relationship with the project-leader and structured interactions with peers in other pre-breeding breeding projects are critical in this process of capacity development of the identified NARS and universities.

What has become clear to us is that few genebanks are partners in this research, and we conclude that only few national genebanks have the human resources, infrastructure and capabilities to be active partners in pre-breeding. However, this does not mean they cannot play a role, but we consider them more to participate in availing and characterizing materials. Perhaps, genebanks as national institutions can play a coordinating role with various NARS and universities at a national level, similar to the role of Crop Trust as PGRFA organisation played for pre-breeding in the CWR Project. We consider it inspiring during our country visits that such initial national engagements were explored by the national genebanks and pre-breeding partners in the CWR Project.

The CWR project has in its results framework, agreed with its donor, a focus to impact farmers' capacity to confront climate change, which has resulted in the promotion of farmer participation in the pre-breeding work. Its partners show however divergent opinions whether farmer participatory work should be part of pre-breeding. Importantly, the activities we focused on in the review concentrated on screening of CWR for desirable traits, further identification of traits and transferring these into cultivated germplasm; these are activities where farmer participation is not easily realised. Farmer involvement is more relevant In the current phase of the pre-breeding projects focusing on evaluation of advanced materials including new traits from CWR, to both the breeders as well as to the farmers.

Institutional commitment of both Crop Trust and its partners to pre-breeding, we consider as a critical aspect for continuing and sustaining the work done and achievements of the CWR Project. The achievements in terms of development of CWR introgressed materials, the tremendous amount of crossability data, partnerships forged, and capacity developed, are instrumental for Crop Trust and partners in dialogues with institution managers and donors; they are a firm foundation. Previously, the conversations whether to invest in pre-breeding were all based on wishful thinking on what we could do; today they are based on data and experiences, e.g. what could be done, what the effort takes and what resources are required. Therefore, the Crop Trust should aspire to continue this job by strengthening the dialogue with institutional managers and donors to foster their commitment and continue their support to pre-breeding. During the concluding period of the CWR Project it will share and publish achievements. But we recommend what is relevant to managers and donors is that it also elaborates with partners pre-breeding work plans and budgets, or even business or investment plans for pre-breeding work to be continued. The recommendation would be in line with above mentioned reference to pre-breeding in the ITPGRFA.

Even though the CWR Project is almost ten-year-old, the exploration of the CWR species through pre-breeding is new. The combination of CWR with the opportunities to develop materials tolerant to abiotic stresses for most of the crops is even newer. From our experience, we know that any new idea requires time to mature and to become part of the strategy and breeding programmes of international centers and NARS. We consider the CWR Project has developed a firm basis which requires continuation and further support to result in practical outcomes—seed of adapted varieties including traits sourced from CWR—that will allow farmers to benefit in an indirect manner from the globally available CWR. This will support farmers to counter with such adapted varieties the climate change challenges they are facing.