OPINION PAPER

Towards Mainstreaming Global Crop Conservation Strategies

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1. INTRODUCTION: CONSERVATION AND USE OF PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Seeds and other reproductive propagules of cultivated plant species and their wild relatives are a critically important resource that underpins the productivity, quality, sustainability, resilience, and adaptive capacity of food and agricultural systems (Hoisington *et al*. 1999; Esquinas-Alcázar 2005; Gepts 2006). Farmers' varieties (landraces) and their wild relatives have been the basis of agricultural production for over 10,000 years (Larson *et al.* 2014) but their value as genetic resources only began to be recognized by scientists in the late 19th and early 20th centuries (Baur 1914; Zeven 1998), in parallel with the rediscovery of Mendel's laws of inheritance and the development of modern genetics (Harwood 2016; Khoury *et al.* 2021). *Ex situ* repositories (genebanks) were subsequently established to maintain plant genetic resource (PGR, or PGRFA more specifically for those related to food and agriculture) collections and to make them available to support the breeding of new crop varieties (Vavilov 1926; Lehmann 1981; Saraiva 2013).

In parallel, concerns began to be raised over the loss of crop diversity from farmers' fields and from wild habitats due to rapid agricultural, environmental, socioeconomic, and other changes (Baur 1914; Harlan and Martini 1936). These concerns were voiced at the Food and Agricultural Organization (FAO) of the United Nations and elsewhere, particularly in light of the perceived large-scale replacement of traditional varieties by modern cultivars in some regions during the "Green Revolution" (Bennett 1964, 1968; Frankel and Bennett 1970; Frankel 1974; Pistorius 1997; Fenzi and Bonneuil 2016). There was also growing awareness of the susceptibility of modern crop cultivars to pests and diseases as a consequence of their genetic uniformity (Tatum 1971; National Research Council, 1972; U.S. Senate 1980). To begin to address these challenges at the international level, the 22nd FAO Conference established the FAO Commission on PGRFA, under which the FAO International Undertaking on PGRFA was negotiated (FAO 1983).

Several initiatives and conferences organized by FAO and related organizations resulted in the expansion of efforts around the world to collect and maintain PGRFA *ex situ* (Plucknett *et al.* 1987). The International Board for Plant Genetic Resources (IBPGR) was established by the international agricultural research centers of the Consultative Group on International Agricultural Research (CGIAR) in 1974, with its secretariat provided by FAO, to coordinate a global initiative to conserve threatened crop diversity. IBPGR supported the collecting of over 200,000 samples of landraces, crop wild relatives, and other materials in 136 countries between 1975 and 1995, and helped to establish international genebank collections, hosted by CGIAR centers, to maintain these samples (Thormann *et al.* 2019).

Over the course of the 1980s and 1990s, while national, regional, and international *ex situ* collections of PGRFA were amassed, there was growing concern about the vulnerability of these collections, due largely to inadequate funding and infrastructure. Genebanks were encouraged to duplicate their holdings to mitigate these challenges as well as to protect them from natural disasters, war, and civil strife (Holden 1984; Lyman 1984; Peeters and Williams 1984).

At the same time, PGRFA were increasingly recognized as important not only for breeding but also in underpinning the resilience and adaptive capacity of agrarian communities and their agroecosystems (Mijatović *et al.* 2013; Fenzi and Bonneuil 2016; Sirami *et al.* 2019). Support for the *in situ* conservation of landraces on farms increased (Brush 1991; Wood and Lenne 1997; Bellon 2004), though some questioned its efficacy in the face of widespread environmental and societal change (Frankel and Soule 1981; Zeven 1996; Peres 2016).

By the 1990s, concern about the loss of biodiversity, in all its forms, had became a global priority and resulted in the adoption of the Convention on Biological Diversity (CBD), which mandated its conservation, sustainable use, and the fair and equitable sharing of the benefits arising from such use (CBD 1992). With the coming into force of the CBD, earlier international agreements on PGRFA (e.g., FAO 1983) were renegotiated, resulting in the adoption in 2001 of the legally-binding International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, also known as the Plant Treaty) (FAO 2002). In alignment with the CBD, the objectives of the Plant Treaty are the conservation and sustainable use of PGRFA and the fair and equitable sharing of the benefits arising out of their use, for sustainable agriculture and food security (FAO 2002). The Plant Treaty established a Multilateral System (MLS) of access and benefit sharing for the PGRFA of 64 major crops and forages (listed in its Annex 1), a negotiated list of crops established according to their relevance to food security and the degree of international interdependence for their genetic resources.

In the 1990s, the International Plant Genetic Resources Institute (IPGRI) (formerly IBPGR, then Bioversity International, and now the Alliance of Bioversity International and CIAT, henceforth referred to here as The Alliance) initiated a System-wide Genetic Resources Programme (SGRP) to coordinate PGRFA activities across the CGIAR. This program sought to advance research on policies, strategies, and technologies for genetic resources conservation and to provide data on genebank holdings to partners through a System-wide Information Network on Genetic Resources (SINGER) (IPGRI 1997). In collaboration with FAO and others, IPGRI also facilitated the development of a wide range of technical guidelines and other documents on the management, exploration, and characterization of PGRFA, for example through publication of crop-specific descriptor lists (Bioversity International 2022).

In 2004, the Global Crop Diversity Trust (Crop Trust) was established with support from FAO and the CGIAR to help secure and provide long-term funding for the *ex situ* conservation of PGRFA (Esquinas-Alcázar 2005). While they are separate entities, the Crop Trust is considered an essential element of the funding strategy of the Plant Treaty. Among the first major steps taken by the Crop Trust in its efforts to enhance the conservation and use of crop diversity around the world was to support the development of crop-specific diversity conservation strategies at the global scale (i.e. Global Crop Conservation Strategies [GCCS]), as well as regional conservation strategies covering multiple crops. The first strategies, starting with many of the crops listed in Annex 1 of the Plant Treaty, were published in 2006, with such efforts continuing to the present and coming to include several non-Annex 1 crops (**Table 1**). These GCCS are the focus of the present opinion paper.

Since its inception, the Crop Trust has supported PGRFA conservation and use through knowledge generation and diffusion, as exemplified by its coordination of the GCCS, as well as through direct support for PGRFA activities, both via its endowment (largely focused on conserving germplasm collections for the long-term in international genebanks) as well as through thematic projects (e.g., the

Global System Project funded by the Bill & Melinda Gates Foundation, which focused on regenerating and safety-duplicating national PGRFA collections; and the Crop Wild Relatives Project [http://www.cwrdiversity.org/], funded by the government of Norway, which aimed to collect, conserve *ex situ*, and pre-breed crop wild relative genetic resources globally). The Crop Trust, in partnership with The Alliance and other international agricultural research centers, also facilitated the further development of global information systems on *ex situ* PGRFA collections, resulting in Genesys PGR (Data providers and the Crop Trust 2017-2022), which expanded earlier efforts such as SINGER to include accession-level data from additional international, regional, national, and other collections around the world.

At the regional level, various multi-crop networks have also emerged to encourage, plan, and coordinate conservation and use of PGRFA. Examples include (FAO 2010):

- European Cooperative Programme for Plant Genetic Resources (ECPGR) and the Nordic Genetic Resource Center (NordGen) in Europe,
- Southern African Development Community (SADC) Plant Genetic Resources Centre (SPGRC) in Southern Africa,
- Red Andina de Recursos Fitogenéticos (REDARFIT) in South America,
- Red Mesoamericana de Recursos Fitogenéticos (REMERFI) in Mesoamerica,
- Caribbean Plant Genetic Resources Network (CAPGERNET),
- NORGEN as part of the Cooperative Program in Agricultural Research and Technology (PROCINORTE) in North America,
- West Asia and North Africa Genetic Resources Network (WANANET),
- Central Asian and Caucasus Network on Plant Genetic Resources (CACN-PGR),
- South Asia Network on Plant Genetic Resources (SANPGR),
- Regional Cooperation in South East Asia on Plant Genetic Resources (RECSEA), and
- Pacific Agricultural Plant Genetic Resources Network (PAPGREN).

While some of these networks still operate, others have become dormant or have ceased to function.

A range of crop-specific networks, mainly focused on crop breeding but sometimes also covering conservation aspects, have also emerged, mainly operating at regional to global scales, but with some national-scale versions as well (see FAO 2010). Examples include:

- International Network for Bamboo and Rattan (INBAR),
- Coconut Genetic Resources Network (COGENT),
- Latin American/Caribbean Consortium on Cassava Research and Development (CLAYUCA),
- Interregional Network on Cotton in Asia and North Africa (INCANA), and
- CacaoNet.

Some of these networks have also published strategies somewhat similar in content and intent to those of the GCCS, for example CacaoNet's *A Global Strategy for the Conservation and Use of Cacao Genetic Resources, as the Foundation for a Sustainable Cocoa Economy* (Bioversity International 2012) and the Crop Vulnerability Statements published by USDA's Crop Germplasm Committees (e.g., Potato Crop Germplasm Committee 2020) as well as the strategies developed by ECPGR crop working groups.

By the end of 2020, 5.7 million accessions of plant genetic resources for food and agriculture were reportedly conserved under medium or long-term conditions in 831 genebanks by 114 countries and 17 regional and international research centers (FAO 2021b). Safety duplication of a proportion of this diversity is known to be accomplished among the genebanks themselves and at the Svalbard Global Seed Vault (Westengen *et al.* 2013), where over 1.1 million samples are now stored (Norwegian Ministry of Agriculture and Food 2022; NordGen 2022). Genetic resources are also conserved by botanic gardens, universities, NGOs, community seedbanks, local conservation networks, and private companies, while plant breeding and other research programs also store genetic resources, at least for short periods, (Miller *et al.* 2015; Vernooy *et al.* 2017). Numerous initiatives, meanwhile, continue to focus on *in situ* and on farm conservation of PGRFA (e.g., Stenner *et al.* 2016; AGUAPAN 2021; GEF 2021).

These decades have seen efforts that are both widespread and substantial, but gaps in both conservation and use of PGRFA continue to persist (FAO 2010; Castañeda-Álvarez *et al.* 2016; Engels and Ebert 2021a, b; Khoury *et al.* 2021; Ramirez-Villegas *et al.* 2022; all GCCS covered in this opinion paper). At the international level, two Global Plans of Action (GPA) for Plant Genetic Resources for Food and Agriculture have been adopted by FAO and its associated conferences over the past 25 years to address these gaps (FAO 1996, 2011), following the publication of the original and the Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture (SOW) (FAO 1997, 2010). A third SOW is currently in preparation, to be published in 2023. The CBD and the United Nations Sustainable Development Goals have also set global targets for enhanced conservation of plant genetic resources (CBD 2002, 2010; United Nations 2015). Ongoing negotiations largely aim to renew previous targets, which were not met by their original (2020) deadlines (Díaz *et al.* 2020).

Considerable further action is needed to comprehensively conserve and to make fuller use of genetic resources of food and agricultural crops. Strategizing how to achieve these aims is as pertinent as ever, and indeed increasingly urgent.

Table 1. Global Crop Conservation Strategies (GCCS) to date

Strategy	**Title**	**Publication year**
Banana and plantain (original)	Global Conservation Strategy for *Musa* (Banana and Plantain)	2006
Potato (original)	Global strategy for the *Ex situ* Conservation of Potato	2006
Breadfruit	Breadfruit Conservation Strategy	2007
Grasspea	Strategy for the *Ex Situ* Conservation of *Lathyrus* (grass pea), with special reference to *Lathyrus sativus, L. cicera, L. ochrus*	2007
Maize	Global Strategy for the *Ex situ* Conservation and Utilization of Maize Germplasm	2007
Sorghum (original)	Strategy for the Global *Ex Situ* Conservation of Sorghum Genetic Diversity	2007

Strategy	Title	Publication year
Sweetpotato	Global strategy for the *ex situ* conservation of sweetpotato genetic resources	2007
Wheat	Global strategy for the *ex situ* conservation with enhanced access to wheat, rye, and triticale genetic resources	2007
Barley	Global Strategy for the *Ex Situ* Conservation and Use of Barley Germplasm	2008
Chickpea	Global Strategy for the *Ex Situ* Conservation of Chickpea (*Cicer* L.)	2008
Coconut	Global Conservation Strategy for *Cocos nucifera*	2008
Lentil	Global Strategy for the *Ex Situ* Conservation of Lentil (*Lens* Miller)	2008
Oat	Global Strategy for the *Ex situ* Conservation of Oats (*Avena* spp.)	2008
Strawberry	Global Conservation Strategy for *Fragaria* (Strawberry)	2008
Faba bean	Global Strategy for the *Ex Situ* Conservation of Faba Bean (*Vicia faba* L.)	2009
Aroids	Edible Aroid Conservation Strategies	2010
Cassava	A Global Conservation Strategy for Cassava and Wild *Manihot* Species	2010
Cowpea (original)	Global Strategy for the Conservation of Cowpea (*Vigna unguiculata* subsp. *unguiculata*)	2010
Rice	Global strategy for the *ex situ* conservation of rice genetic resources	2010
Yams (original)	Towards a Global Strategy for the conservation and use of yam	2010
Finger millet (original)	Global Strategy for the *Ex Situ* Conservation of Finger Millet and its Wild Relatives	2012
Pearl millet (original)	Global strategy for the *ex situ* conservation of pearl millet	2012
Beans	Conservation of *Phaseolus* beans genetic resources: A strategy	2014
Forages (tropical and subtropical)	Global Strategy for the Conservation and Utilization of Tropical and Sub-Tropical Forage Genetic Resources	2015
Bananas (updated)	Global Conservation Strategy for the Conservation and Use of *Musa* (Banana) Genetic Resources	2016
Coffee	Global Conservation Strategy for Coffee Genetic Resources	2017
Apple	A global strategy for the conservation and use of apple genetic resources	2019
Tea	A Global Strategy for the Conservation and Use of Tea Genetic Resources	2019

Strategy	Title	Publication year
Cucurbits	A global conservation strategy for crops in the Cucurbitaceae family	2021
Forages (temperate)	Global strategy for the *ex situ* conservation of temperate forages	2021
Vanilla	Global strategy for the conservation and use of Vanilla genetic resources	2021
Yams (updated)	Global strategy for the conservation and use of yam genetic resources	2021
Capsicum	A Global Strategy for the Conservation and Use of *Capsicum* Genetic Resources	2022
Eggplant	Global strategy for the conservation and use of eggplants	2022
Millets (updated)	Global strategy for the conservation and use of genetic resources of selected millets	2022
Peanut	Global strategy for the conservation and use of peanut genetic resources	2022
Potato (updated)	Global Strategy for the Conservation of Potato	2022
Sorghum (updated)	Global Strategy for the conservation and use of sorghum (*Sorghum bicolor* (L.) Moench) genetic resources	2022
Brassicas	Global Strategy for the Conservation of *Brassica* genetic resources	2023
Citrus	Global Strategy for the Conservation of Citrus Genetic Resources	2023
Pea	Global Strategy for the conservation and use of pea (*Pisum sativum* L.) genetic resources	2023
Sunflower	Global strategy for the conservation of sunflower (*Helianthus* spp.) genetic resources	2023
Vigna (updated[1])	Global Strategy for the Conservation and Use of *Vigna*	2023

2. PURPOSE AND METHODOLOGY OF THIS OPINION PAPER

The preparation of this opinion paper was motivated by a resolution of the eighth session of the Governing Body of the Plant Treaty. Among other policy guidance, the Governing Body recommended that the Crop Trust further enhance its collaboration with the Plant Treaty on scientific and technical matters and, specifically, *"invites the Crop Trust, subject to the availability of resources, to expand cooperation with the Secretary to elaborate a dynamic system for developing, implementing and updating*

[1] The 2023 Global Strategy for the Conservation and Use of Vigna genetic resources has a broader scope than the Global Strategy for the Conservation of Cowpea published in 2010. The former focuses on all Vigna crops, while the latter focuses only on cowpea.

Crop Conservation Strategies, with a view to enhancing their use by Contracting Parties and relevant stakeholders, as practical tools to realize the implementation of the International Treaty" (FAO 2019).

The aims of this opinion paper are to:

1. Develop and describe a conceptual framework for a more dynamic and sustainable process for developing, implementing, and updating GCCS. The purpose is to identify how improvements to the GCCS process will help make conservation and use of PGRFA more effective and efficient.
2. Propose ways to mainstream the GCCS in the supporting mechanisms of the Plant Treaty. Starting from the Plant Treaty's Governing Body resolution on GCCS, the purpose is to outline how the GCCS can better provide an evidence-based enabling mechanism for the implementation of the MLS and provide guidance, or otherwise contribute, to the aims of the Governing Body.

The process of developing this opinion paper included an in-person expert meeting (May 2022, Bonn, Germany) as an initiation and planning exercise, followed by eliciting wider expert stakeholder input via a short survey sent by email to the main authors/facilitators of the GCCS published over the past two decades. The survey aimed to garner feedback on authors' experiences in developing the GCCS and their opinions on future directions for the GCCS, including regarding strengths and weaknesses, further updating priorities, governance and ownership, and buy-in from stakeholders. The authors of this opinion paper compiled and analyzed these inputs, with further comments contributed by the Crop Trust and Plant Treaty, as well as participants at a second stakeholder meeting, held in November 2022, Bonn, Germany.

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3. GLOBAL CROP CONSERVATION STRATEGIES (GCCS)

The global PGRFA community has long grappled with complex challenges to the comprehensive conservation and fuller use of genetic resources of food and agricultural crops (see, e.g., FAO 1997, 2010, Khoury *et al.* 2010; Engels and Ebert 2021a, b). These can be summarized in terms of gaps in knowledge, resources, technologies, infrastructure, security, capacities, partnerships, and policies, which are often interrelated. While the overriding challenges are universal, the contexts are often crop- and geographic area-specific.

Global crop conservation strategies (GCCS) represent unique processes and products in their aim to compile, generate, and analyze the information needed to understand the current status of conservation and use of individual crops' PGRFA globally, including providing sufficient detail and specific recommendations to enable informed decision-making toward improvements in this status. While they are meant to broadly report the state of conservation and use of PGRFA for a given crop, the GCCS also prioritize actions, activities, and actors based on attributes such as urgency and long-term impact.

The GCCS acknowledge that the current status of PGRFA conservation and use is not optimal, typically recognizing both the need to increase actions in many technical areas (e.g., often regarding regeneration or safety duplication of unique germplasm), and also to reduce or redirect others (e.g., to reduce excessive duplication of germplasm among collections) (Khoury *et al.* 2010). The combination of these recommendations is important in the ongoing context of limited financial and other resources available

for PGRFA conservation and use at all scales (international, national, and sub-national), and thus the pragmatic need for a more effective and also efficient (together sometimes referred to as "more rational"), global system of PGRFA conservation and use (FAO 1996). Thus, in the words of the Crop Trust, the GCCS are intended to contribute "to create a conservation system that is more secure, more representative of [crop] diversity, and more cost-effective, with better links between collections and users." (Crop Trust 2022b).

GCCS development has typically followed a fairly standardized methodology (but with significant variation among strategies [Williams and Drummond 2020]). This involves the recruitment of one or more long-standing experts in conservation and use of the crop (authors/facilitators). These authors are responsible for contacting *ex situ* genebanks worldwide - mainly through a survey - to obtain information regarding the contents of the collections, and current status and needs with regards to acquisition, regeneration and multiplication, safety duplication, distribution and use, data management, etc. This information is typically supplemented by data compiled from global germplasm information systems such as Genesys PGR (Data providers and the Crop Trust 2017-2022) and FAO's World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture (WIEWS) (FAO 2022d), as well as authors' own knowledge and experience.

These data are collated and then reviewed and discussed during in-person (or, more recently and mainly due to the COVID pandemic, virtual) meetings among selected crop experts. Participants generally include genebank curators and managers, plant breeders, and other crop researchers, from both national and international institutions as well as other organizations pertinent to the given crop. The groups typically aim to identify the most important, unique, or valuable PGRFA collections for the given crop, as well as highlight overlaps, gaps and needs in collections worldwide. Ways to expand or enhance partnerships and networks, training and capacity building, and other facets of PGRFA conservation and use are also discussed.

While the GCCS have over their history mainly focused on *ex situ* conservation status and needs, several of the strategies have also attempted to address *in situ* conservation, or to more comprehensively strategize about increasing the use of the given crops' PGRFA. The more recently published GCCS have tended to be more inclusive of these two aspects, including reflecting this in their titles (**Table 1**).

Once the information has been collated, analyzed and discussed, a strategy document is drafted by the authors/facilitators in a long-form report format, often numbering over 100 pages in length. The strategy starts with baseline information compiled from published literature about the diversity, history, and current use of the given crop(s) and their wild relatives. It then reports the status, gaps, and challenges of *ex situ* collections as well as, increasingly, *in situ* conservation and use aspects. The strategy then makes a series of recommendations for improvements to the global system of conservation and use of the PGRFA of the crop. In accompanying annexes, it may also provide access to the data retrieved from the surveys and global germplasm databases, as well as report other pertinent metrics regarding the conservation and use of the crop.

Following a peer review process involving stakeholders who participated in the meetings and/or surveys, as well as relevant Crop Trust staff and (for some strategies) other experts, the strategy is finalized and published online, and thus accessible to anyone with an internet connection (Crop Trust 2022a). Even though the strategies are published in a static (.pdf) format, they are generally framed as the results of ongoing processes whose recommendations are meant to evolve as new information becomes available

and as PGRFA activities progress. In this respect, some of the earlier crop strategies have been updated (see **Table 1**).

4. STRENGTHS AND WEAKNESSES OF THE GCCS PROCESSES

The process and methodology, resulting products, and intended outcomes and impact of the GCCS as they have historically been accomplished entail inherent tradeoffs, having both strengths and weaknesses.

4.1 Process and methodology

Regarding process and methodology, the GCCS synthesize a wide range of pertinent information on specific crops and their PGRFA in a novel format. The GCCS process typically incorporates expert inputs via surveys, meetings, and peer-review of the strategy, while also drawing information from global germplasm databases and from published literature. Due to this diversified and semi-standardized format, the GCCS process can in theory incorporate virtually any kind of data or other input and is not wholly dependent on any one information source.

In many senses, this mixed-methods approach represents a robust, and perhaps the best current, means by which to compile the global state of knowledge on the status and needs of a crop's PGRFA. This is so because pertinent global information systems such as Genesys PGR (Data providers and the Crop Trust 2017-2022) and FAO's WIEWS (FAO 2022d), while having made remarkable progress in the past decade, still have a long way to go before they can offer fully comprehensive, accurate, up-to-date data on *ex situ* collections and their gaps (Khoury *et al.* 2020; Williams and Drummond 2020), let alone on *in situ* and on farm conservation as well as on use of PGRFA. Likewise, while there is an ever increasing plethora of published literature on PGRFA and evolving means by which to capture data from publications as they appear online, efficiently finding, compiling, and analyzing comprehensive information from journal articles remains very challenging and time consuming. Moreover, detailed information about PGRFA status and gaps, particularly at national and sub-national levels, is mainly to be found within those specific organizations.

However, this mixed methods approach requires quite a lot of time and financial resources. A GCCS process for a given crop typically takes at least one year from start to finish, and sometimes considerably more. The topical-expert authors/facilitators must contribute a significant amount of their time to the effort, which is a challenge for full-time professionals engaged in PGRFA collection management, plant breeding, or other activities. The stakeholder surveys generally require many hours, or even multiple days, to be completed by crop germplasm curators. The in-person meetings, which aim to engage the necessary quantity of experts from around the world to achieve a global understanding and, thus, must support their travel, accommodation, and other costs, are very expensive (see Section 9).

The dedicated financial resources for the GCCS that have been made available over the past two decades (by a small number of donors) should absolutely be recognized as a strength - this funding has surely motivated completion of tasks within an allotted time period and provided incentives for stakeholder participation, such as the opportunity to travel and attend in-person meetings among peers. At the same

time, it should be recognized that the GCCS, at least in the format that they have historically been conducted, cannot be accomplished without a continued significant investment of time and funding going forward.

Further, the mixed method approach is neither a fully standardized nor completely reproducible process, thus making analysis of future change over time for specific crops, or the synthesis of results across multiple crops, inexact. More recent GCCS efforts have increasingly aimed toward greater replicability. In 2020, a comparative analysis of the 26 GCCS that had been published to that date identified priority areas for standardization and improvement, and, as a result, a standard model outline was produced to guide the development of future strategies (Williams and Drummond 2020). This outline was further enhanced during the development of the latest set of GCCS from 2019 to 2022, under the BMEL grant. Alongside greater standardization of GCCS sections, the new standard emphasizes the provision of disaggregated data and more thorough documentation of the methods. These additional steps have necessarily increased the complexity and cost of producing the strategies, however.

Moreover, despite the aim to gather essentially all pertinent information from different information sources, persistent gaps in knowledge and data still commonly constrain a full understanding of the status and needs for a given crop's PGRFA. This includes pragmatic details pertinent to GCCS recommendations, such as the breadth and quality of particular collections, but also basic information such taxonomy and systematics. There is a risk that such gaps may be filled with conjecture or the opinions of dominant participants in the GCCS process, whether they be the authors/facilitators or other stakeholders. While the process of expert participant engagement certainly aims to be inclusive and global, it invariably falls short due to funding, language, and other limitations.

In the end, following the current approach, the quality and objectivity of the GCCS is very dependent on the time and expertise of authors/facilitators, the availability and accessibility of information about the given crop, the degree of organization and resources allotted to the strategy process, and the number, diversity, knowledge, priorities, and willingness to collaborate of the participating stakeholders (see also Williams and Drummond 2020).

A further notable challenge with some of the GCCS produced to date is taking the final step of converting the vast amounts of information generated and analyzed into specific priorities and recommendations (Williams and Drummond 2020). Without this final step, these efforts are more compilations of potentially useful data rather than actual strategies.

One particular aspect of the GCCS process should be highlighted for its additional benefits beyond the strategies themselves - the convening of a wide range of a given crop's experts in *ex situ* collections, plant breeding, and other aspects, from different institutions and organizational scales, from around the world. Especially through in-person interactions during meetings, this process creates new relationships and collaborations, and strengthens existing ones. The process also enables community awareness-raising among the participants about the status and gaps of a given crop's PGRFA, as well as the GCCS process itself. Along with being critical to the production of the strategies, this engagement process is thus an important step in creating a global community of peers willing and able to act on the recommendations of the GCCS. Given, in our experience, that trust and goodwill among PGRFA actors worldwide needs to be

cultivated continually to develop and maintain functional global mechanisms for crop diversity conservation and use, the productive convening of PGRFA peers may be of equal, and perhaps even more, value and impact than the published strategies themselves.

4.2 Products

Regarding the products of the GCCS, the strategies truly represent a novel output, combining useful background information, current data on status and gaps, and recommendations for positive change. The crop-specific focus enables the potential for a product that is both comprehensive and detailed. The recommendations are often direct and honest. Being published outside of the constraints of political fora or academic journals, the GCCS are free to report, hypothesize, and recommend based on whatever data and knowledge exists, at the length needed to do the process justice. To the reader of the GCCS, there is often a sense of celebration of the usefulness of a given crop and its diversity, and an experience-based concern for the future of this diversity. All of these attributes are unique for technical documents in the PGRFA field.

Weaknesses of the GCCS products include that information and recommendations in static reports that take a relatively long time to be published can rather quickly become outdated. The long-form format of reporting that information may also limit the readership to only those with sufficient time and resources. As 'gray' literature, not peer-reviewed in an anonymous (i.e., single or double blind) sense, the strategies may not be considered by readers as robust as academic literature and, therefore, may not be as widely shared, cited, or valued. Available currently mainly only from the Crop Trust website, the strategies may also be challenging to find online unless the reader already knows where to look. Finally, the crop-specific focus has its limitations, particularly when an understanding of status and needs in PGRFA must be arrived at across multiple crops; data and recommendations in different strategies are not easily compared or combined.

4.3 Outcomes and impact

Regarding the outcomes and impact of the GCCS, in theory, the information and recommendations from the GCCS can be used by relevant institutions and policymakers to inform decision-making and planning. The crop-specific format of the GCCS allows extensive detail, that higher level documents, such as FAO's GPA's, cannot provide for each crop. This format may also be helpful for fundraising purposes tailored to individual crop communities. Created by subject matter experts arguably without political constraints, these unique, holistic, technical documents may be valued for their objectivity and comprehensiveness.

The Crop Trust has considered the strategies to be important documents informing its work, including using their recommendations as inputs in the planning for global initiatives (e.g., the Crop Wild Relatives Project) and for crop-specific activities, such as on coffee, sorghum, and forage crops (Crop Trust 2017). The Governing Body of the Plant Treaty has repeatedly expressed an interest in the GCCS becoming more useful to its objectives and has recommended that its Secretariat publicize and highlight strategy recommendations (FAO 2015, 2017, 2019, 2022e).

These potential strengths having been noted, uptake and impact of the GCCS may have historically suffered from insufficient organizational ownership or even a clear understanding of the target audiences of the strategies; or at least confusion among PGRFA stakeholders regarding strategy ownership and audiences. This may be so, at least in part, because no similar model exists, with the GCCS standing outside of long-standing and well-understood international political processes such as FAO's Report(s) on the State of the World's Plant Genetic Resources for Food and Agriculture (FAO 1997, 2010) and GPA (both of which are higher level and not very crop-specific), as well as outside of international (e.g., CGIAR's multi-year work plans) and national (e.g., USDA's Crop Vulnerability Statements - see Potato Crop Germplasm Committee [2020] for an example) PGRFA conservation and use planning. The GCCS are commonly considered by the PGRFA community, including most GCCS participating stakeholders, as being "Crop Trust Strategies" and thus mainly serving the purpose of informing the Crop Trust's decision-making (i.e., funding) processes. These viewpoints persist despite the Crop Trust repeatedly attempting to clarify that the strategies should be considered to be owned by the pertinent PGRFA communities themselves. While it is laudable to consider the wider community as the owners of the GCCS process, in reality the strategies typically lack clear ownership, either by organizations such as the Crop Trust and the Plant Treaty, or the wider set of stakeholders.

More importantly, a parallel uncertainty around the GCCS persists regarding who is responsible for translating strategy recommendations into action. Again, the laudable aspiration over the past two decades seems to have been that a wide diversity of institutions, at international, national, and perhaps other levels, could implement recommendations published in the strategies, and in this sense they may be considered guidance documents of potential use to any PGRFA stakeholder. The drawback of this approach is that no organization is clearly responsible or held accountable for taking action, and thus it is not surprising that reports of actions based on the GCCS are scarce or limited. Critically, no dedicated enabling mechanisms (i.e., funding sources) exist to implement the recommendations arising specifically from the GCCS processes. If such mechanisms did exist, perhaps responsibility for action would be much more easily assigned.

5. CURRENT STATUS AND FUTURE DEVELOPMENT OF GCCS

5.1 Current status of GCCS

A total of 43 GCCS processes and resulting publications have taken place over the past two decades, including both new strategies and updates to existing ones, with the first two of the strategies published in 2006 and the latest three (as of December 2022) due to be completed in early 2023 (**Table 1**). In combination, these focus on around 60 food crops, plus two specific strategies dedicated to a wide diversity of forage crop species. The GCCS have been led by over 70 authors/facilitators and have directly engaged hundreds, if not thousands, of crop experts and other stakeholders worldwide. The published GCCS are currently available at: https://www.croptrust.org/pgrfa-hub/ex-situ-conservation-strategies/.

Twenty-five of the GCCS were published more than five years ago, of which 20 were published more than ten years ago, all with overall facilitation by the Crop Trust. GCCS processes were boosted in recent years thanks to a grant to the Crop Trust from the German Federal Ministry of Food and Agriculture

(BMEL). Through this (2019 to 2022) project, ten new strategies have been developed and five of the original strategies were updated, approximately ten years after their original publication (**Table 1**) (Crop Trust 2022b).

Eight regional (sometimes called hemispheric) conservation strategies, all of which produced between 2006 to 2008 and not updated since, were developed following a somewhat similar methodology as the GCCS, but drawing upon a series of meetings of scientists and national program managers via regional networks to identify regional priorities. These regional strategies are not analyzed in this opinion paper.

5.2 Priority crops for future GCCS

Several criteria may be considered in deciding for which crops to develop GCCS, for example the crop's contribution to food and nutrition security or to economies and livelihoods globally or regionally, the degree of commitment from the crop's conservation and research stakeholders, perceived PGRFA conservation urgency, and data availability. This said, it is difficult to accurately predict which crops may serve important roles for society in the future (Khoury *et al.* 2022b), and investments in planning and research, including through GCCS processes, may partly determine their future relevance as well as encourage stakeholder interest and the generation of pertinent data. In this "chicken and egg" situation, it is sensible that both crops that are currently important, have high stakeholder activity, high conservation urgency and high data availability, and also those crops not yet at that stage but indicating potential, should benefit from GCCS development. In terms of selecting which crops with existing strategies should be updated and in what order, the above concepts also largely apply, alongside more straightforward considerations of how long it has been since the given crop's strategy was most recently updated, as well as available funding. Williams and Drummond (2020) reviewed the 26 GCCS produced to that date and identified ten strategies most in need of updating, based on their age, relative completeness, and the availability of new information.

Of the 35 food crops or crop groups listed in Annex 1 of the Plant Treaty, 31 have GCCS published or near finalization (**Table 1**). Strategies for one pulse (pigeonpea) and three vegetable crops (asparagus, beet, and carrot) remain to be developed. Historically, discussions on crops and their contributions to food security have tended to focus on energy dense staple cereals, pulses, and roots and tubers, and these crops are well reflected in Annex 1 and in the GCCS completed thus far (with a few exceptions, noted below). More recently, the essential contributions of vegetables and other crop groups such as fruits and nuts to food and nutrition security have been more widely recognized. Preparing GCCS for the remaining Annex 1 vegetable crops would thus be fitting and timely. Further emphasis on vegetable and other uses of crops currently on Annex 1 due to their main uses as starches, for example the use of the leaves of sweetpotato as a green, could also be of value.

Regarding Annex 1 forage crops, two global strategies - one on tropical and subtropical forages (2015) and another on temperate forages (2021) have been developed. The tropical and subtropical forages strategy attempts to cover all forages in those environments, and does not provide a list of species. The strategy does mention that the great majority of such species are not listed in Annex 1, but further notes that tropical and subtropical forage species conserved in the CGIAR centers (i.e., the International Center for Tropical Agriculture [CIAT] and the International Livestock Research Institute [ILRI]) are included in the Multilateral System of the Plant Treaty via its Article 15, which covers international collections.

The temperate forage strategy prioritizes a list of forage species, including both grasses and legumes. The strategy mentions that:

> "All taxa included in the sample set, with the exception of *Biserrula pelecinus*, are covered in Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) under Forages (grasses and legumes) or Crops (*Hordeum* and *Lathrus*). Annex I of the ITPGRFA includes additional temperate forage species within the genera included in the sample (5 spp. of *Festuca*, 3 spp. of *Lolium*, 2 spp. of *Lotus*, 2 spp. of *Lupinus*, 5 spp. of *Medicago*, 11 spp. of *Trifolium*), as well as additional temperate forage genera and selected species (2 spp. of *Agropyron*, 2 spp. of *Agrostis*, 1 spp. of *Arrhenatherum*, 3 spp. of *Astragalus*, 1 spp. of *Coronilla*, 2 spp. of *Melilotus*, 1 spp. of *Ornithopus*, 1 spp. of *Phleum*, 3 spp. of *Poa*)."

In sum, of the 29 forage genera included in Annex 1 of the Plant Treaty, 17 genera are covered by the temperate forage strategy.

Alongside the 34 GCCS covering Annex 1 food and forage crops, six additional strategies have been published thus far for non-Annex 1 crops. These include, by date of publication: coffee, tea, cucurbit crops, vanilla, capsicum crops, and peanuts (groundnuts). These represent an assortment of highly economically important crops, vegetables, and one staple pulse/oil crop (peanut/groundnut).

Other globally and regionally significant food crops, as well as, potentially, fiber, forage, and industrial crops, for GCCS processes could usefully be prioritized based on the considerations listed in the first paragraph of this section. Several information sources, including FAOSTAT (FAO 2022b), FAO's World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture (WIEWS) (FAO 2022d), and Genesys PGR (Data providers and the Crop Trust 2017-2022), among others, could be used to indicate contributions to food security as well as PGRFA conservation status.

A recent project directed by the Plant Treaty, "The Plants That Feed the World: Baseline data and metrics to inform strategies for the conservation and use of plant genetic resources for food and agriculture," compiles these and other data on over 350 food and agricultural plants worldwide (Khoury *et al.* 2022b), that could usefully be applied to future GCCS prioritization. These data highlight the extensive global contributions, for example, of oil crops such as oil palm and soybeans, as well as sugar crops such as sugar beets and sugarcane, none of which currently have GCCS. They could also help prioritize among the long list of vegetable, fruit, nut, and other crops of global or regional significance that likewise lack GCCS, for example: almonds, amaranth, apricots, avocados, blueberries, buckwheat, cashews, cherries, cotton, cranberries, dates, figs, garlic, ginger, grapes, guavas, hazelnuts, kiwi fruit, lettuce, mangoes, olives, onions, papayas, passionfruit, peaches and nectarines, pepper (*Piper* L.), pineapples, plums, pistachios, quinoa, raspberries, sesame, spinach, tomatoes, and walnuts. Additional aspects, such as international funding priorities or specific projects for which GCCS-type information would be useful, could also serve as prioritization filters.

5.3 Scope of GCCS

The GCCS processes conducted over the past two decades have mainly focused on *ex situ* conservation status and needs, which makes sense in light of their development coordination by the Crop Trust, whose

mandate is restricted to *ex situ* conservation. This said, several of the more recent strategies, for example for yams (2021), *Capsicum* (2022), millets (2022), peanut (2022), and potato (2022), have developed more extensive sections on *in situ* conservation and on farm management of the crops' genetic resources.

While all strategies have included some consideration of the status of use of PGRFA, this aspect has also been increasingly emphasized in more recent GCCS, including being reflected more often within their titles (**Table 1**). This is important and sensible, especially as advances in genetics and genomics, phenomics, the production of digital sequence information related to these -omics, and their application to plant breeding, have all advanced quite rapidly in recent years, compared to other aspects of conservation and use of PGRFA.

The inclusion of these additional elements likely adds considerable value to the GCCS but also further increases their complexity and production costs - both monetary and non-monetary - including needing to involve a greater number and diversity of stakeholders in the planning process. For *in situ* conservation, these may include protected area managers, government agencies involved in nature conservation and Indigenous and Farmers' Rights, international land conservation organizations, and Indigenous organizers and leaders. To strengthen use aspects, the engagement of more crop breeders (both from public and private sectors), geneticists, taxonomists, and other researchers and users of genetic resources would be necessary. This could partly be achieved by expanding the scope of the survey that has been used to gather information from stakeholders/experts, but it should be acknowledged that the surveys employed in many of the GCCS have been widely seen as far too long and complex already, representing a major burden to recipients and to the authors charged with synthesizing and analyzing their inputs. Considering the significant challenges and increased burden caused by widening the scope of the GCCS, narrowing the specific focus of the additional areas, in particular use, to those aspects most pertinent to a global conservation strategy, will be essential. That is, GCCS should focus more on how to stimulate use of collections, rather than more specifically on how to use them.

5.4 Updating and timing of GCCS processes

Ideally, all GCCS would be as current as possible, but the substantial time and financial resources required to produce the strategies, at least in their current format (see sections 4.1 and 5.5), suggest that a more realistic aspiration would be an update every three to five years at a minimum, with a maximum of ten years between updates. If more concise formats were successfully developed (see section 5.5), updates could also in theory occur more frequently. The periodic development of a comprehensive strategy over a longer period (e.g., every 10 years), with more limited and concise updates produced much more regularly (e.g., every one to three years), might represent useful compromise.

The timing of GCCS publications and updates could be planned to maximize impact within international PGRFA reporting and planning processes such as FAO's State of the World's Plant Genetic Resources for Food and Agriculture Reports and accompanying Global Plans of Action, Plant Treaty implementation milestones such as meetings of the Governing Body, and updates to the United Nations Sustainable Development Goals (SDGs) and the Convention on Biological Diversity (e.g., the post 2020 Global Biodiversity framework). Most of these processes occur approximately every decade, although Governing Body meetings happen more often. Given the large number of GCCS that would need to be updated to have current versions for most or all crops, such an extensive updating process would need to

be carefully planned, with plenty of lead time and strong connections to the intended recipients of GCCS information. As a more pragmatic option, summaries of the priorities and recommendations across the GCCS could be efficiently prepared to input into and influence these wider processes.

A major consideration brought up by various GCCS authors in our survey for the preparation of this opinion paper was the questioning of the strategic value of investing in further updates to strategies when the recommendations from earlier versions have not yet received adequate attention, let alone investment. Authors noted that very little follow-up in terms of meetings and other further planning and networking opportunities, as well as direct funding for conservation and use actions, have thus far occurred in connection with the GCCS. They warned that crop experts and other stakeholders may be reluctant to continue to participate in strategy processes if they see little tangible benefit from previous work.

It should be noted, however, that there has been marked progress made in some cases through coordinated crop-based community processes, for example by apple researchers in their investment in recent years in systematic genotyping of collections, and similarly regarding the genomics of bread wheat by that crop community. To what degree these advancements stem from the recommendations of GCCS has not been documented. The results of these initiatives could contribute significantly to higher quality information for updated strategies, and the absence of these data in the existing strategies could likewise lead to their being outdated. Detailed reviews of the data and recommendations of existing strategies would be worthwhile investments before prioritization for updating, to assess whether the recommendations appear to remain largely valid or are clearly no longer pertinent. During the GCCS updating process, such comparisons are also extremely useful. The authors of various recently updated strategies, for example for yams (2021), potato (2022), sorghum (2022), and *Vigna* (2022), examined the previous versions and assessed whether their recommendations remained sound, providing a helpful longitudinal change aspect to the analysis.

5.5 Format of the GCCS

The GCCS have been envisioned as comprehensive processes, valued for their global synthesis of all the information available and needed to implement action to improve the conservation and use of PGRFA for different crops. Thus far, these processes have resulted in very long strategy documents, which are costly to produce (both in terms of time and financial resources) and may limit their readership, and, ultimately, their impact, which requires uptake of the recommendations by decision-makers.

It is therefore worth considering options for making the GCCS processes more efficient and more cost-effective, and the products more accessible to consume. A more concise version of the strategies may be advisable, perhaps especially for updated versions, as much of the background information filling the long-form version (for example, on global use of the crops, or their taxonomy) may not require regular revision. Such a concise version would ideally be focused on priorities and recommendations. A digest of the strategy could also include key standardized metrics which could be used to monitor the status of conservation and other aspects for the target crop(s). The production of stand-alone summaries of the priorities and recommendations of the GCCS would likely be extremely valuable to increasing readership and potential impact.

In this regard, the experience of the USDA's National Plant Germplasm System (NPGS) could serve as a useful model. The NPGS has faced the challenge of securing timely information from its Crop Germplasm Committees (CGCs) about PGRFA status at the national level. Some CGCs produce Crop Vulnerability Statements (https://www.ars-grin.gov/CGC) sufficiently regularly to provide timely information, but others cannot. Consequently, the NPGS has in the past decade experimented with more concise formats as alternatives to the historical format of reports (e.g., Potato Crop Germplasm Committee 2020) or scientific publications (e.g., Volk *et al.* 2015). This experimentation has generated a one-page quad chart type format, somewhat akin to a SWOT analysis, where the CGC experts insert information on vulnerabilities and threats, PGRFA status and impacts, genetic research and breeding capacities (i.e., use aspects), and priority issues. This standardized, concise format has facilitated reporting PGRFA status at more frequent intervals, as well as efficient consumption of the information by national program leaders and other readers.

At the extreme end of the spectrum of potential methods for efficient reporting of GCCS outputs, it may be worth investigating the degree to which pertinent global information systems such as Genesys PGR (Data providers and the Crop Trust 2017-2022), FAO's WIEWS (FAO 2022d), and the Plant Treaty's Data Store or other components of the Global Information System for PGRFA (GLIS) (ITPGRFA 2022), may be able to automatically produce part or all of the needed information (Williams and Drummond 2020). These systems have made remarkable progress in the past decade in terms of quantities of information held, numbers of contributing organizations, and standardization of the data. This said, at the crop level, they are mainly useful for understanding quantities and types of PGRFA maintained *ex situ*, or distributed from *ex situ* systems, with other conservation and use aspects often reported at more aggregated levels, or not yet at all. Moreover, these systems still need to make further progress before they can offer globally comprehensive, accurate data on PGRFA conservation and use, as well as highlight their gaps (Khoury *et al.* 2022b). It may also be worth considering how GCCS processes could better complement these global databases as they continue to improve, including the potential for the information presented in the strategies to be deposited within the databases, for example summary information regarding *ex situ* collections not directly reported in the databases. This would likely be technically challenging and would require modifications to the current agreed scope of these online database systems (FAO 2021a).

As an alternative, further investigation of how the GCCS could become more of an online process may provide potential for increased efficiencies. As the engagement of crop experts represents one of the most novel and important aspects of the GCCS, but also requires a considerable portion of the resources expended in strategy production, alternative means to engage a wide and diverse set of stakeholders might be explored, for instance by engendering a responsive, mostly (or entirely) virtual network of experts similar to the Specialist Groups and Task Forces of the IUCN Red List processes (IUCN 2022) or to the Affiliates, Species Stewards, and Steering Committees of the Global Conservation Consortia mobilized by the botanic garden community (BGCI 2022). Such a wider network might in theory be able to provide a platform for broadening participation worldwide, facilitating greater information exchange among participants. It could help in building trust and collaboration opportunities among stakeholders, creating more transparency, inclusivity, and repeatability in the GCCS process. Further, the platform could serve as a mechanism for peer review of the strategies and of decisions regarding their updating, as well as monitoring implementation based on their recommendations.

In short, further investment in engagement of the expert stakeholders surrounding the GCCS is very likely to have multiple benefits, not only to the strategies but also to the impacts the strategies aim for. The efficient mobilization and continuance of such groups would be very valuable. However, these would likely require substantial investment in their facilitation.

6. LEADERSHIP, GOVERNANCE, AND OWNERSHIP

Leadership regarding the GCCS is essential to their future development as well as to the implementation of their recommendations. This includes responsibility for managing the GCCS processes, as well as governance and ownership over the products and recommendations, and the actions taken based on them.

Thus far, the Crop Trust has been the main organization that has initiated and led the development of the strategies, while working to make it clear that governance and ownership over the strategies should be considered to be the honor and the responsibility of the entire relevant crop community. While it is laudable to consider the wider community the owners of the GCCS, in reality the majority (though not all) of strategies typically lack a clear sense of ownership and buy-in by any particular group, institution or organization. This same uncertainty also applies to responsibility for implementation.

In view of potentially expanding the scope of the strategies (beyond a primary focus on *ex situ* conservation), as well as changing their format or updating timing and developing strategies for other crop types and groups (as discussed in Section 5), the most appropriate and promising institution(s) to lead future GCCS efforts might be revisited. A number of considerations may be taken into account. At a minimum, the lead organization(s) should have an international mandate, be reputable, have broad, productive working relationships with national, international, and other PGRFA stakeholders, and be independent and apolitical.

Whether the same organization that leads the GCCS processes should also be responsible for governance and ownership over the products and recommendations, and the actions taken based on them, is a critical question worthy of discussion, and potentially experimentation, to arrive at more effective arrangements, wherein uptake of recommendations is better assured and more impactful. Those taking up governance and ownership would ideally have the ability and capacity to raise funds to support the development, updating and implementation of the GCCS as well as to invest in conservation and use actions based on their recommendations.

There are a number of possible organizational scenarios for leadership of the GCCS processes as well as ownership and governance of the products, including:

Crop Trust. The Crop Trust is an independent, technical, globally recognized international organization with a specific mandate on the conservation and use of PGRFA, including being structured to secure and distribute long-term funding for PGRFA conserved *ex situ*. The Crop Trust is considered an essential element of the funding strategy of the Plant Treaty. The Crop Trust has predominantly been involved in *ex situ* conservation as well as information management, germplasm characterization, pre-breeding, and other aspects supporting the increased use of germplasm held *ex situ*. The Crop Trust provides long-term funding for international (Article 15) collections and may expand to supporting key national collections in the future. The organization recognises the importance of integrated and complementary conservation

(i.e., coordinated conservation including both *ex situ* and *in situ*/on farm formats), and has been involved in collaborative projects including *in situ* conservation aspects. The Crop Trust manages Genesys PGR (Data providers and the Crop Trust 2017-2022).

Leadership of future GCCS processes by the Crop Trust would certainly carry the momentum generated by its previous two decades of work in this area. The Crop Trust has been reluctant to claim full governance and ownership over the strategies; doing so, and demonstrating impact through action based on the recommendations, would likely provide a much clearer understanding for the PGRFA community of the role and potential power of the strategies. If it were preferred to widen, somewhat, this governance and ownership, without diluting the power of a single organization's responsibilities, supplementary participation in the governance by other institutions could be considered. This might occur, for example, through the creation of an advisory group gathering together organizations such as the Plant Treaty, FAO's Commission on PGRFA, One CGIAR and other international agricultural research institutions, representatives of national PGR institutions from each region of the world, as well as authorities on *in situ* conservation and on PGRFA use aspects.

Leadership, governance, and ownership over the GCCS by the Crop Trust, if it were willing to fully assume these roles, would provide a strong pathway by which the strategies could influence implementation of conservation and use activities funded by or via the Crop Trust. Influencing implementation by others may be less straightforward. While the Crop Trust has intensive and ongoing collaborations with national and international agricultural research organizations, it is likely limited in its potential to influence the degree to which national governments or international institutions will contribute to the development and updating of GCCS, as well as to implement actions based on strategy recommendations. The creation of an international advisory panel (i.e. to focus on governance) may be useful to expand the Crop Trust's reach toward these aims, as might co-leadership involving the Crop Trust and also organizations such as the Plant Treaty or FAO's Commission on PGRFA.

United Nations (UN) organizations. Several UN organizations have PGRFA mandates, including the Plant Treaty and FAO's Commission on Genetic Resources for Food and Agriculture (CGRFA). These organizations have a strong global convening power, particularly regarding national governments and their agencies involved in the conservation and use of PGRFA. They would be in a good position to coordinate and guide national governments (as well as UN agencies themselves) to contribute to the development and updating of GCCS, and to encourage implementation of actions based on their recommendations. Both the Plant Treaty and CGRFA have mechanisms in place to gather and synthesize information on the conservation and/or use of genetic resources, mainly from national partners, publishing these in the Plant Treaty's GLIS (ITPGRFA 2022) and FAO's World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture (WIEWS) (FAO 2022d). Information from the latter also provides a foundation for key documents such as the State of the World's Plant Genetic Resources for Food and Agriculture (SOW) (FAO 1997, 2010) and the Global Plans of Action on conservation and use of PGRFA. However, by the very nature of being part of the UN, these organizations and their methods are politically influenced, with governance fundamentally in the hands of member states. Without carefully constructed safeguards, this may negatively affect the objectivity, or at least perceived objectivity, of GCCS recommendations.

One CGIAR/ International Agricultural Research Centers (IARCs). IARCs operating under or outside the One CGIAR system have international mandates for the conservation and use of PGRFA of specific crops, and are highly involved in research and breeding activities. Many of the centers, especially The Alliance, also provide international PGRFA knowledge generation, coordination, and provision roles. Leadership regarding GCCS processes for crops under the mandate of these organizations would likely fit well with their organizational priorities; crops outside of these mandates may not receive as much attention (with The Alliance being a possible exception). Leadership, governance, and ownership over the GCCS by the IARCs would provide a strong pathway by which the strategies could influence implementation of conservation and use activities through these international organizations, and potentially a way by which funders of the IARCs, such as national overseas development agencies and the World Bank, could become aware of the strategies and potentially support implementation based on their recommendations. The IARCs also have intensive and ongoing collaborations with national agricultural research organizations, although they are likely limited in their potential to influence the degree to which national governments will contribute to the development and updating of GCCS, or to implement actions based on strategy recommendations.

Global Crop Committees or Virtual Networks. Global crop committees or other forms of virtual networks of technical experts could be created for leadership and/or ownership of the GCCS, composed of relevant stakeholders from different areas of expertise and regions of the world. Such structures could be modeled after the more successful versions of the many regional and crop-specific crop networks that have existed over the last few decades, and from examples such as the GCCS process for strawberry, which was developed without primary leadership or funding from the Crop Trust. Networks exist for IUCN Red List processes (IUCN 2022) (i.e., Specialist Groups and Task Forces) and for the Global Conservation Consortia mobilized by the botanic garden community (BGCI 2022) (i.e., Affiliates, Species Stewards, and Steering Committees). Such structures have been proposed earlier in this opinion paper as ways to expand stakeholder participation in the GCCS processes, but could additionally be considered as potential formats for leadership and/or governance and ownership. For consistency and to ensure momentum, overall responsibility for coordination of GCCS (across all crops) would still ideally be assigned to one organization, however. Leadership, governance, and ownership over individual GCCS by these committees/networks could provide a strong pathway by which the strategies could influence implementation of conservation and use activities by those involved in these networks, although this leadership may be limited in its power to influence the funding priorities of national and international organizations.

7. SUPPORTING THE PLANT TREATY AND ITS MULTILATERAL SYSTEM

7.1 The Plant Treaty and its Multilateral System of access and benefit sharing

The Plant Treaty, adopted in 2001 and in force since 2004, currently has 148 Contracting Parties, including the EU (FAO 2022a). The objectives of the Plant Treaty are the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising from their use, in harmony with the CBD, for sustainable agriculture and food security. Part IV of the Treaty (Article 10) creates a Multilateral System (MLS) of access and benefit sharing, to facilitate access to PGRFA and to share benefits arising from their use, while recognizing the sovereign rights of Contracting Parties over these resources. The MLS includes PGRFA of 64 major crops and forages, referred to as Annex 1 crops, that have been selected and negotiated among Contracting Parties, based on explicitly stated criteria of food security and interdependence regarding PGRFA (Article 11.1), although some countries have voluntarily added other species in their genebanks to the MLS, and the overall scope and functioning of the MLS is under discussion. All species included within a (crop) genus (including wild relatives) are meant to be included in the Annex 1 list, unless specifically excluded in the notes published in the Annex. The 64 crops listed in the current Annex 1 provide approximately 72-80% of the calories humans derive from plants globally (Khoury *et al.* 2015; FAO 2009).

According to the Plant Treaty, PGRFA in the public domain and under the management and control of governments are included in the MLS when Contracting Parties ratify or accede to the Plant Treaty. Natural and legal persons holding a collection of PGRFA can also voluntarily include their PGRFA in the MLS and can share their germplasm using the Treaty's Standard Material Transfer Agreement (SMTA). Further, PGRFA collections hosted by international agricultural research institutions (IARCs), such as CGIAR centers, that have signed agreements with the Treaty's Governing Body (so called Article 15 collections) are also included in the MLS, regardless of whether they are of crops listed in Annex 1. *In situ* Annex 1 PGRFA that is 'under the management and control of Contracting Parties and in the public domain' are also included within the scope of the MLS in the absence of national regulations that spell out access conditions to PGRFA found *in situ*. A number of countries have put policies in place which explicitly include only *ex situ* public domain Annex 1 materials in the MLS. Other countries are sharing on a voluntary basis non-Annex 1 PGRFA using the SMTA.

The Plant Treaty has established a Benefit-Sharing Fund (BSF) that aims to support projects in developing countries, addressing smallholder livelihoods, food security and adaptation of crops to climate change. This is achieved by enhancing the on-farm management of plant genetic diversity, strengthening local seed value chains and developing a community of practices to share plant genetic material, data and knowledge (ITPGRFA 2022b). Eligible organizations include governmental and non-governmental organizations, including genebanks and research institutions, farmers and farmers' organizations, and regional and international organizations, based in developing countries that are Contracting Parties. The BSF is intended to be replenished by funds obligatorily arising from commercialization and privatization of crop varieties developed from materials obtained under the SMTA; however, direct contributions (e.g., by national governments) are also welcome and have so far been the main source of BSF revenue.

7.2 Contribution of GCCS to the Plant Treaty and its Multilateral System

The core aims of the GCCS are to improve the conservation and use of crops' PGRFA, which are in line with the objectives of the Plant Treaty. Successful implementation of strategy recommendations towards these aims directly contributes to the Plant Treaty and its MLS, for example through improved access to a greater diversity of PGRFA materials as a result of more comprehensive and secure conservation. The spirit of collaboration and sharing embedded in the GCCS process, among other things, also directly aligns with the spirit of the Treaty and the MLS. Effective processes for developing, updating as well as implementing the GCCS would directly contribute to the further implementation of the Plant Treaty and its MLS. This could occur through enhanced collaborations among crop experts, genebank curators, breeders, researchers, protected area managers, farmers, and other stakeholders.

As per the diversity of means by which sharing of benefits of PGRFA can occur through the MLS (Article 13.2), the GCCS processes contribute through exchange of information, access to and transfer to technology, and capacity building.

Exchange of information. The GCCS are unique documents providing information at the crop level on status and gaps in conservation and use of PGRFA. These can be used to facilitate the sharing of information regarding the status and gaps in PGRFA globally, as well as that included within, and alternatively outside, of the MLS. Data from the surveys, compiled from global databases, and arising from the stakeholder meetings, could all represent valuable information that can usefully be shared with stakeholders. Such information includes germplasm collection contents, current status and conditions, regeneration and multiplication status, safety duplication status, acquisition priorities, status and accessibility of passport, characterization, and evaluation data, germplasm distribution levels, use types and levels etc., as well as information regarding networks, *in situ* conservation, and other aspects. Currently, Parties are providing such information to the Plant Treaty in a rather limited way. For example, GLIS (ITPGRFA 2022) mainly compiles information on germplasm with a DOI and distributions of germplasm with the SMTA. If kept up to date, the GCCS could provide substantial additional and valuable information facilitating PGRFA conservation and use. This may even include helping to clarify which collections and specific PGRFA are in the public domain and under the management and control of Parties to the Plant Treaty, and thus included in the MLS, and which ones are not.

Access to and transfer of technology. GCCS include discussion of topics focused on technology, and this information as well as the recommendations could be used to better clarify the state of access to and transfer of technologies, and aspirations to improve this situation. The GCCS could be further enhanced to more comprehensively review the current state of relevant technologies as applied to each crop and the degree to which these are accessible, including to Parties. The stakeholder processes and some of the potential new/enhanced governance structures proposed for the GCCS could also be used as platforms for Parties to collaborate and develop joint ventures for more effective access to genetic materials, technologies, research facilities, and other resources, while adhering to the adequate and effective protection of intellectual property rights (Article 3b[iii]) and to Farmers' Rights (Article 9).

Capacity building. The GCCS specifically include sections focused on capacity building status and needs, which can be applied to needs of Contracting Parties. Further, the stakeholder processes in the strategies already represent a form of capacity building through meeting and sharing of information and the building of relationships and mutual learning. These processes could be further strengthened, and in combination

with some of the potential new/enhanced governance structures proposed for the GCCS could also be used as platforms to build capacity in PGRFA conservation and use.

The GCCS also have the potential to contribute to strengthening the evidence base underpinning funding decisions made for the Plant Treaty's BSF, for example by assigning funding based in part on strategy recommendations. Applicants to the BSF could be encouraged to align their proposals with GCCS recommendations, increasing awareness and buy-in regarding the strategies and potentially also incentives for wider engagement in GCCS processes.

7.3 Contribution of the GCCS to discussions regarding Annex 1

While the Plant Treaty covers all PGRFA (Article 3), commiting Contracting Parties to their conservation, exploration, collection, characterization, evaluation, and documentation (Article 5) as well as sustainable use (Article 6), the MLS initially covers only PGRFA listed under its Annex 1 (as well as the Article 15 collections). In accordance with Articles 23 and 24 of the Plant Treaty, it is possible to amend the Annex 1 list to include other crops considered important for food security and interdependence among countries regarding PGRFA, and also to voluntarily add material not in Annex 1. The Governing Body at its seventh session in 2013 extended the mandate of the 'Ad hoc Open-ended Working Group on enhancing functioning of the MLS' to consider, among others, criteria and options for possible adaptation of the coverage of the MLS. A proposal by the Working Group for an amendment to Annex 1 was made and a Draft Resolution XX/2019: Enhancement of the Multilateral System of Access and Benefit-Sharing of the International Treaty was delivered in its report to it eighth session of the Governing Body (IT/GB-8/19/8/8.2 Rev1) to be considered by the Parties. The ninth session of the Governing Body in 2022 gave the go-ahead to re-start negotiations in this area after a hiatus since the eighth session).

In the context of ongoing discussions around the potential expansion of Annex 1, GCCS published for non-Annex 1 crops could be a very useful tool in providing information on the global use of these crops as well as the status and gaps in the conservation and use of their PGRFA. The strategies could officially serve as a stakeholder-peer reviewed, scientifically-based, technical input to the Governing Body and its Contracting Parties and other interested stakeholders, including in their discussions and negotiations on the potential expansion of Annex 1 and enhancement of the MLS. In addition, information in the GCCS on the status of *in situ* conservation of crops could be useful to discussions around the scope of Annex 1 in terms of *in situ* occurrences of PGRFA.

7.4 Contribution of the Plant Treaty and the Multilateral System to the GCCS

As the Plant Treaty and its MLS share with the GCCS the core aim of an effective and efficient global system for the conservation and (sustainable) use of PGRFA, further development of the Plant Treaty is likely to also facilitate the objectives and recommendations of the GCCS, perhaps especially regarding those crops listed in Annex 1 or covered by Article 15.

The Plant Treaty, or FAO, may be candidates for potential leadership or otherwise involvement in the facilitation, governance, and ownership over the GCCS; this potential is explored in section 6. Regardless of whether the Plant Treaty enters into such a formal arrangement with the GCCS, it has considerable potential to leverage its forum to further the work of the strategies. This could occur, for example, by encouraging Contracting Parties to engage in the GCCS processes, as well as in the uptake and

implementation of their recommendations. Connecting the BSF of the Plant Treaty to the recommendations of the strategies would also likely contribute significantly to GCCS implementation and to tangible impacts.

8. AWARENESS RAISING AND BUY-IN

PGRFA conservationists, breeders, and other stakeholders connected with the work of the Crop Trust, or who follow in detail the reports and discussions of the Plant Treaty, are likely to have some degree of awareness of the GCCS. Others who are less integrated with these institutions, regardless of whether working in international, national, or sub-national contexts, probably have limited awareness of the strategies, despite almost two decades of GCCS processes.

When strategies are published, the Crop Trust, authors and their organizations, and other actors have worked to various degrees to raise awareness of their existence through various communications channels, including social media, blogs, and scientific/technical outlets (e.g., ISHS 2008, World Coffee Research 2017).

Communication, awareness raising, and advocacy about the GCCS and its recommendations are critical for increased uptake and implementation. These processes ideally need to be directed at, and tailored to, different target groups for maximum impact. Proper communication to different target groups would ensure a greater understanding of the GCCS and help to motivate their buy-in and commitments to the implementation of the strategies.

There is a wide range of stakeholders - both direct and indirect - for which the GCCS could be of value and interest. Direct stakeholders groups are those intimately concerned with and/or having responsibility for the conservation and use of the PGRFA of specific crops. These include crop and PGRFA experts, genebank curators and other *ex situ* plant conservationists, public and private plant breeders, private sector, protected area authorities and managers, farming communities, and policy makers, especially at international and national levels. Indirect stakeholder groups are those who are not directly managing PGRFA and have not been involved in the development of the GCCS, but could make use of the information contained in the GCCS. These may include a wide range of crop researchers, academic researchers and students, civil society organizations, and more.

Crop and PGRFA experts. Crop experts are critically important stakeholders in the GCCS processes, as they can contribute to the development, peer review, and updating of the strategies, based on their knowledge and expertise. These experts work for a variety of institutions, including international, national, and other agricultural research organizations, UN agencies, botanic gardens, universities, NGOs, and more. The GCCS are typically of high interest to this group. Efforts could be made to encourage a wider range of crop experts to participate in the GCCS processes, for example through the global crop network/committee concepts mentioned in section 5.5. Overcoming historical hurdles, such as conducting the strategy process in a limited number of languages, would need to be overcome to fully engage crop and PGRFA experts for crops that are of interest worldwide. Communications strategies could be developed specifically for these experts, including, for example, crop-specific newsletters or social media. Further publication of the strategies in academic journals and other scientific media (or, at the least,

generating DOIs to facilitate citation of the GCCS) would also likely raise the potential for awareness as well as buy-in; many of these experts mainly read and cite peer-reviewed journals and are primarily incentivized by authorship in these fora.

Genebank Curators. Curators are responsible for conservation, characterization, and distribution of PGRFA from *ex situ* repositories. Their knowledge in these areas represents an essential resource for GCCS development, and not only for those institutions that do not make their data available through global databases, but also those that do, since additional nuance is very often required to fully understand PGRFA status and gaps. To reach this community globally, GCCS authors often rely on lists of collections available through global databases such as Genesys PGR (Data providers and the Crop Trust 2017-2022) and FAO's WIEWS (FAO 2022d), as well as through personal contacts and knowledge. Outdated contact information, particularly regarding email addresses, has constrained the ability of GCCS authors to reach all potential curators. The Crop Trust and FAO, in collaboration with reporting organizations, could support GCCS processes by ensuring that this contact information remains up to date and easily available through more active curation.

The experiences of various authors of GCCS have shown that there have been limitations, reluctance, or constraints for several genebank curators to participate in or fully report data through the surveys. In these circumstances, it has often only been through personal contacts within the crop community that responses were finally obtained. While the leaders of the GCCS processes can surely do further work to ensure awareness of the strategies and their importance within curator communities, the substantial time investment by curators to fill in the survey (typically many hours, or even days) likely represents a real constraint. This may potentially be overcome by shortening the surveys as well as making them more accessible (i.e., through multiple languages), or through creative means by which to incentivize completion (beyond potential attendance in stakeholder meetings, which has likely become less of an attraction as these meetings have become increasingly virtual), including, potentially, financial compensation. Buy-in to the GCCS is very likely also predicated on and constrained by institutional leadership as well as institutional and higher level (i.e., national) policies regarding information sharing and exchange. Efforts by GCCS leaders and supporting institutions (such as the Plant Treaty) may be critical to removing these roadblocks to full participation by genebank curators worldwide.

Plant Breeders. Breeders are among the most important users of PGRFA and as such should be considered primary participants in, as well as beneficiaries of, the GCCS. Breeders can provide the most direct insights into the current use of PGRFA as well as evolving and upcoming needs. Increased awareness of, and buy-in to, the GCCS within the crop breeding community (i.e., greater demand for the strategies by its primary intended beneficiaries) would likely create greater overall momentum for the strategies. Given further awareness-raising and buy-in, breeding institutions, perhaps especially from the private sector, could also represent sources of financial support for future GCCS.

Private sector. Private sector actors and industry (other than breeders, who are covered above) are important stakeholders, especially those in the agroindustry sector. They obtain, process, and market a wide range of crops and consequently could be a major target group for expanding the 'use' scope of the GCCS.

Protected areas authorities/managers. Land managers and their respective institutions, e.g. ministries of the environment, are responsible for maintaining natural habitats and the flora and fauna living in them. To this end, they may be conserving crop wild relatives and crop pollinators, with some protected areas also prioritizing Indigenous and agrarian livelihoods and thus the protection of biocultural processes that support crop landrace diversity. Compared to other stakeholder groups historically involved in the GCCS processes, protected areas authorities may be more challenging to engage, as PGRFA conservation and use is generally not at the core of their mandates. Many protected areas often restrict collecting and use of biodiversity. If the GCCS are to expand to more fully document the state of *in situ* conservation of PGRFA, as well as to make evidence-based recommendations regarding strengthened *in situ* conservation, land managers would be essential additional stakeholders. Awareness-raising efforts targeted at this community regarding the relevance of habitat protection to food and nutrition security, and thus further justification for habitat conservation, may be valuable to increasing buy-in.

Farming communities. Farmers are the primary custodians of cultivated crop diversity and are considered the ultimate (potential) beneficiaries of PGRFA programs and processes, including the GCCS. They have an intimate knowledge of the PGRFA that they manage on-farm and, for this reason, could theoretically make a major contribution to the GCCS if they were effectively engaged. Globally, farmers represent a highly decentralized and extremely diverse stakeholder group and are thus particularly difficult to include efficiently or comprehensively. Farmer organizations and pro-farmer NGOs operate in most world regions and may represent a potential means by which to further engage farming communities in the GCCS processes.

Policy makers. Policy-makers - also called decision-makers - relevant to the GCCS include international treaties and organizations, national institutions, and sub-national organizations responsible for the development of policies and rules that influence the conservation and use of PGRFA. Effective policies enabling international collaboration provide the foundation on which processes such as the GCCS are formed; without these there would be no reason to create such strategies at the global level. Likewise, deficiencies and constraints in policies facilitating conservation and use of PGRFA - at all levels - may impede the aims and recommendations of the strategies. Awareness-raising and buy-in to the strategies by policy-makers are thus incredibly important.

International agreements and organizations such as the Plant Treaty, FAO (especially its CGRFA), and the CGIAR are already well aware of the GCCS, although continued efforts to highlight their relevance throughout these organizations are likely useful. Better integration of the GCCS with their major processes, such as FAO's *State of the World's Plant Genetic Resources for Food and Agriculture* Reports and accompanying Global Plans of Action, as well as Plant Treaty Governing Body meetings, would represent promising means by which to increase overall awareness and buy-in.

Decision-makers operating in other relevant international treaties and agreements, such as the CBD and the SDGs, are likely much less aware of the GCCS. Further integration of the strategies in processes such as the post-2020 Global Biodiversity Framework and future updates to the SDGs would be very useful to increase awareness and buy-in of the GCCS.

National and sub-national level policy makers relevant to PGRFA likely have varied levels of awareness of the GCCS. The strategies could serve as useful, independent information sources for these decision-makers, including for their negotiation processes in international fora. Awareness raising regarding the GCCS targeted to these stakeholders may be particularly effective via international processes in which they are already engaged, for example through the Plant Treaty, FAO and other organizations of the United Nations, and the CBD.

Indirect stakeholders. Making crop researchers, academic researchers and students, civil society organizations, and other indirect stakeholders more aware of the value of the GCCS, both as comprehensive, independent processes resulting in detailed information about the current status of conservation and use of crop PGRFA, and also as sources of clear recommendations for improvements to that status, could serve to expand the impact of the strategies. Awareness raising through diverse channels, including academic publications, blogs, mainstream news, social media, and educational curricula would be needed to reach this wide range of stakeholders.

9. SUSTAINABILITY OF AND FUNDING FOR THE DEVELOPMENT AND/OR UPDATING OF GCCS

9.1 Funding for GCCS to date

The early rounds of GCCS, initiated in 2004 and published between 2006 and 2009, were developed through leadership and coordination by the Crop Trust and funding from the Australian Grains Research and Development Corporation and other sources (**Table 1**). Each strategy cost an estimated USD $100,000 to support the authors'/facilitators' time, stakeholder meeting(s) and other travel, and coordination by the Crop Trust. Despite this funding, several of the strategies, including for chickpea (2008), lentil (2008), and faba bean (2009), were not fully completed by the assigned authors/facilitators; these were finalized through intensive writing and editing by Crop Trust staff, contributed in-kind. The (uncompensated) contributions by genebank curators and others to the survey and meeting processes are not included in this general cost calculation and are difficult to estimate.

At least a couple of the early strategies - for strawberry (2008) and coconut (2008), for example - were developed by the relevant crop stakeholder community without major financial support via the Crop Trust. The strawberry strategy was prepared by the strawberry genetic resource community with the support of the Crop Trust, Bioversity International, the North American Strawberry Growers Association, and the US Department of Agriculture, Agricultural Research Service, and was published in collaboration with the International Society for Horticultural Science. The coconut strategy was funded by Bioversity International, the Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), the CGIAR research program on Forests, Trees and Agroforestry (FTA), the Australian Centre for International Agricultural Research (ACIAR) and the Australian Department of Foreign Affairs and Trade (DFAT).

The GCCS processes were boosted in recent years thanks to a grant of USD 1.4 million to the Crop Trust from the German Federal Ministry of Food and Agriculture (BMEL). Through this (2019 to 2022)

project, ten new strategies have been developed and five of the original strategies were updated, approximately ten years after their original publication (**Table 1**) (Crop Trust 2022b). This overall budget was allocated at approximately 42% to authors/facilitators, 40% to personnel and overhead at the Crop Trust, 8% for meetings, 8% for communications, and 2% for travel (a much smaller amount than originally planned, due to the COVID pandemic). Encompassing all these expenses, each strategy cost around USD $93,000. The coordination by the Crop Trust, as per several of the early strategies, involved substantial staff time not only to guide the primary authors but also to compile additional data and conduct analyses, write various sections of the strategies, and review and edit the documents. Part of these expenses were contributed in kind, for a total estimated cost per strategy of approximately USD $100,000.

9.2 Estimated future costs and priorities

As a forward-looking costing exercise, expenses for completion of GCCS for the remaining four food crops in Annex 1 (asparagus, beet, carrot, and pigeonpea), at a similar cost to the recent BMEL-funded project, would require approximately $372,000-$400,000 USD. Thereafter, updating all 35 Annex 1 food crops, as well as forages (covered in a few multi-species strategies, as per the work done to date), would cost around $3.4-$3.7 million USD every 10 years. Additional funding for the development of important non-Annex 1 crops, as discussed in section 5.2, would cost around $1 million USD for every 10 new crops.

The total funding needed for the GCCS highly depends on their scope and format. Expansion of the processes to more comprehensively include *in situ* conservation as well as (some) use aspects would likely increase GCCS costs substantially, particularly in terms of in-person meetings costs. On the other hand, the successful development of more concise versions of the strategies may cost considerably less than current expenses. A potential ideal in terms of timing of GCCS production - i.e., the periodic development of a comprehensive strategy over a longer period (e.g., every 10 years), with more concise updates produced much more regularly (e.g., every one to three years) - would entail the combination of both the standard costs for the long-form version estimated above, as well as additional costs for facilitation and production of the concise versions.

9.3 Funding mechanisms

Production of crop-level global strategies of the quality and comprehensiveness of the GCCS cannot be accomplished without funding. For the long-term sustainability of the GCCS processes, this funding would ideally be specifically allocated through stable channels. This could include through core funding allocations to international organizations such as FAO from participating member countries or via the endowment of the Crop Trust. For crops with high commercial value, funding from private companies could be further explored and encouraged.

If such a stable funding mechanism is not possible, periodic generation of funds for the GCCS through grants may be feasible, such as was done by the Crop Trust in its partnership with the BMEL, or alternatively by organizations such as the Plant Treaty for the BSF or FAO for the development of the FAO's Report(s) on the State of the World's Plant Genetic Resources for Food and Agriculture. A mixture of funding from different partner organizations may be considered, for example via the Crop

Trust for the *ex situ* conservation aspects and via the Plant Treaty or the FAO's CGRFA for *in situ* and use components.

10. SUMMARY AND RECOMMENDATIONS FOR THE FUTURE OF GCCS

Conservation and use of PGRFA are essential to food and nutrition security, agricultural sustainability, adaptation to and mitigation of climate change, and social progress and equity. It is clear that considerable further actions are needed to comprehensively conserve and to make fuller use of PGRFA globally. Strategizing how to effectively and efficiently achieve these aims crop by crop as well as holistically is as pertinent as ever.

The GCCS represent unique processes and products in their aim to generate, compile and analyze the information needed to understand the current status of conservation and use of individual crops' PGRFA globally, providing sufficient detail and specific recommendations to enable informed decision-making toward improvements in this status. Their mixed-methods approach - incorporating information from multiple sources including expert surveys, global databases, the published literature, and stakeholder meetings - represents a robust, and perhaps the best current, means by which to compile the global state of knowledge on the status and needs of a crop's PGRFA.

The mobilization of a large crop-specific stakeholder community through the GCCS process is of particular value, not only leading to more comprehensive strategies but also facilitating the collaborations and relationships needed to implement recommendations globally.

Thus far, 43 GCCS have been developed or are in the process of being completed, mostly covering the Annex 1 crops of the Plant Treaty (food crops, temperate forages, and tropical and subtropical forages), with strategies for a few non-Annex 1 crops also published. Of the 35 food crops or crop groups in Annex 1, strategies for one pulse (pigeonpea) and three vegetable crops (asparagus, beet, and carrot) remain to be developed. There are many other crops and crop groups, such as vegetables, oilseeds, fruits, and nuts, that make important contributions to global food and nutrition security and sustainable agriculture, which should be considered for GCCS development.

These GCCS processes require a very significant amount of time and financial resources. With the methods that have been employed thus far, they cost approximately $100,000 USD per strategy and take one year or more to complete. The current evolution of the strategies toward more comprehensive coverage of *in situ* conservation as well as PGRFA use aspects will likely further increase these costs if the same methods are followed.

Whether these investments in the GCCS are leading to impacts that justify their costs is difficult to assess. Accounts of implementation of conservation and use actions based on strategy recommendations are anecdotal and scarce. The GCCS offer considerable information and knowledge; this value has very likely not been taken advantage of nearly as much as it could be.

The potential of the GCCS has suffered from unclear organizational ownership and understanding of the target audiences of the strategies; or, at the least, considerable confusion among PGRFA stakeholders regarding strategy ownership and audiences. An equivalent uncertainty has persisted regarding who is

responsible for turning strategy recommendations into action. No dedicated funding mechanisms currently exist to implement the recommendations arising from the GCCS processes.

The Plant Treaty and the GCCS share a spirit of international collaboration towards the conservation and use of PGRFA. The strategies support the Treaty through exchange of information, access to and transfer of technology, and capacity building; and could contribute to providing an evidence base for BSF allocations and for discussions around expansion of the scope of the MLS. The Plant Treaty could significantly increase the impact of the GCCS by encouraging engagement in the GCCS processes and implementation of its recommendations by Contracting Parties, as well as by contributing to a funding mechanism for this implementation.

10.1 Recommendations

Here we provide our recommendations regarding the future of the GCCS, with particular reference to sustainability and impact, based on the key findings discussed above.

- ***Clarify leadership, governance, and ownership over the GCCS***.
    - Various options involving international organizations and/or expert committees and networks offer potential, as well as tradeoffs, for leadership, governance, and ownership.
    - The Crop Trust remains among the most appropriate organizations for leadership of the GCCS. Its facilitating impact could be widened through the creation of an advisory group (focusing on governance) gathering together organizations such as the Plant Treaty, FAO's Commission on PGRFA, One CGIAR and other international agricultural research institutions, representatives of national PGR institutions, and authorities on *in situ* conservation and on use aspects. Co-leadership by the Crop Trust and other organizations could also be explored, for example with Crop Trust leadership for *ex situ* conservation aspects and the Plant Treaty or the FAO's CGRFA for *in situ* components.
    - Organizing virtual expert committees or networks to lead, govern, and/or own the GCCS may be a promising addition or alternative. Overall facilitation and funding coordination would still likely need to be assigned to a single international organization.
    - An ideal arrangement could be the Crop Trust for primary leadership of the GCCS processes, an international advisory group contributing to governance, and expert committees/groups taking on primary ownership of the strategy priorities and recommendations.
- ***Develop new GCCS for other priority crops***.
    - A set of criteria should be developed for prioritizing and selecting crops for new GCCS. These could include, for example, crops' contributions to food and nutrition security or to economies and livelihoods globally or regionally, the degree of interest in or commitment from the crops' conservation and research stakeholders, perceived PGRFA conservation urgency, and data availability. Various information sources can be utilized to facilitate this prioritization.
    - Priority could be given to the remaining crops of Annex 1 - one pulse (pigeonpea) and three vegetable crops (asparagus, beet, and carrot) - for which strategies remain to be developed, as well as other globally and regionally significant food crops, for instance as compiled in the 'Plants that feed the world' list (Khoury *et al.* 2022b).

- ***Increase awareness of and buy-in to the GCCS***.
    - Strengthened connections between the GCCS and the Plant Treaty, FAO, and potentially other institutions, treaties, and processes would likely dramatically increase awareness and buy-in globally. Integration of the GCCS into key international processes such as FAO's State of the World's Plant Genetic Resources for Food and Agriculture Reports and accompanying Global Plans of Action and Plant Treaty implementation milestones such as meetings of the Governing Body, would be highly strategic. Connecting funding, for instance from the Plant Treaty's BSF, or from the Crop Trust's endowment, to the recommendations of the strategies, would likely vastly increase awareness of, and buy-in to, the GCCS as well as impact from them.
    - Considerable further work could also be done to increase awareness and buy-in with specific stakeholders, including crop experts, germplasm curators, plant breeders, private sector actors, land managers, farming communities, and policy makers. These efforts would need to be tailored to the stakeholder group, and would include outreach to these communities as well, potentially, as adjusting GCCS processes to better facilitate their engagement.
    - Further efforts should be made to make the strategies more widely findable, accessible, interoperable, and repeatable. Multiple publication venues should be explored, including in collaboration with international organizations as well as academic journals and other media.
- ***Make the GCCS easier to produce and to consume***
    - Greater integration between the GCCS and global databases such as Genesys PGR and FAO's WIEWS would be worthwhile, although there are likely to be constraints to full integration due to the different methodologies and scope.
    - A much more concise version of the GCCS represents a valuable goal, perhaps especially for updated strategies. These would ideally be focused on priorities and recommendations. Shortening of the strategies may also allow for expansion in their scope (i.e., *in situ* conservation as well as use) without additional costs. Several models of concise products for PGRFA planning already exist at the national level (e.g., the USDA's short format for their Crop Vulnerability Statements).
    - Future strategies would be strengthened by including action plans, with milestones and targets, to guide progress in the implementation of their priorities and recommendations.
    - The production and distribution of stand-alone summaries of the priorities and recommendations of the GCCS would likely be extremely valuable to increasing readership and potential impact.
    - Summaries of GCCS recommendations across all strategies for use in the preparation of international PGRFA reporting and planning processes such as FAO's State of the World's Plant Genetic Resources for Food and Agriculture Reports and accompanying Global Plans of Action, Plant Treaty implementation milestones such as meetings of the Governing Body, and updates to the United Nations Sustainable Development Goals (SDGs) and the Convention on Biological Diversity (e.g., the post 2020 Global Biodiversity framework), in coordination with colleagues from those processes, would likely increase coordination and integration of the GCCS in these fora.

    - In terms of timing, a realistic aspiration that balances the costs of production against the need for timely data would be a strategy update every three to five years at a minimum, with a maximum of ten years between updates. If more concise formats were implemented (i.e. focused mainly on priorities and recommendations) updates could occur more frequently. The periodic development of a comprehensive strategy over a longer period (e.g., every 10 years), with more concise updates produced much more regularly (e.g., every one to three years), might be an ideal balance.
    - As the engagement of crop experts represents one of the most novel and important aspects of the GCCS, but also requires a considerable portion of the resources expended, alternative means to engage a wide and diverse set of stakeholders might be explored, for instance by engendering virtual committees/networks.
- ***Pivot to implementation***
    - The GCCS are unique, comprehensive sources of information on the status and gaps in the conservation and use of PGRFA. Their scope, format, timing, and other variables could be changed to further increase their value and/or decrease costs, but ultimately the much greater concern is the historical lack of action based on strategy recommendations. Further changes or investments in the strategies may not provide much strategic value without more focus on uptake and implementation.
    - Further investment in engagement of expert stakeholders surrounding the GCCS is very likely to have multiple benefits, not only to the strategies but also to the impacts the strategies aim toward. The efficient mobilization and continuance of such groups would be very valuable; these would likely require thoughtful investment in their facilitation.
    - Specific funding for implementation of conservation and use activities based on the recommendations of the strategies is paramount. This funding would ideally be specifically allocated through stable channels. This could include through core funding allocations such as FAO from participating member countries or via the endowment of the Crop Trust. If such a mechanism is not possible, periodic generation of funds through grants may be more feasible. A mixture of funding from different partner organizations may be considered, for example via the Crop Trust for the *ex situ* conservation aspects and via the Plant Treaty or the FAO's CGRFA for *in situ* and use components.

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