REVIEW & INTERPRETATION

CGIAR Operations under the Plant Treaty Framework

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ABSTRACT

The history of CGIAR and the development and implementation of the International Treaty on Plant Genetic Resources for Food and Agriculture ("Plant Treaty") are closely intertwined. In accordance with the agreements that 11 CGIAR centers signed with the Plant Treaty's Governing Body under Article 15 of the treaty, >730,000 accessions of crop, tree, and forage germplasm conserved in CGIAR genebanks are made available under the terms and conditions of the multilateral system of access and benefit sharing, and the CGIAR centers have transferred almost 4 million samples of plant genetic resources under the system. Many activities of CGIAR centers and their genebanks (e.g., crop enhancement, improved agronomic methods, seed system strengthening, and capacity building) are influenced by, and promote, the Plant Treaty's objectives. The continued existence and optimal functioning of the Plant Treaty's multilateral system of access and benefit sharing is critically important to CGIAR in the pursuit of its mission. However, the multilateral system has encountered some challenges since the Plant Treaty came into force. The successful conclusion of the ongoing process for enhancing the functioning of the multilateral system could increase monetary benefit sharing and incentives for exchanging more germplasm. In the meantime, increased efforts are necessary to promote nonmonetary benefit sharing through partnerships, technology transfer, information exchange, and capacity building. These efforts should be integrated into countries' and organizations' work to implement the Plant Treaty's provisions on conservation and sustainable use of plant genetic resources, and farmers' rights.

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Abbreviations: DOI, digital object identifier; GHU, germplasm health unit; GLIS, global information system; IA Principles, CGIAR Principles on the Management of Intellectual Assets; INGER, International Network for Genetic Evaluation of Rice; ITPGRFA, International Treaty on Plant Genetic Resources for Food and Agriculture; KALRO, Kenyan Agriculture and Livestock Research Organization; LEA, limited exclusivity agreement; PGRFA, plant genetic resources for food and agriculture; PVP, Plant Variety Protection; QMS, quality management system; RUA, restricted use agreement; SMTA, Standard Material Transfer Agreement adopted under the International Treaty on Plant Genetic Resources for Food and Agriculture.

Agricultural biodiversity plays a major role in sustaining agricultural development and food security worldwide, and the livelihoods of poor rural communities. Its loss combined with

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climate change and land degradation are major global challenges for sustainable development. The mission of CGIAR is to "advance agricultural science and innovation to enable poor people, especially women, to better nourish their families, and improve productivity and resilience so they can share in economic growth and manage natural resources in the face of climate change and other challenges." Its research is performed by 15 CGIAR centers in close collaboration with >3000 partners, including national and regional research institutes, civil society organizations, academia, development organizations, and the private sector. The primary geographical focus of CGIAR research and development is developing countries. Eleven of the CGIAR centers focus much of their work on conservation and use of the diversity of plant genetic resources for food and agriculture (PGRFA), using that diversity to develop improved crops, forages, and agroforestry tree species for food security and rural development.

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, or Plant Treaty) came into force in 2004. The Plant Treaty's objectives are the conservation and sustainable use of PGRFA and the fair and equitable sharing of the benefits arising from their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security. Currently (as of 1 July 2018), there are 144 contracting parties to the Plant Treaty. Among the most recent ratifications are those of Argentina, Bolivia, Chile, and the United States.

It is not surprising that the history of CGIAR and the development of the ITPGRFA are closely intertwined. CGIAR has been very much engaged in the international community's efforts over the last 50 yr to develop a global system for the conservation and the sustainable use of PGRFA. CGIAR centers, and the international ex situ collections they host, have always been considered key components of the implementation of internationally concerted policies and strategies on PGRFA. CGIAR is explicitly mentioned in the text of the International Undertaking on Plant Genetic Resources (adopted in 1983), within its provisions on international cooperation and international arrangements. Based on these provisions, in 1989, the Commission on Genetic Resources for Food and Agriculture of FAO called for the development of an International Network of Ex Situ Collections under the auspices of FAO. In 1994, centers of CGIAR signed agreements with FAO, placing most of their collections in the International Network under the overall framework of the International Undertaking. Through these agreements, the centers accepted a number of responsibilities and obligations, in particular, to hold designated germplasm "in trust for the benefit of the international community," and "not to claim ownership, or seek intellectual property rights over the designated germplasm and related information." In 1997, the FAO council launched a renegotiation of the International Undertaking to, among other things, bring it into line with the Convention on Biological Diversity. Those negotiations culminated in 2001 with the adoption of the text of the ITPGRFA. Article 15 of the ITPGRFA recognizes the importance of the CGIAR collections as one of the supporting components of the Plant Treaty, and it invites the CGIAR centers to sign agreements with the ITPGRFA Governing Body to bring their in trust collections under the framework of the ITPGRFA and to recognize the authority of the Governing Body to provide policy guidance relating to those collections. In October 2006, 11 CGIAR centers signed such agreements with the Governing Body. Since that time, CGIAR has been actively engaged in many ITPGRFA-related activities, some of which are described below. Although the centers' Article 15 agreements are concerned almost exclusively with the in trust collections hosted by centers' genebanks, many other activities of CGIAR centers and their genebanks (e.g., crop enhancement, implementing improved agronomic methods, seed system strengthening, and capacity building) are influenced by, and promote, the ITPGRFA's objectives.

This paper describes how CGIAR activities fit within the overall framework of the Plant Treaty, focusing on those activities that most directly contribute to the implementation of the Treaty: conservation of PGRFA, phenotypic and genetic characterization of genetic resources, plant pre-breeding and breeding and germplasm distribution (both of landraces and improved lines), and supporting activities such as capacity building, technology transfer, and information exchange. The paper is structured around the Plant Treaty's most relevant elements: conservation, exploration, collection, characterization, evaluation, and documentation of plant genetic resources (Article 5); sustainable use of plant genetic resources (Article 6); the multilateral system of access and benefit sharing (Articles 10–13); the global information system (Article 17); and farmers' rights (Article 9). CGIAR activities are grouped and presented in relation to these Treaty components. The paper also highlights challenges CGIAR has experienced in the implementation of the Plant Treaty and proposes optional ways forward on key issues to increase its impact.

CONSERVATION, EXPLORATION, COLLECTION, CHARACTERIZATION, EVALUATION, AND DOCUMENTATION OF PGRFA

Holdings

The 11 CGIAR centers that signed agreements with the Governing Body of the ITPGRFA in 2006 currently (as of August 2018) conserve and make available under the Plant Treaty's multilateral system a total of >730,000 accessions of crop, tree, and forage germplasm (Table 1) (CGIAR Genebank Platform and Crop Trust, 2018).

Most accessions are held and distributed as seed; just 23,862 are conserved as clones in vitro and 29,122 in field collections. Since these accessions are virtually irreplaceable, securing them against risk of loss is imperative. The criterion established in the CGIAR collections for acceptable mitigation of the risk of loss of seed accessions is maintenance in long-term storage and safe duplication in two external locations, one of which is the Svalbard Global Seed Vault. On this basis, 73% of the seed accessions have been secured against risks of loss. Of the clonal accessions, 73% of accessions are safely duplicated in the form of in vitro or cryopreserved samples. Since information on accessions is critical to use, 87% of accessions have passport or characterization data accessible online (Genebanks CGIAR Research Program, 2016).

Table 1. Plant genetic resources for food and agriculture conserved and made available by CGIAR centers' genebanks pursuant to their Article 15 agreements with the Governing Body.

Center	Crop	Accessions available with SMTA†
AfricaRice	Rice	21,300
Bioversity	Banana	1,500
CIAT	Beans	37,987
	Forages	23,140
	Cassava	6,643
CIMMYT	Maize	28,193
	Wheat	154,744
CIP	Andean roots and tubers	1,173
	Potato	6,527
	Sweetpotato	5,328
ICARDA	Lentils	11,635
	Grass pea	4,193
	Forages	25,556
	Faba bean	9,900
	Chickpea	14,238
	Barley	31,554
	Pea	6,105
	Wheat	41,181
ICRAF	Multipurpose trees	5,594
	Fruit trees	3,600
ICRISAT	Chickpea	19,266
	Groundnut	15,039
	Pigeonpea	13,482
	Pearl millet	23,057
	Small millets	11,365
	Sorghum	39,264
IITA	Cowpea	15,115
	Cassava	3,398
	Maize	1,561
	Miscellaneous legumes	6,623
	Banana	321
	Yam	5,839
ILRI	Forages and fodder	18,627
IRRI	Rice	123,019
Total		736,111

† SMTA, Standard Material Transfer Agreement.

In recent years, the ICARDA genebank has gone through a process of reallocation of the collections and of its main activities. The ICARDA genebank was established in 1985 at Tel Hadiya, Syria. Since 2012, the Syrian conflict has affected the genebank's core activities of regeneration, characterization, conservation, and distribution. To resume these activities, in September 2014, ICARDA made the decision to relocate its genebank activities to Lebanon and Morocco. Since 2015, genebank and field facilities have been established in these two countries. Currently, an intensive program of regeneration and characterization aims to reconstitute the active and base collections in the current locations. The seeds conserved at the Svalbard Global Seed Vault have been gradually retrieved and planted for this purpose. On average, 25,000 accessions are regenerated and characterized annually. It is expected that the whole process will last until 2030 to allow the regeneration of forage and range lands for which seed production requires special isolation conditions, and facilitated pollination using bumble bees. So far, >70,000 accessions have been regenerated, including 14,000 accessions newly acquired since 2012. These efforts have allowed ICARDA to resume the distribution of accessions to plant genetic resource users around the world.

Most of the genetic resources conserved in the CGIAR genebanks are of crops, forages, and trees listed in Annex 1 of the ITPGRFA. After the decision of the Second Session of the Governing Body in 2009 to allow use of the Standard Material Transfer Agreement (SMTA, the standard agreement adopted by the Governing Body for germplasm transfers under the multilateral system) for non-Annex 1 crops, the CGIAR centers have been using the SMTA to distribute non-Annex 1 plant genetic resources from their in trust germplasm collections and other plant genetic resources acquired with permission from the providers for the center to make them available under the same terms and conditions as the SMTA.

Conservation-Related Work

Ex situ PGRFA collections held by CGIAR centers are undergoing active regeneration. From 2012 to 2015, the CGIAR genebanks regenerated 271,428 accessions and characterized 176,409 accessions. In addition, 193,662 accessions were subject to phytosanitary cleaning to generate pest- and disease-free stocks for conservation and distribution. In this period, the CGIAR genebanks received 45,894 accessions from collecting missions and organizations. A large portion of these acquisitions were through an international regeneration project implemented by the Global Crop Diversity Trust (GCDT) with support of the Bill & Melinda Gates Foundation (CGIAR-IEA, 2017). Six collecting projects undertaken by five centers (AfricaRice, CIMMYT, ICARDA, IITA, and IRRI) in eight countries (Bangladesh, Benin, Cameroon, the Democratic Republic of Congo, Greece, Nepal, and Nigeria) also supported by the same project resulted in >2500 new accessions of diverse species being duplicated in the CGIAR genebanks (Genebanks CGIAR Research Program, 2016).

The germplasm health units (GHUs) of CGIAR centers ensure compliance to national and international phytosanitary regulatory requirements for international exchange of germplasm and breeding lines and play an important role in preventing the spread of seed-borne pathogens with the germplasm. The GHUs essentially serve as gateway for distribution of germplasm through multidimensional activities, including liaison with national quarantine authorities, germplasm health indexing, and phytosanitary cleaning.

CGIAR centers facilitate accessibility and use of their collections through different strategies: they assemble core sets that represent the diversity within the collection and that allow users to identify and evaluate target traits more easily (examples are described in Upadhyaya et al., 2009, and Ndjiondjop et al., 2017); they facilitate coordination with the breeding programs, in particular through the use of digital object identifiers, which allow breeders to easily identify accessions within the collections and to trace their use in breeding activities; and they maintain public records of their holdings through Genesys, a gateway from which germplasm accessions from genebanks around the world can be found and ordered (www.genesys-pgr.org).

To improve quality and efficiency in operations, support staff succession, and manage risks, in the last years, CGIAR genebanks have strengthened their quality management systems (QMSs). The focus of QMS development was to formally document and review genebank operations, eventually also to audit procedures against international standards. CGIAR GHUs have since adopted a similar approach. This use of QMS is providing an important, evidence-based framework through which the quality of genebanks and GHUs can be demonstrated and improved, and compliance with FAO Genebank Standards, International Standards for Phytosanitary Measures, and other regulatory policy is ensured (CGIAR-IEA, 2017).

Although focused on ex situ conservation, CGIAR centers also contribute to understanding and conserving crop diversity on farms and in the wild in various forms: restoring lost varieties from ex situ to in situ conditions; repatriating disease-free seed of traditional varieties of local crops; characterizing crop diversity on farms; enhancing local capacity for crop diversity management; identifying opportunities for adding value and creating market linkages for local crop diversity; increasing awareness about the value of crop diversity and its conservation on farms; and documenting and disseminating good management practices through modern and traditional information, education, and communication channels (Westengen et al., 2017;2018). CGIAR centers have also supported national genebanks in emergency situations (e.g., rebuilding maize [*Zea mays* L.] collections in Guatemala and the Philippines).

SUSTAINABLE USE OF PGRFA

CGIAR went through a profound reform in 2010 and 2011. Since 2012, research and development work of CGIAR centers is articulated around research programs, including one covering the conservation and sustainable use of crop diversity in CGIAR genebanks. The current CGIAR's Strategy and Results Framework and the United Nations' Sustainable Development Goals underpin the overall strategic direction of CGIAR.

From 2012 to 2016, crop breeding, forage improvement, and tree domestication work in CGIAR took place in the framework of the following CGIAR research programs: MAIZE; WHEAT; Dryland Cereals; Grain Legumes; Roots, Tubers, and Bananas (RTB); Global Rice Science Partnership (GRiSP, currently called RICE); Livestock and Fish (for forages); and Forests, Trees, and Agroforestry (for trees). CGIAR centers' work on plant genetic resource characterization, evaluation, and improvement under all these programs contributes to the implementation of the Plant Treaty provisions on conservation and sustainable use. We highlight some recent advancements of this work in the paragraphs below.

Phenotypic characterization has continued to be the primary basis for plant selection in CGIAR breeding programs. CGIAR centers have set up internationally networked partnerships and platforms for phenotyping. Phenotyping remains by far the most expensive and time-consuming activity for breeding programs. To increase the quantities of high-quality phenotype data and reduce costs, some CGIAR research programs have been experimenting with remote and ground sensing, mechanization and automation of seed preparation, and field and greenhouse trials.

Genotyping and genome sequencing information are increasingly used for characterization, pre-breeding, breeding, and as a fingerprinting tool to manage the large germplasm collections. For some crops, DNA sequencing of thousands of accessions has generated a mass of data that can be used to create more accurate crop phylogenies, link genomic regions to specific traits, and develop markers for marker-assisted selection. This research has shed new light on the relationships among crop varieties, landraces, and wild relatives in the centers' collections and has helped breeders identify germplasm with desired traits.

CGIAR centers' genomic work involves partners (mainly public research organizations) from many countries including China, France, India, Mexico, and the

United States. The CIMMYT, ICRISAT, IITA, ILRI, and IRRI have facilities for engaging genomic work. Some of these facilities provide genomic services to organizations in the region, including, for example, the Kenyan Agriculture and Livestock Research Organization (KALRO)–CIMMYT facility for screening maize and wheat (*Triticum aestivum* L.) germplasm for public and private sector partners against maize lethal necrosis and wheat stem rust (*Puccinia graminis* Pers.:Pers. f. sp. *tritici* Erikss. & E. Henning, Ug99) under artificial inoculation; it was established in 2013 at the KALRO Naivasha and Njoro research stations in Kenya's Rift Valley. The genomics and bioinformatics platforms of the Biosciences Eastern and Central Africa (BecA) Hub located at ILRI in Nairobi provides a regional facility for research on crop and livestock genotyping. The Bioscience Center at IITA (Ibadan, Nigeria) serves as a regional hub for national programs and universities. Most genomic sequencing information and genomic tools are made publicly available through online platforms and databases. Examples of these platforms and databases include the one maintained by the International Rice Informatics Consortium (http://iric.irri.org/), the Cassava Genome Hub (http://www.cassavagenome.org/), and the Banana Genome Hub (http://banana-genome-hub.southgreen.fr/). Genomic information is now included to varying degrees in CGIAR centers' and their partners' breeding work on most of the CGIAR mandate crops listed in Table 1. It is used and combined with classic breeding to guide selection, crossing, and evaluation. In general, data and information flows are increasingly important aspects of breeding programs. Recent developments such as CassavaBase, YamBase, and Breeding for Results improve data management and sharing and facilitate collaboration in breeding.

In the last decade, various centers have included work on multidimensional crop improvement. This work aims at concomitant improvement of food (grain) and fodder (straw, stover, and haulms) in crops, responding to farmers' demand, and increasing the monetary value of crop residues relative to grain value (Blümmel et al., 2019). An ILRI collaboration with ICRISAT, CIMMYT, IRRI, and IITA has shown (i) that livestock nutritionally significant variations exist in fodder quality of straws, stover, and haulms among cultivars of a crop species that can be exploited without detriment to primary traits (e.g., grain yield), and (ii) that further concomitant improvement of food and fodder traits is possible using conventional and molecular breeding (Blümmel et al., 2019).

Table 2 presents the crop and geographical coverage of CGIAR breeding programs, and their main objectives. CGIAR breeding work takes place in partnership with public and private organizations in the target countries. These organizations collaborate with CGIAR genebanks and breeding programs to evaluate accessions and develop improved lines. They then develop varieties derived from CGIAR lines, release these varieties through public and private sector partners, and catalyze deployment of planting material of the improved varieties in the target geographies. The breeding activities performed by the centers are critically dependent on international germplasm exchange, physically and in terms of data sharing.

Centers' breeding activities do not take place in a vacuum; they are complemented by other activities that promote the sustainable use of PGRFA, sharing information with and transferring technologies to developing countries and building capacities of PGRFA users, from farmers to scientists. These activities include pre-breeding and genetic base broadening, providing support for improving agronomic practices, strengthening seed systems, delivery of pest- and disease-free seed and planting material, developing markets for target crops and their products, impact analysis to quantify the impact of improved varieties, and integrating and empowering women and youth in crop research, development, and market chains. All these activities relate to the Plant Treaty's Articles 5 (regarding conservation) and 6 (regarding sustainable use).

THE MULTILATERAL SYSTEM OF ACCESS AND BENEFIT SHARING

Through the multilateral system, parties to the Plant Treaty agree to create a global, virtual pool of genetic resources for 64 crops and forages (these are listed in the Plant Treaty's Annex 1). In addition to conservation, this germplasm is intended to be used for the purposes of training, breeding, and research for food and agriculture. Member states agree to provide facilitated access to one another (including natural and legal persons within their borders) on the understanding that monetary benefits will be shared if the recipients incorporate materials in new, commercialized PGRFA products that are not available to others for research, training, or breeding. Monetary benefit sharing takes place through a Benefit Sharing Fund managed by the Governing Body of the Plant Treaty. This fund is used to support projects for the conservation and sustainable use of PGRFA in countries that are parties to the Plant Treaty, favoring in particular smallholder farmers in developing countries.

Distribution of Germplasm under the ITPGRFA's Multilateral System

Over the first 10 yr of operation under the ITPGRFA framework—from January 2007 to December 2016—the CGIAR centers distributed almost 4 million samples of PGRFA with >47,000 SMTAs. This represents 93% of the reported global distribution of germplasm under the multilateral system. Distribution data of PGRFA by both genebanks and breeding programs of the centers during this 10-yr period are detailed in Table 3.

Table 2. Summary of CGIAR pre-breeding and breeding efforts (2012–2016).

Crop	Center	Target countries and regions	Breeding objectives
Maize	CIMMYT, IITA	Sub-Saharan Africa, Latin America, and Asia	High grain yield, drought tolerance, heat tolerance, N use efficiency, resistance to major diseases including tar spot complex, *Maize streak virus*, Turcicum leaf blight, gray leaf spot, etc., resistance to stem borers and postharvest insect-pests, increased protein quality, increased pro-vitamin A content, increased kernel Zn content, and superior stover fodder quality
		Eastern Africa	Resistance to maize lethal necrosis, and drought tolerance
		East and West Africa	Resistance to *Striga* and drought tolerance
Sorghum	ICRISAT	India (Deccan Plateau)	Drought tolerance, delayed foliar senescence (stay-green), and stover fodder quality
		Burkina Faso, Mali, and Nigeria	Increased grain yield, high stover quality, drought tolerance, and *Striga* resistance.
		Ethiopia, Eritrea, Tanzania, South Sudan, Kenya, Malawi, and Zimbabwe	Shoot fly resistance, high nutrient content (Fe and Zn), leaf disease resistance, and *Striga* resistance
Finger millet	ICRISAT	Ethiopia, Kenya, Tanzania, Uganda, and Malawi	Resistance to blast, resistance to *Striga*, tolerance to drought, and high nutrient content (Ca, Fe, and Zn).
Barley	ICARDA	North and East Africa; Central, West, and South Asia	Improved nutritional (Zn, Fe, and β-glucan) and malting qualities, drought tolerance, resistance to powdery mildew, resistance to stem gall midge, resistance to net blotch, resistance to *Yellow dwarf virus*, and improved fodder and forage.
Pearl millet	ICRISAT	West Africa	Increased grain and fodder yield, resistance to downy mildew, head miner, and *Striga hermonthica*, improved nutrition characteristics (Fe and Zn), and stay-green types
		India	Increasing genetic base, downy mildew resistance in popular hybrids, resistance to blast disease caused by *Magnaporthe grisea*, resistance to downy mildew pathotype, and high biomass.
		India, South Asia	Resistance to blast disease, improved fodder and forage, heat tolerance, and high Fe
		Eastern and southern Africa	Resistance to blast disease, improved forage, and heat tolerance
Common bean	CIAT	Eastern and southern Africa	Tolerance to drought and low soil P
		South America, Africa	Heat tolerance
		Africa	Greater potential of symbiotic N_2 fixation
Cowpea	IITA	West Africa, Burkina Faso, Ghana, Mali, Niger, and Nigeria	Tolerance to drought, heat, and low soil P, pest and disease resistance (including aphids, thrips, bacterial blight, and viruses), and *Striga* tolerance
		Eastern and southern Africa, Mozambique, Tanzania, and Zambia	Pest and disease resistance (including aphids, thrips, bacterial blight, and viruses) and resistance to *Alectra*
Soybean	IITA	Sub-Saharan Africa	Resistance to pests and diseases, tolerance to abiotic stress, and increased yield.
Groundnut	ICRISAT	Eastern and southern Africa, West and Central Africa, and South Asia	Short duration, low aflatoxin incidence, drought tolerance, rosette resistance, leaf spot resistance, and high fodder quality
Chickpea	ICRISAT	India	Heat tolerance (for late-sown cultivation)
		India, Bangladesh, Ethiopia, and Kenya	Early-maturing and short-duration varieties
		Turkey, Lebanon, Tunisia, Georgia, Azerbaijan, Iran, Kazakhstan, Russia, and India	Machine-harvestable varieties, resistance to Ascochyta blight, and resistance to Fusarium wilt
		North Africa, Central Asia, and South Asia	Tolerance to herbicides
		South Asia and Africa	Greater potential of symbiotic N_2 fixation under limited soil P
Pigeonpea	ICRISAT	India	Early and medium maturity, resistance to Fusarium wilt and sterility mosaic disease, drought tolerance, and pod borer tolerance
		Kenya, Tanzania, Malawi, Mozambique, Uganda, and Zambia	Medium maturity, photoperiod insensitivity, resistance to Fusarium wilt and Cercospora leaf spot, pod borer and pod fly tolerance, grain quality, and drought tolerance
Lentil	ICARDA	Bangladesh, Nepal and India	Early-maturing and short-duration varieties, extra-early-maturing varieties for rice–lentil–*boro* rice systems
		North and East Africa	Tolerance to herbicides, resistance to Asochyta blight, and tolerance to *Orobanche* spp. (parasitic weed)
Faba bean	ICARDA	North and East Africa	Tolerance to herbicides, tolerance to *Orobanche* spp. (parasitic weed), and tolerance to various diseases.
Rice (*sativa* and *glaberrima*)	IRRI, AfricaRice, CIAT	Worldwide	High grain yield, superior grain quality (taste, texture, and shape), tolerance to major rice pests and diseases, and increased Fe and Zn content

Table 2. Continued.

Crop	Center	Target countries and regions	Breeding objectives
		South Asia and Southeast Asia	Tolerance to drought, submergence, salinity, high temperature, low temperature, and low solar radiation, tolerance to region-required combination of abiotic stresses, earliness and mechanized dry direct seeded and alternate wetting and drying, high straw quality, tolerance to major diseases (blast, bacterial blight, sheath blight, and false smut), tolerance to major insects (brown plant hopper and stem borer), region-preferred grain and cooking quality traits, low chalkiness, medium to high amylose content, high head rice recovery, and export-oriented segmented market quality traits
		Latin America	High grain yield, superior grain quality, tolerance to major rice diseases, and good performance under reduced light
		Africa	Tolerance to drought, submergence, salinity, and low temperatures, tolerance to major biotic stresses, and region-preferred grain and cooking quality traits
Wheat (bread and durum)	CIMMYT, ICARDA	Worldwide	More durable yellow, stem, and leaf rust resistance based on combinations of minor, slow-rusting genes, resistance to other diseases of global importance (7 diseases), high Zn and Fe content, and industrial/bread-making quality
		Central Asia (Aral Sea and Fergana Valley)	Resistance to frost, salinity, and yellow rust
		South America, South Asia, Ethiopia, Nigeria, and Sudan	Heat tolerance
		South America and South Asia	Resistance to various diseases, including wheat blast, Septoria leaf blotch, leaf rust, and Fusarium head blight
		North Africa and Middle East	Tolerance to *Septoria tritici* blotch in durum wheat, and resistance to *Fusarium*, nematodes, and root diseases
Sweetpotato	CIP	Sub-saharan Africa	Pro-vitamin A orange flesh, increased yield and earliness, sweetpotato virus disease resistance, storability, high dry matter, non-sweet, adaptation to drought-prone environments, and dual-purpose use for pig feed
		South and Southeast Asia	Increased yield and earliness, pro-vitamin A orange flesh, and high dry matter content
Banana and plantain	IITA	Worldwide	High yield, resistance to black leaf streak
	Bioversity	East Africa	Earliness, drought tolerance, resistance to nematodes and weevils, Fusarium wilt resistance, and banana Xanthomonas wilt resistance.
		West and Central Africa	Earliness, drought tolerance, and resistance to nematodes and weevils..
		Latin America and Asia	Resistance to black sigatoka complex and Fusarium wilt
Cassava	CIAT, IITA	Worldwide	Yield and high dry matter
		West and Central Africa	Cassava mosaic disease resistance, high carotenoids content, preemptive cassava brown streak disease resistance, improved poundability, and low cyanogenic potential.
		East Africa	Cassava mosaic disease and cassava brown streak disease resistance and preferred culinary attributes
		Latin America	High carotenoid content, value-added starch functional properties, and resistance to cassava bacterial blight and green mites.
		Asia	New starches, resistance to cassava witch's broom disease, and earliness for multicropping systems
Potato	CIP	Worldwide	Earliness
		African and Andean highland tropics	Drought tolerance, late blight resistance, Fe and Zn biofortification, and table-potato preference
		African and Asian mid-elevation tropics	Resistance to various viruses, chipping ability, heat tolerance, and low antinutrient content
		Asian subtropical lowlands (Indo-Gangetic Plains, Indochina)	Resistance to various viruses, heat tolerance, long dormancy period, cold chipping ability, and high dry matter content
		Central Asia temperate lowlands and mid-altitude	Photoperiod insensitivity, drought tolerance, salinity tolerance, virus resistance, and red skin
Yam	IITA	Worldwide	Yield, earliness, and anthracnose resistance
		West Africa	High dry matter and nematode resistance
		Asia, East Africa, Latin America, and the Pacific	Tuber quality and *Yam mosaic virus* resistance
Urochloa decumbens, U. brizantha ruziziensis	CIAT	Global tropics	Tolerance to biotic (spittlebug and Rhizoctonia) and abiotic (drought, water logging, Al, and soil fertility) stresses, productivity, water use efficiency, nutrient use efficiency, nutritive quality, and seed yield
Urochloa humidicola	CIAT	Global tropics	Nutritive quality, biological nitrification inhibition, tolerance to biotic (spittlebug and Rhizoctonia) and abiotic (drought, water-logging, Al, and soil fertility) stresses, productivity, water use efficiency, nutrient use efficiency, and seed yield,
Megathyrsus maximus	CIAT	Global tropics	Tolerance abiotic (drought, water-logging, Al, and soil fertility) stresses, productivity, water use efficiency, nutrient use efficiency, nutritive quality, and seed yield

Table 3. CGIAR centers' distributions of plant genetic resources for food and agriculture using the Standard Material Transfer Agreement (SMTA), January 2007 to December 2016.

Center	SMTAs	Samples	PUD†	From	To
	no.				
AfricaRice	483	46,440	28,492	5 Mar. 2007	5 Jan. 2017
Bioversity	386	6,109	653	24 Jan. 2007	22 Dec. 2016
CIAT	2,547	246,650	36,034	5 Jan. 2007	5 May 2017
CIMMYT	18,127	1,986,228	0	16 Mar. 2007	28 Dec. 2016
CIP	560	15,391	10,183	19 Jan. 2007	8 May 2017
ICARDA	12,977	779,390	698,110	13 Feb. 2007	14 Dec. 2016
ICRAF	154	679	0	3 Sept. 2011	4 Dec. 2016
ICRISAT	3,885	159,362	34,313	11 Nov. 2009	19 Jan. 2017
IITA	728	29,792	0	7 Mar. 2007	28 Apr. 2017
ILRI	777	9,390	0	22 Feb. 2007	30 Nov. 2016
IRRI	7,186	635,090	379,491	4 Jan. 2007	18 May 2017
Total	47,810	3,908,412			

† PUD, plant genetic resources for food and agriculture under development, as defined by the Plant Treaty.

The proportion of germplasm coming from CGIAR centers' genebanks and breeding programs varies from year to year; in general, approximately between one-fifth and one-quarter of the germplasm distributed each year are genebank accessions.

Most of the 3.9 million samples distributed by the CGIAR centers went to recipients in developing countries or countries with economies in transition, mainly to public sector research organizations, universities, regional organizations, germplasm networks, and other genebanks. Figure 1 provides a breakdown of regional distribution of materials from the CGIAR centers. As a representative example, Fig. 2 and 3 show CIMMYT's and IRRI's distribution, respectively, to recipients worldwide for the 2-yr period of 2015 through 2016.

CGIAR centers transfer center-improved materials for breeding, research, and training for food and agriculture through a number of modalities. These include:

- direct transfer from the genebank or breeding program in response to individual, ad hoc requests;
- international evaluation and performance nurseries;
- specialized networks created for sharing, evaluating and characterizing improved materials (e.g., the International Network for Genetic Evaluation of Rice [INGER]-Asia, INGER-Africa, and the International Wheat Improvement Network [IWIN]-Global);
- consortia developed to support breeding and dissemination of hybrids (e.g., IRRI's Hybrid Rice Development Consortium and ICRISAT's Hybrid Parents Research Consortia for pigeonpea [*Cajanus cajan* (L.) Millsp.], pearl millet [*Pennisetum glaucum* (L.) R. Br.], and sorghum [*Sorghum bicolor* (L.) Moench]); and
- decentralized or collaborative breeding programs, primarily with national programs in developing countries.

In addition to complying with the ITPGRFA and the SMTA, the centers' management of their own improved germplasm must also comply with the CGIAR Principles on the Management of Intellectual Assets (IA Principles), which were approved by the CGIAR Consortium Board and Fund Council in 2012 and endorsed by the System Council and the System Management Board under the new governance structure of CGIAR in 2016.

The IA Principles were created in response to the growing felt need by some centers (and their research partners and donors) to occasionally depart from their long-established role as creators of global public goods, and, under certain circumstances, to place limits on the availability of the goods they created. The pressure to explore such options was driven by a combination of factors, including (i) the need to create incentives for downstream research partners and recipients to make additional investments of their own to further develop and release improved materials received from CGIAR centers, and to get those technologies effectively distributed, including through market channels where appropriate; (ii) the need

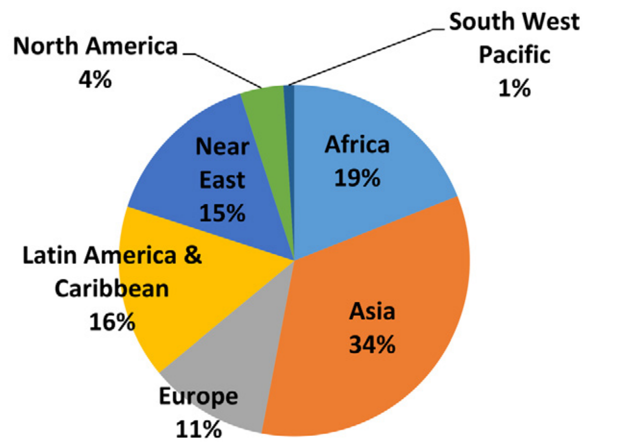

Fig. 1. Regional distribution of Standard Material Transfer Agreements from the CGIAR centers, January 2007 to December 2016.

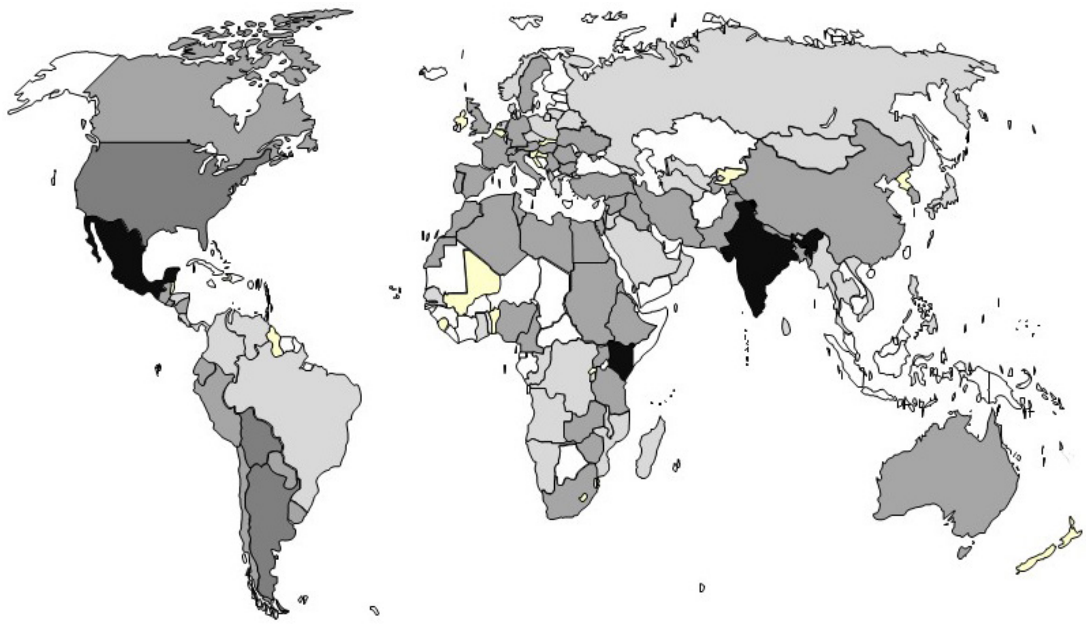

Fig. 2. The CIMMYT's distributions worldwide, 2015–2016. Countries in yellow received from 1 to 100 samples. Countries in pale gray received from 101 to 1000 samples. Countries in medium gray received from 1001 to 10,000 samples. Countries in dark gray received from 10,001 to 20,000 samples. Countries in black received from 20,001 to 40,000 samples.

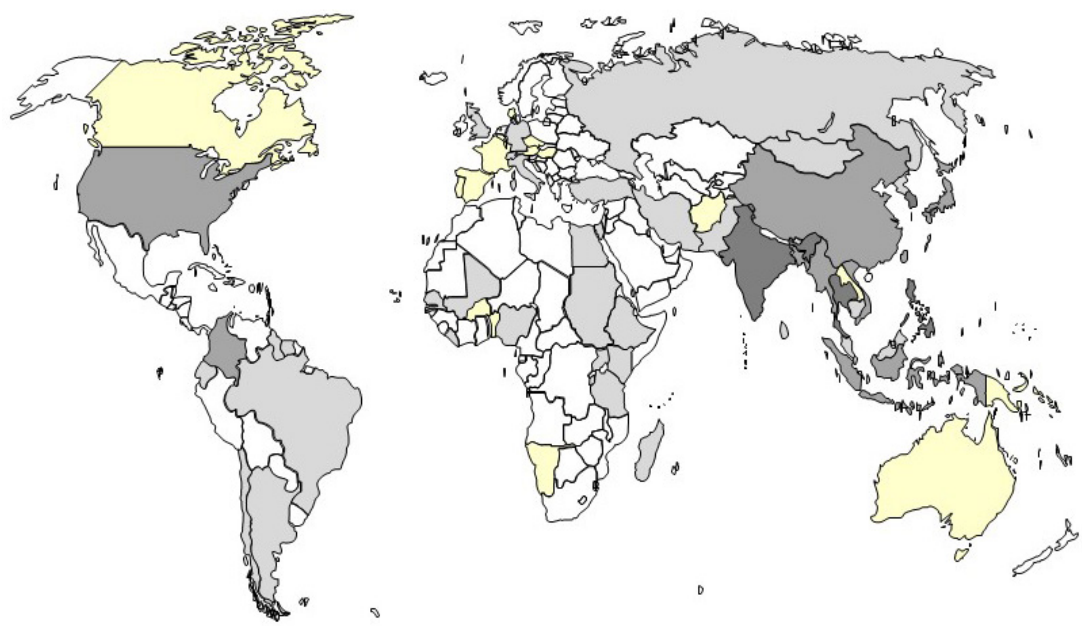

Fig. 3. The IRRI's distributions worldwide, 2015–2016. Countries in yellow received from 1 to 100 samples. Countries in pale gray received from 101 to 1000 samples. Countries in medium gray received from 1001 to 10,000 samples. Countries in dark gray received from 10,001 to 20,000 samples.

for CGIAR centers to obtain and incorporate technologies from the private sector that are themselves subject to intellectual property protection; (iii) the need for more efficient use of centers' intellectual assets to prevent misappropriation; and (iv) using the leverage of intellectual property rights to obtain some form of compensation, partly in response to decreasing and uncertain traditional donors' support. The IA Principles establish a CGIAR-wide regime on intellectual asset management and create a system for monitoring compliance.

The IA Principles underscore that Centers must comply with the ITPGRFA and the Convention on Biological Diversity when they access and distribute PGRFA. They go further, however, by limiting how centers can exercise the wider discretion they would have under the ITPGRFA when distributing center-improved germplasm. The IA Principles' default position is that centers should treat their intellectual assets, including center-improved PGRFA, as global public goods. However, the IA Principles also recognize three kinds of restrictions that centers can place on such assets and establish threshold criteria that centers must satisfy for creating such restrictions.

First, centers may grant limited-exclusive rights to third parties to commercialize the materials they have (co)developed (called "limited exclusivity agreements" or LEAs), provided the exclusivity is limited in scope (e.g., country specific, time limited), and the restrictive arrangement is necessary for the further development, or to maximize the scale and scope of impact, of the intellectual assets concerned. Importantly, the IA Principles require that the materials that are subject to a limited exclusivity arrangement continue to be made available to public research organizations for noncommercial research and breeding, and for emergency use, in the countries where the exclusivity applies. Second, the acquisition of third-party materials on terms that restrict the global accessibility of products or services of the CGIAR center materials into which they are incorporated (called "restrictive use agreements" or RUAs) is only permitted provided equivalent materials are not available from alternative sources under less restrictive conditions and the products and services in question will further CGIAR's mission in the countries in which they are made available. Third, a center may file or authorize a third party to file a patent or Plant Variety Protection (PVP) over CGIAR center-improved germplasm provided such protection is necessary for the further development, or to maximize the scale and scope of impact, of the germplasm concerned (CGIAR, 2012).

Breeding lines and other improved (not yet released) material developed by centers that incorporate PGRFA received from the multilateral system fall within the definition of "PGRFA under development" adopted by the Plant Treaty and the SMTA. In accordance with the multilateral system, when providers transfer these PGRFA to users, they can require additional conditions to those in the SMTA, including restrictive terms and conditions that are consistent with the ITPGRFA and the IA Principles. No additional conditions to the SMTA can be required when transferring accessions conserved in the in-trust collections maintained by CGIAR centers.

Every year, each center submits a report on its compliance with the IA principles to the CGIAR System Office. Each RUA, LEA, patent, and PVP application is scrutinized by an independent expert panel appointed by the CGIAR System Council. An annual CGIAR Intellectual Assets Management Report concerning all centers' compliance, and including summary information about all RUAs, LEAs, and intellectual property applications, is published by the System Office.

From 2012 through 2017, CGIAR centers have entered into 45 LEAs and 16 RUAs. They have filled patent applications concerning 16 inventions, out of which five are the subject of active applications or registrations (the remainder have been discontinued or will be permitted to lapse), and they applied or authorized partners to apply for a PVP three times (CGIAR, 2013, 2014, 2015, 2016, 2017, 2018).

Some civil society organizations and country delegates to the Governing Body have expressed concern with respect to some centers' recent patent applications and have sought reassurance that the centers are indeed complying with the IA principles. To that end, the Seventh Session of the ITPGRFA Governing Body (in 2017) passed resolution 4/2017, requesting CGIAR to submit the annual CGIAR Intellectual Asset Management Reports to the Treaty Secretariat and the Governing Body (FAO, 2017).

Acquisitions of PGRFA through the Multilateral System

Most CGIAR centers' genebanks have encountered difficulties at different times and with different types of organizations, in varying parts of the world, obtaining permission to access genetic diversity for inclusion into the in-trust collections. Among the contributing factors are uncertainties regarding institutional ownership over genetic resources, unresolved tensions concerning benefit sharing, and lack of capacity to put national and organizational access and benefit-sharing systems in place (Halewood et al., 2013; Halewood, 2014). On the other hand, many providers, from a wide range of countries, are sharing materials with the CGIAR centers for inclusion in the genebanks to be redistributed under the multilateral system or for use in the centers' breeding programs. For example, between 2013 and 2016 inclusive, the centers' genebanks and breeders received at least 17,426 PGRFA samples, under at least 190 SMTAs, from providers in at least 53 countries.

Generating and Sharing Benefits

CGIAR centers pursue their mission primarily through generation of what are described as nonmonetary benefits in the lexicon of the ITPGRFA (Article 13), the Convention on Biological Diversity (Articles 16–18), and the Nagoya Protocol (Annex), such as through provision of germplasm, technology transfer, capacity strengthening, and information exchange. All of the breeding programs described above and complementary efforts to enhance agronomic practices and seed systems produce new technologies and knowledge that are transferred to national agricultural research and extension services and ultimately farmers. Although the use of these technologies and knowledge results in increased household income, as well as national and regional economic development, they are considered nonmonetary benefits under the Plant Treaty. Monetary benefit sharing under the Plant Treaty is understood to refer to royalty payments by commercializers of new PGRFA products to the ITPGRFA's international

Benefit Sharing Fund. The paragraphs below provide a snapshot of the extent of complementary capacity building and information sharing that the centers are engaged in.

In the past decade, CGIAR centers have explored innovative approaches to facilitate the generation and exchange of information among different national and regional entities, taking advantage of advances in information and communication technologies. The numerous open-access databases maintained by CGIAR centers are used by thousands of scientists from countries throughout the world, and a number of them target extension agents and technicians. Innovation platforms and hubs have been set up and facilitated by various CGIAR programs to enhance the quality of interaction, relationships, confidence, and trust among stakeholders involved in the research, development, and market chains of target crops.

As presented in the sections above, CGIAR centers transfer technologies primarily in the form of improved germplasm and associated agronomic techniques and technologies. In addition, CGIAR centers and partner organizations generate and share technologies and innovative practices for the conservation, characterization, evaluation, and use of plant genetic resources for food and agriculture as part of their activities for efficient and rational conservation of germplasm, phenotyping, genotyping, safe exchange of germplasm, and seed production. Global partnerships for large-scale phenotyping and genotyping within CGIAR programs have facilitated the co-generation and sharing of these advanced technologies and techniques.

Capacity building is at the core of the CGIAR centers' work. CGIAR research programs support ~1000 students in their BS, MS, and Ph.D. degrees annually. Various long-duration courses (>90 d) on crop improvement (including breeding, pathology, germplasm health, and marker-assisted selection) have been organized and supported by CGIAR research programs for advanced-degree students and junior and mid-career scientists from all over the world. Numerous additional short-term regional and national training courses have been organized through CGIAR research programs and projects. These have been oriented not only to scientists in research organizations, but also to officers and technicians working in governmental agencies and staff of nongovernmental organizations. Capacity development for farmers has covered a wide range of topics including sustainable intensification, postharvest practices, production using hybrid seed, produce processing and marketing, seed selection, seed multiplication, seed health, business model development, and gender awareness. Training events have taken place in the form of field days, farmer schools, and travelling workshops for thousands of events worldwide, in total. Hundreds of capacity-building materials have been made available by CGIAR centers during the first series of CGIAR research programs (2012–2016). Despite increasing efforts to publish these materials in other languages than English, language continues to be a limitation to their full accessibility.

Most of these activities have been designed and implemented in accordance with the Plant Treaty's objectives and in line with connected international instruments such as the Global Plan of Action for the Conservation and Sustainable Use of Plant Genetic Resources for Food and Agriculture.

FARMERS' RIGHTS

The CGIAR Intellectual Assets Principles include a section on Farmers Rights, which states:

"3.1 CGIAR recognizes the indispensable role of farmers, indigenous communities, agricultural professionals and scientists in conserving and improving genetic resources"

"3.2 CGIAR seeks to be respectful of national and international efforts to protect and promote farmers' rights as envisaged by the Treaty and support the development of appropriate policies and procedures for their recognition and promotion" (CGIAR, 2012).

The Implementation Guidelines for the CGIAR Principles on the Management of Intellectual Assets elaborate on these articles and provide a list of practical actions that centers should take to promote farmers' rights as described in Article 9 of the ITPGRFA, including obtaining prior informed consent from farmers when accessing genetic resources or traditional knowledge, regardless of whether or not required by national law. Some other more concrete ways that CGIAR centers contribute to the recognition and implementation of farmers' rights include restoration of landraces, involvement of farmers in breeding programs and policy dialogues, enhancement of local seed systems, sharing knowledge and enhanced germplasm with farmers, and creating markets for food products based on local crops. It is beyond the scope of this paper to provide more details about these activities. Various publications present experiences and outlook of CGIAR centers on farmers' rights (Chaves Posada, 2013; Clancy and Vernooy, 2016; Halewood, 2016).

GLOBAL INFORMATION SYSTEM

CGIAR centers, and IRRI in particular, are contributing to the creation of a global information system (GLIS) under the framework of the Plant Treaty. Work on the GLIS has focused on the development of digital object identifiers (DOIs) as permanent, unique identifiers for PGRFA accessions. Through the CGIAR Genebank Platform, the global version of the Germplasm Resource Information Network (GRIN-Global) and Genesys have been enhanced to accommodate DOIs and link with the GLIS server. The CGIAR genebanks have already assigned DOIs to 73% of their accessions (as of 1 Apr. 2018) and have a goal to have DOIs for all in trust CGIAR genebank accessions by the end of 2018. Under the RICE research program and the Excellence in Breeding Platform, efforts are being made to accommodate DOIs and link breeding and research germplasm with the GLIS server, which will help to store and link evaluation and genetic sequence information to related germplasm.

DISCUSSION

Clearly, CGIAR genebanks and breeders' daily operations are closely aligned with, and influenced and supported by, the Plant Treaty. In particular, the continued existence and optimal functioning of the multilateral system is critically important to CGIAR in the pursuit of its mission. Facilitated national, regional, and international exchange of germplasm for the purposes of research and development is critically important for ensuring food security. However, the multilateral system has encountered some challenges since the Plant Treaty came into force. To date, there has been only one payment to the Plant Treaty's Benefit Sharing Fund as a result of the mandatory monetary benefit-sharing conditions included in the SMTA. This outcome is partly due to the fact that the kinds of commercial users that would trigger those benefit-sharing conditions have acquired the genetic resources they need from elsewhere. Many potential providers are demonstrating reluctance to proactively provide access to plant genetic resources in the multilateral system until more money from commercial users is contributed to the Benefit Sharing Fund. Furthermore, the Plant Treaty's relatively low profile in many countries has made it difficult for national competent authorities to marshal the necessary resources and political attention to push through national implementation measures.

CGIAR centers encounter these challenges in their daily operations. Some companies and universities have explicitly declined to take materials from CGIAR centers, citing dissatisfaction with the SMTA (including its benefit-sharing conditions), and have turned to other sources of germplasm that do not operate under the multilateral system (Hammond, 2011). Some national research organizations have been unable or unwilling to share germplasm with CGIAR genebanks and breeders. Except for germplasm of forages and trees, which are more often requested for direct cultivation, very few requests for CGIAR germplasm come from farmers or farmers' organizations, civil society organizations, or countries with small, or no, plant breeding programs. Although the amount of material distributed to date through the multilateral system is impressive, it is only a small proportion of what it could be if more stakeholders had the technical capacity, for example, to identify plant genetic resources that are potentially adapted to changing climate conditions in their local areas, and to request, evaluate, and breed with those materials in local settings. CGIAR centers transferring germplasm to organizations through the multilateral system often cannot ascertain how that material is being used (this is more a concern for the centers with respect to germplasm they have improved), and whether those organizations are using the SMTA when they transfer that germplasm (or derived material) to third-party users. Despite repeated requests for information from recipients concerning their evaluation of germplasm received through the multilateral system, CGIAR centers rarely get information back, including when national research organizations register and release, as cultivars, improved lines they received from CGIAR centers. As a result, the international community is losing opportunities to accumulate and add value to the plant genetic resources in the multilateral system through information sharing. The global information system under the Plant Treaty is in its infancy, and research organizations only rarely publish or share research data vis-à-vis materials they received under the SMTA.

In 2013, the Plant Treaty Governing Body established the Ad Hoc Open Ended Working Group to Enhance the Functioning of the Multilateral System ("Working Group") to develop options for increasing user-based payments to the Benefit Sharing Fund and to increase the scope of the multilateral system to include more crops. This was already a challenging exercise, and it has become considerably more so since the emergence of concerns about "dematerialization" (i.e., the use of information related to genetic resources [including DNA sequence information] detached from the access to physical samples of plant genetic material). Although it was not included in the Working Group's original terms of reference, many delegations are now insisting that monetary benefit sharing from commercial users of genomic sequence information (in addition to genetic material per se) should be included in the final package of revisions to the multilateral system. Since the beginning of the process for enhancing the multilateral system, CGIAR has underscored the practicality of adopting a variant of the so-called "Norway model" as the most effective way of sharing monetary benefits and encouraging more material exchange under the multilateral system. According to this model, which takes its name from the way Norway has voluntarily made contributions to the Plant Treaty's Benefit Sharing Fund in recent years, each contracting party would undertake to make payments to the fund based on national seed sales or some other parameters related to the use of plant genetic resources. In return, all natural and legal persons in the country would have access to the multilateral system (Rosendal and Andresen, 2016). CGIAR has also endorsed the subscription system being developed by the Working Group (FAO, 2018). Payments under both models—by contracting parties under an adapted Norway model and by subscribers under the subscription system—would be based on final sales, and not on sales of particular products that physically incorporate material accessed from the multilateral system. Consequently, those payments would reflect sharing of benefits realized by users from access to both material genetic resources and genomic sequence data. Both of these models are attractive because they could increase upfront payments to the Benefit Sharing Fund, minimize transaction costs related to tracking and tracing, increase transparency and predictability for users, and possibly represent a way of resolving issues concerning benefit sharing from use of genomic sequence information.

Successful conclusion of the process for revising the multilateral system could increase monetary benefit sharing and incentives for more sharing of materials in the multilateral system. Meanwhile, launching the GLIS and widespread adoption and use of DOIs could address the problem of information loss and contribute to substantial value being added to the multilateral system overall.

In the meantime, the Plant Treaty's Governing Body has not dedicated significant resources to encouraging the generation and sharing of nonmonetary benefits as set out in the Plant Treaty's provisions on the multilateral system (i.e., technology transfer, information exchange, and capacity building). Working documents prepared for Governing Body meetings tend to focus on the number of transferred germplasm samples on the one hand, and funds disbursed by the Benefit Sharing Fund on the other. The documents generally do not mention contracting parties' obligations and efforts—or those of other stakeholders—to promote nonmonetary benefit sharing. However, it is ultimately—primarily through technology transfer, information exchange, and capacity building—that farmers and research organizations will be able to use PGRFA for food security and economic development. Similarly, the Governing Body has not dedicated the required energy to connecting sustainable use, improved conservation, and farmers' rights to the generation and sharing of nonmonetary benefits. These issues are generally addressed separately by the Governing Body and its subsidiary bodies, but in many ways, they are inextricably linked. The monetary value of improved crops and associated technologies, information, and enhanced capacities around the world far exceeds the levels of income and impact that could possibly be made by revised monetary benefit-sharing conditions under the multilateral system. These nonmonetary benefits are absolutely critical to reach the Plant Treaty's objectives, and to make PGRFA efficiently serve broader global objectives like Sustainable Development Goals 2 (zero hunger), 3 (good health and well-being), 13 (climate action), 15 (life on land), and 17 (partnerships for the goals).

Nonmonetary benefits should be integrated much more systematically into the future work of the Governing Body, developing innovative measures to foster contracting parties (and other stakeholders) generating and sharing nonmonetary benefits, and to monitor progress in this area. Nonmonetary benefit-sharing promotion and monitoring could be included as one of the key thematic areas in the Plant Treaty's multiyear program of work (2020–2028) to be adopted by the Eighth Session of the Governing Body in 2019. Ultimately, increasing nonmonetary benefit sharing should be one of the core outcomes of the Plant Treaty community's work to fully implement the Plant Treaty, from enhancing the functioning of the multilateral system, to developing enhanced partnerships and programs for sustainable use, to realizing farmers' rights.

Conflict of Interest

The authors declare that there is no conflict of interest.

Author Contributions

I.L. Noriega and M. Halewood designed and led the development of the article, wrote the manuscript, and integrated contributions from all other coauthors. M. Abberton, A. Amri, I.I. Angarawai, N. Anglin, M. Blümmel, B. Bouman, H. Campos, D. Costich, D. Ellis, P. Gaur, L. Guarino, J. Hanson, V. Kommerell, L. Kumar, C. Lusty, M.-N. Ndjiondjop, T. Payne, M. Peters, E. Popova, G. Prakash, R. Sackville-Hamilton, R. Tabo, H. Upadhyaya, M. Yazbek, and P. Wenzl provided comments on the manuscript and corrected and added information based on their own expertise and knowledge. They are listed in alphabetical order in the list of authors.

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