The importance of international exchanges of plant genetic resources for national crop improvement in Guatemala

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CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Abstract

One of the main considerations underlying the establishment of the International Treaty on Plant Genetic Resources for Food and Agriculture and its Multilateral System of Access and Benefit Sharing is the recognition of countries' high interdependence on the genetic resources of the crops and forages which they depend upon for their food security. A continued appreciation of how countries have benefited from facilitated exchange of germplasm in the past and are likely to continue doing so in the future is needed, in order to move forward the implementation of the Multilateral System and creating a truly global pool of genetic resources for countries' agricultural development and adaptation to climate change. Using Guatemala as a case and maize and beans as key crops, the paper presents a picture of the dynamics of their genetic resources, both inside and outside of the country, over past years and into the future. It illustrates the extent to which Guatemala is dependent upon germplasm from other countries for its food security, and how, in a complementary manner, other countries rely upon germplasm from Guatemala. It is hoped that the information presented here may encourage and facilitate the implementation of the International Treaty and its Multilateral System in the country.

Keywords

Plant genetic resources; Multilateral System; interdependence; climate change.

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Contents

Introduction

From the origins of agriculture until around the 1980s, the prevailing idea was to consider genetic resources (including those for food and agriculture) a common heritage of mankind, an idea that posed no limitations or formal rules to their exchange and use, regardless of how far from their area of origin these events took place. However, the increasing application of intellectual property rights in the biological arena gradually led to an international scenario in which diversity-rich countries, mostly in the developing world, felt 'robbed' of the benefits deriving from the commercial exploitation of resources from their territory, and thus began demanding the abolition of the principle of free access to genetic resources. After years of negotiations, their demand was recognized in 1992 in the Convention on Biological Diversity (CBD), which establishes the sovereignty of countries over the natural and genetic resources found within their borders, defining the conditions and procedures required to obtain access to these (i.e. access and benefit-sharing regulations). In 1993, the Conference of the Food and Agriculture Organization of the United Nations (FAO) requested the Commission on Plant Genetic Resources for Food and Agriculture (established in the early 1980s) to host intergovernmental negotiations for addressing issues that were not covered by the CBD, or that did not fit into the framework established by the CBD. Among these issues was the status of *ex situ* collections, the identification of a univocal origin/provider for crop genetic resources (which, in contrast to natural species, tend to be the result of generations of selection by farming communities in different environments), and farmers' rights. After seven years, these negotiations led to the development of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). The ITPGRFA establishes a multilateral system of access and benefit sharing (from here on, the MLS) through which countries create an international pool of PGRFA for sixty-four priority crops and forages of global importance, to be used for research, training and breeding purposes. In exchange for putting their own PGRFA in the pool, countries obtain access to PGRFA held in all other countries that are contracting parties to the ITPGRFA, along with those in the collections held by international organizations that have signed agreements with its Governing Body. The ITPGRFA sets out mandatory benefit-sharing requirements: when recipients commercialize new PGRFA products that incorporate material from the MLS, and don't allow others to use those products for research and breeding, they must pay 1.1% of gross sales to an international benefit-sharing fund created under the framework of the ITPGRFA. This fund is used to support research and capacity building in developing countries, in projects selected through a competitive bidding scheme.

The fact that countries are highly interdependent on the genetic resources of food security crops and forages is the main reason for creating the multilateral system. An appreciation of the extent to which any contracting party to the ITPGRFA depends on resources from other countries for its agricultural development is an important element to fully understand why participation in the multilateral system is so relevant.

It is hoped that the data presented in this working paper will contribute to increased awareness among stakeholders on the extent to which Guatemala is dependent upon germplasm from other countries for its food security, and how, in a complementary manner, other countries rely upon germplasm from Guatemala. The analyses include a retrospective element, which traces the history of domestication or introduction of key crops in Guatemala and their subsequent adoption/diffusion; a present-day snapshot of important achievements based on international PGRFA exchanges; and an analysis of future potential germplasm needs required for responding to the likely impacts of climate change on Guatemalan agricultural production. The working paper starts with a general overview of Guatemala's agricultural system. Thereafter, most of the in-depth analyses focus on pearl millet and rice, and to a lesser extent on grain legumes (cowpea and groundnut), in an effort to present a picture of the contrasting dynamics of crop genetic resources both inside and outside the country, over the years and into the future. The research presented here was supported by the Genetic Resources Policy Initiative (GRPI2), a multi-country project aimed at strengthening capacities for the implementation of the ITPGRFA and its multilateral system in eight countries. Bioversity International provided international coordination and research support for the project. In Guatemala, the project was led by the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) and the Ministry of Agriculture[1].

Overview of agriculture in Guatemala

Agriculture is the backbone of Guatemala's economy, contributing 25% of GDP, employing over half of the labour force and providing two thirds of exports, mostly coffee, sugar, bananas and beef. Small farms make up over 80% of the total number of farmsteads in

[1] Briefs setting out comparable results from other countries are also being developed. Once finished they will be available on the GRPI project blog at http://grpi2.wordpress.com/about/grpi-2/; on the publications page of Bioversity International at https://www.bioversityinternational.org/e-library/publications/; on the CCAFS working papers page at https://cgspace.cgiar.org/handle/10568/5468

Guatemala, but occupy only 10% of the farmed area. Most small farms are concentrated in the highlands, the 'Altiplano', where the population is predominantly of Mayan ancestry; and in the east, the 'Oriente', where the population is mixed or 'mestizo'. Strong cultural traditions exist among the people of the Altiplano, and are protected mainly through their use of various Indian dialects, although now most male adults also speak Spanish as a second language. Both in the Altiplano and Oriente, as well as in the lowlands of the Petén department, rural poverty is widespread. Such poverty is to a large extent due to inequality in land distribution: 3% of landlords own 70% of the land, and dominate cultivation of the fertile coastal regions. The majority of Guatemala's small-scale farmers produce food crops mainly for home consumption, selling off any surplus in order to buy other necessary goods. In some areas of the Altiplano, where the average size of farm rarely exceeds half a hectare, families compensate by working off farm, and carrying out artisan work in textiles, pottery and other activities. The main food crop cultivated by these small-scale farmers is maize, together with beans and followed by wheat, sorghum, potatoes and faba beans (IFAD 1992). However, national production is insufficient to cover the national demand for food, and many poor families face seasonal food shortages. As an alternative source of employment and income, a growing number of farmers have been turning to non-traditional crops (such as snow pea, broccoli, cauliflower and melon), which have been promoted since the 1990s by government agricultural policies geared towards export-led growth. Whilst returns can be fruitful, expensive inputs are required to grow these crops to the standards required for export. Snow pea has become one of Guatemala's most important non-traditional crops, generating more than 50 million US dollars annually in exports to the United States of America (USA). The crop costs six times more to produce than traditional crops like maize, but returns may be up to fifteen times higher. However, snow pea prices are highly volatile, creating uncertainty for small-scale farmers (The New Agriculturalist 2015).

In recent years, the Pacto Hambre Cero (Zero Hunger Pact) was launched as an inter-sectoral collaboration to reduce malnutrition and rural poverty; it aims to support the country's family farming sector, by improving the capacities of small-scale farmers to produce the country's staple foods, such as maize and beans, using sustainable management practices. Efforts cover the full range of agricultural operations, from soil and crop management strategies, to post-harvest and processing innovations, linkages to markets, and access to inputs such as quality seed of local or improved varieties. The pact incorporates socio-economic and also climate change vulnerability factors, taking into consideration the exposure of poor farmers particularly in marginal areas to challenges posed by increasing droughts and high temperatures (Gobierno de Guatemala 2012). Continued availability and improved use of genetic diversity are likely to be an important pre-requisite or a component of strategies intended to boost the small-scale production of basic crops, such as the Pacto Hambre Cero.

Lessons learned concerning the contribution of genetic diversity to food security can be taken from the successes of the Guatemalan components of regional initiatives such as the Programa de Fitomejoramiento Participativo (FP), and the Semillas para el Desarrollo project led by FAO, which placed an emphasis, although from different angles, on the improvement and dissemination of local and introduced varieties of the country's basic grains. All this further makes the case for the country's participation in the MLS, which will be expanded on in the following sections.

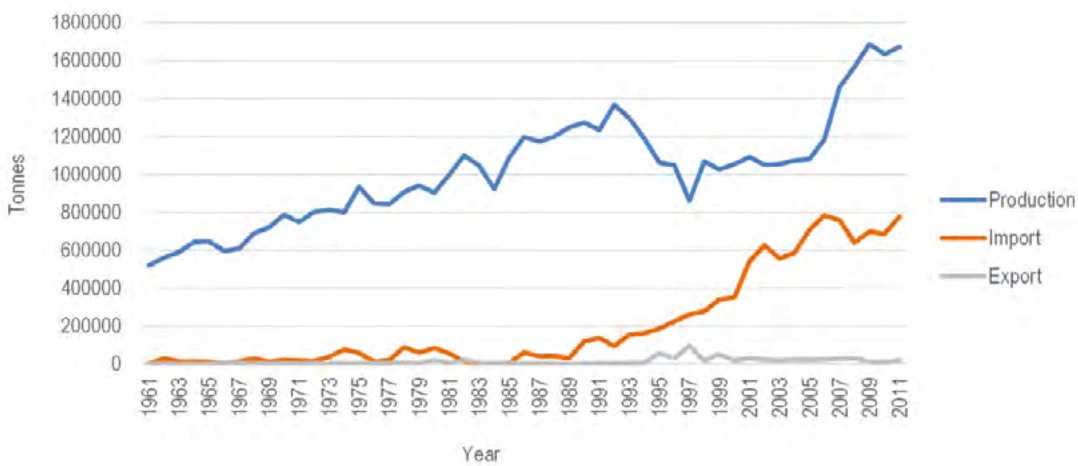
Maize and beans: origins, dispersal and present-day importance in Guatemala

Maize

Archaeological and genetic data strongly suggest that maize was domesticated in southern Mexico between 6,000 and 10,000 years ago (Piperno and Flannery 2001; Matsuoka et al. 2002a): the oldest maize starch grains recorded date back to 9000 BP (or 'before present', where 'present' is defined as AD 1950), and are from the Balsas river valley in the state of Guerrero in southern Mexico (Piperno et al. 2009); genetic data indicate that the type of teosinte most closely related to maize (*Zea mays* ssp. *parviglumis*) also comes from the Balsas river basin at the convergence of Michoaca and Guerrero states in Mexico (Matsuoka et al. 2002a). This supports the hypothesis of a single domestication in that region, even if other analyses of genetic data have considered the possibility of multiple origins (Kato 1984; Galinat 1988). Through trade and seed exchange among indigenous peoples, domesticated maize rapidly spread along two most likely dispersal routes, one tracing through western and northern Mexico into the south-western USA and another leading out of the highlands to the western and southern lowlands of Mexico into Guatemala, the Caribbean, the lowlands of South America, and finally the Andes (Matsuoka et al. 2002b). Guatemala is part of the Mesoamerican centre of maize diversity (Mangelsdorf and Cameron 1942; Wellhausen 1957; Goodman and Brown 1988): Wellhausen described 15 Guatemalan maize races, among which isozyme variation was later found to be strongly associated with altitude (Bretting et al. 1990). Guatemala also harbours two populations of teosinte, *Zea mays* ssp. *huehuetenanguensis* and *Zea luxurians* (Iltis and Doebley 1980), and there has been evidence of introgression with cultivated maize (Kempton and Popenoe 1937; Wilkes 1967). Populations of *Zea*'s sister genus *Tripsacum* also grow in Guatemala (Iltis and Doebley 1980).

Soon after its spread into Guatemala, maize quickly became a fundamental staple and a cultural symbol of local Mayan populations, as reflected in their mythology and present-day indigenous culture and rituals. The Popol Vuh, the sacred book of the Quiché Mayas of the Guatemalan highlands, narrates that the gods created men and women from white and yellow maize. Today, the crop's continued importance is evident from its broad distribution in the country, where it is cultivated across more than 94% of the territory, occupying a broad range of agro-ecological areas and altitudes (between 0-3,100 metres above sea level) and yielding around 40 million tonnes of grain, mostly white (85.5% of the cultivated area) and to a lesser extent yellow (13.7%). More than half of the production (67%), comprising around 13.7 million tonnes, comes from small farms (less than ten 'manzanas' in size, with one 'manzana' corresponding to approximately 0.7 hectares). Per capita maize consumption is 110 kg/year, which contributes to 65% of the daily intake of carbohydrates in the average diet (Fuentes López et al. 2005). Although domestic maize production has increased over time (figure 1, blue line), as with other staples it has become relatively less important compared with rising commodities destined for export, such as sugarcane and bananas (FAO 2014). Furthermore, the last few years have witnessed oscillations in yields, mostly due to disturbances in the climate and consequent pest and disease incidence. This has led to increased imports (figure 1, orange line), in parallel with the establishment of programmes aimed at stabilizing and improving domestic production, such as the provision of improved seed and inputs to farmers (IICA 2009).

Figure 1. Quantities of maize produced, imported and exported by Guatemala over the 1961-2011 time period (FAO 2014)



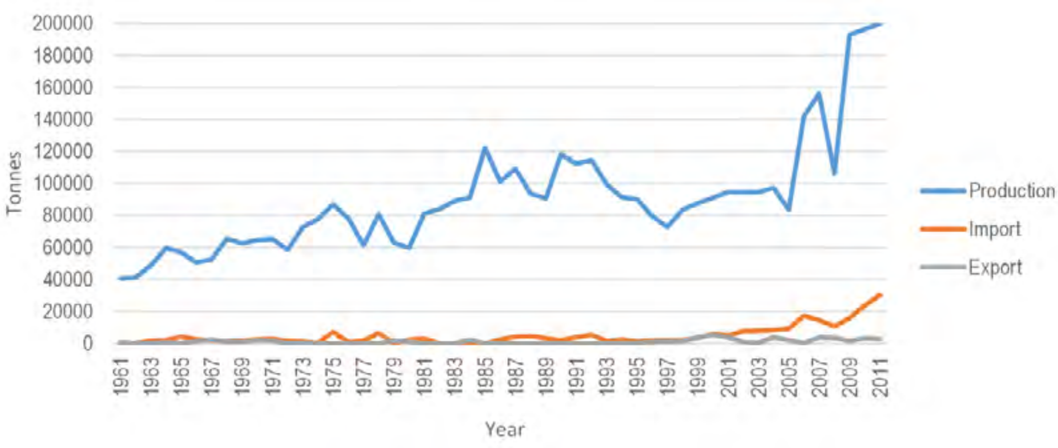
Beans

Beans are considered to have been domesticated in two places, from two separate gene pools - Andean and Mesoamerican - that diverged some 11,000 years ago, although some authors suggest a single place of origin in Mesoamerica (Bitocchi et al. 2012), most likely in Mexico (Gepts et al. 1986). The Mesoamerican gene pool extends from Mexico through Central America and into Venezuela and Colombia. Mesoamerican seeds are smaller (up to 40 grams per 100-seed weight) than those of Andean beans (more than 40 grams per 100-seed weight), which are found across Ecuador and Peru. The two types differ in the type of phaseolin (the main storage protein in beans) they carry (Gepts et al. 1986). Mesoamerican cultivars have been classified into three races: the lowland race 'Mesoamerica', and highland races 'Durango' and 'Jalisco' (Singh et al. 1991). The Mesoamerica race comprises the black, navy and small-red market classes, and is more adapted to the lowlands (Voysest 1983).

Soon after their domestication, Mesoamerican beans rapidly spread into Central America and then proceeded southwards into South America, through trade and seed exchanges among local populations. Spanish colonizers commented on the use of the crop in both hemispheres, noting both resemblances and differences with European legumes such as faba beans. Mesoamerican cultivars are now more widespread than Andean bean cultivars in the lowlands of South America (Brazil) and in south-western USA. Guatemala harbours at least 12 *Phaseolus* species (Freytag and Debouck 2002): in addition to common bean (*P. vulgaris*), four other species have been domesticated (*P. lunatus, P. coccineus, P. dumosus y P. acutifolius)* (Gepts and Debouck 1991).

Beans are the second most important food crop in the country, occupying 85% of the cultivated area, with production reaching 500,000 tonnes in 2013. Beans are grown in all 22 departments of Guatemala, at elevations ranging from sea level to 2,500 metres above sea level (masl); bean consumption, which is mostly of black-grained varieties, is 9.4 kg/year per capita, providing around 22% of the total protein intake (ICTA 2010). Similarly to that of maize, domestic bean production has suffered from competition with commodities such as tropical fruits and sugarcane plantations, and experienced a decrease throughout the 1990s and early 2000s. However, the quantities produced nationally have remained sufficient to meet internal demand, reducing imports to a minimum (Ministerio de Agricultura Ganadería y Alimentación de Guatemala 2014) (figure 2). Since the late 2000s, under the umbrella of regional initiatives, beans have been among the target crops of programmes aimed at boosting domestic production of basic grains by supporting farmers with improved seed and technologies.

Figure 2. Quantities of beans produced, imported and exported by Guatemala over the 1961-2011 time period (FAO 2014)



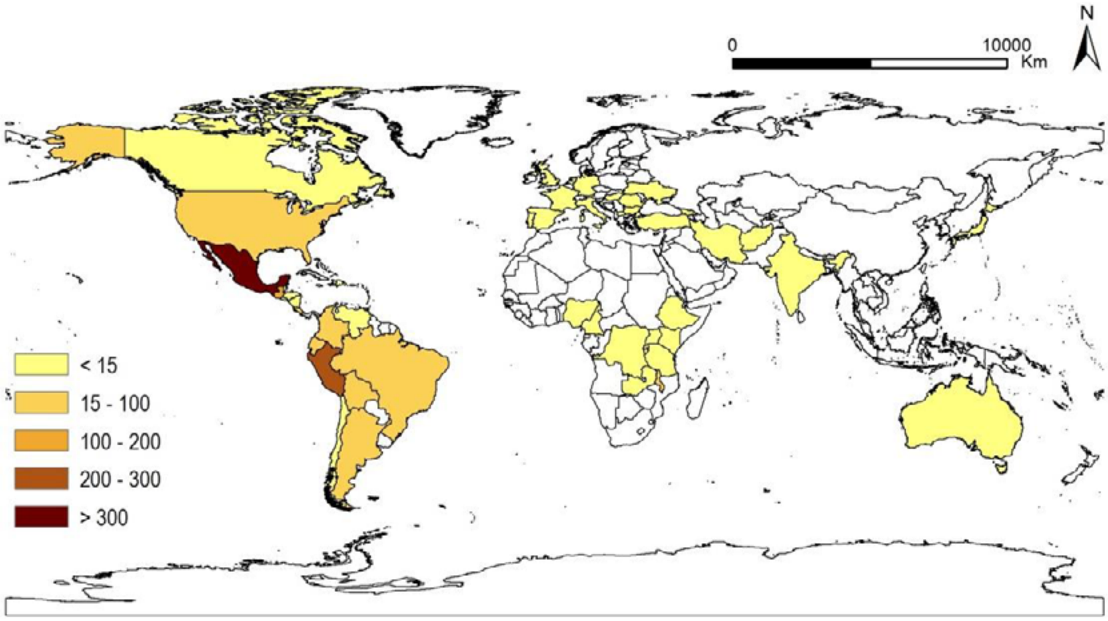
Regional and international collaborations on agricultural research and exchanges of plant genetic resources

Maize and beans have long been protagonists of the country's research efforts, although recent years have witnessed a decline in the country's capacity to sustain well-functioning breeding programmes for these crops (discussed in further detail below). Since its establishment in 1972, the Instituto de Ciencia e Tecnología Agricola (ICTA) has been undertaking conservation, breeding, varietal release and quality seed production efforts for both crops. ICTA's genebank holds 344 *Zea* and 615 *Phaseolus* accessions collected across the country (Suchini). Universities such as the Facultad de Agronomía de la Universidad de San Carlos (FAUSAC/USAC), the Centro Universitario de Sur Occidente (CUNSUROC/USAC), and the Universidad del Valle de Guatemala (UVG) have also been involved in conservation, research and development initiatives for maize and bean genetic resources (Ministerio de Agricultura Ganadería y Alimentación de Guatemala 2008). Guatemalan maize and bean materials are being conserved and used by other institutions too: thanks to international collaborations and or/joint collection missions, genetic resources from Guatemala have been deposited into international collections that can be accessed by institutions in other countries for research purposes: as of today, the International Maize and

Wheat Improvement Center (CIMMYT) contains 1,037 accessions, among *Zea* and *Tripsacum* accessions from Guatemala (174 and 863 respectively), while the International Centre for Tropical Agriculture (CIAT) holds 2,771 accessions of both domesticated and wild *Phaseolus* from the country (2,270 *P. vulgaris*; 112 *P. lunatus*; 216 *P. coccineus*; 133 *P. dumosus*; and 2 *P. acutifolius;* with the remainder comprising wild species) (Genesys 2014).

Guatemalan institutions have themselves received germplasm from other countries, mostly through international institutions: with regard to maize, as early as 1975, ICTA received 540 materials (lines, crosses, hybrids and landraces) from CIMMYT, which became the basis of the institute's breeding programme. Although most of these materials are of Mesoamerican origin (243 from the lowlands, 143 from subtropical areas), they also include South American (22), Asian (20) and African (80) samples. These materials have been used for improving a variety of traits such as tolerance to drought and biotic stresses; grain filling, texture and colour; high quality protein content; and plant architecture (Fuentes López 2014). More recently (between 2009 and 2013), 33 samples were sent from CIMMYT's genebank to Guatemalan researchers (Payne 2014), and certainly many more samples were sent from the centre's breeding programmes (data unavailable). Similar exchanges of germplasm took place between ICTA's bean programme and CIAT: from 1979 to 2009, Guatemala received at least 1,388 *Phaseolus* accessions from CIAT's genebank, almost all being landraces or traditional cultivars (97%). While 156 of these materials were originally sourced in the country itself, 519 came from other Central American countries, mostly from Mexico (471), and other countries across the globe (figure 3) (SINGER 2012). Data concerning the samples sent to Guatemala from CIAT's bean breeding programme were not available but are likely to surpass the quantities sent from the genebank, since working with pre-bred materials is a more widespread and accessible practice.

Figure 3. Origins of the *Phaseolus* samples sent to Guatemala from CIAT's genebank during the 1979-2009 period, with darker shades indicating greater numbers of samples (SINGER 2012)



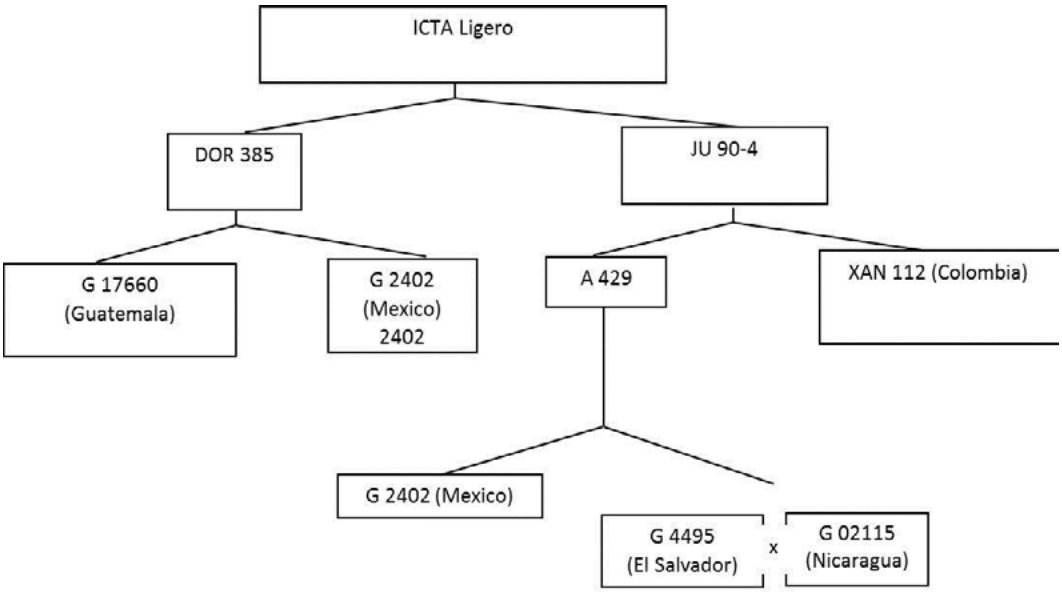
Further exchanges of germplasm with international and national institutions in other countries were made possible thanks to the establishment of initiatives such as the Central American Cooperative Programme for the Improvement of Crops and Animals (PCCMCA), which began in 1954; the Regional Maize Programme for Central America and the Caribbean (PRM), which was initiated in 1975; and the Cooperative Regional Bean Programme for Mexico, Central America and the Caribbean (PROFRIJOL), which began in 1981. The latter two thematic networks, established with funds from the Swiss Agency for Development and Cooperation (SDC), involved the participation of CIMMYT and CIAT respectively as lead technical agencies. The Escuela Agrícola Panamericana Zamorano (from here on, Zamorano) became another important actor in PROFRIJOL in 1996, with financial support from the Bean/Cowpea Collaborative Research Support Program (CRSP) funded by the United States Agency for International Development (USAID). These programmes have facilitated exchanges of germplasm particularly through a system of regional nurseries, in which materials from international breeding programmes are tested and then distributed to countries for continued improvement, and eventually, national release as finished varieties. This approach has been instrumental in allowing experimentation with maize and bean germplasm not available within countries, resulting in a consistent release of new varieties that incorporate materials from international sources. In the case of maize in Guatemala, over the 1991-1996 period, 3,760 materials from other countries in the region were introduced through the PRM (Sain et al. 1999), and 43 new materials were developed (42 of which were subsequently released) during the same period (Fuentes López 2014). In terms of productivity and performance benefits, it is estimated that the PRM, thanks to the circulation of materials, information and technologies, has obtained genetic gains close to 2% per selection cycle (Córdova 1991). While we do not have data on the quantities received by Guatemala through PROFRIJOL, the network is known to have allowed the circulation of over 30,000 materials among countries in the region (COSUDE 2005). In Guatemala, 17 bean varieties were released between 1978 and 1998, with material pre-bred at CIAT; another six were released between 2010 and 2011, thanks to Zamorano's efforts within the CRSP (Jamora and Maredia 2011)(table 1).

Table 1. Bean varieties with CIAT germplasm released in Guatemala through PROFRIJOL and in collaboration with international institutions, from 1978 to 2011 (Jamora and Maredia 2011)

Country	Market class	Variety	Year released	Source
Guatemala	Small red	DORICTA	1992	CIAT
Guatemala	Black	ICTA ACHUAPA	1978	CIAT
Guatemala	Black	ICTA ALTENSE	1996	CIAT
Guatemala	Black	ICTA CHAPINA	1996	CIAT
Guatemala	Black	ICTA COSTEÑA	1992	CIAT
Guatemala	Black	ICTA HUNAPU	1996	CIAT
Guatemala	Black	ICTA JUTIAPAN	1979	CIAT
Guatemala	Black	ICTA LIGERO	1998	CIAT
Guatemala	Black	ICTA OSTUA	1978	CIAT
Guatemala	Black	ICTA PARRAMOS	1978	CIAT
Guatemala	Black	ICTA QUETZAL	1979	CIAT
Guatemala	Black	ICTA QUINACK-CHE	1978	CIAT
Guatemala	Black	ICTA SAN MARTIN	1978	CIAT
Guatemala	Black	ICTA STA GERTRUDIS	1996	CIAT
Guatemala	Black	ICTA TAMAZULAPA	1979	CIAT
Guatemala	Black	ICTA TEXEL	1978	CIAT
Guatemala	Black	SUCHITAN	1978	CIAT
Guatemala	Black	Altense Precoz	2011	CRSP
Guatemala	Black	ICTA Peten	2010	CRSP
Guatemala	Black	ICTA Sayaxche	2010	CRSP
Guatemala	Black	ICTA Super Chiva	2011	CRSP
Guatemala	Black	ICTA Zam	2011	CRSP
Guatemala	Black	MEN 2207-17	2010	CRSP

Pedigree analyses of some of the above varieties can provide a measure of the contribution of foreign germplasm, introduced through these international collaborations, to national crop improvement. While it was not possible to retrieve the pedigrees of important maize hybrids of relatively recent release (such as ICTA Maya and ICTA B7), our analyses in bean yielded interesting results in this sense. ICTA Ligero was one of the most successful bean varieties released through PROFRIJOL, and is still a favourite in agricultural development programmes involving the distribution of improved seed to farmers (Jamora and Maredia 2011). It has greater resistance to golden yellow mosaic virus (GYMV), anthracnose, bacterial blight and rust, compared with other varieties used among farmers (Genesys 2014; RedSICTA 2014a). The genetic resources that lie at the basis of the crosses through which ICTA Ligero was obtained come from a variety of countries (CIAT 1989; Voysest 2000; Genesys 2014): an accession from Mexico (reported as G2402 in Genesys, a global portal to information on PGRFA) is the carrier of resistance to GYMV (Blair and Beaver 1992); other countries that acted as providers of the materials incorporated into ICTA Ligero are el Salvador, Nicaragua and Colombia (figure 4).

Figure 4. Pedigree of the successful bean variety ICTA Ligero (CIAT 1989; Voysest 2000; Genesys 2014)



ICTA Hunapu is another successful variety, well adapted to medium elevation areas (RedSICTA 2014b), and based on a cross between a Guatemalan traditional variety (Negro Pacoc) and a line produced from crossing Brazilian and Mexican materials. ICTA Santa Gertrudis and ICTA Costeña incorporate a Brazilian landrace (G18521); ICTA Jutiapán derives from a cross between a Colombian (G4525) and a Costa Rican (G4485) landrace; ICTA Quetzal was developed from Salvadorian (G4495) and Costa Rican (G4485) parents; ICTA Tamazulapa has Colombian (G4525) and Costa Rican (G4485) ancestry; and ICTA has Mexican (G2402) and Guatemalan (G17660) parents (Genesys 2014).

Since the 1990s, under a policy that gradually dismantled public institutions operating in agricultural development, national programmes dealing with PGRFA have experienced severe budget cuts. This has affected the number of breeders working on staple crops: by 1991, the number of breeders employed at ICTA had decreased from 166 to 67 breeders, with particularly strong reductions in the staff working on maize and beans. While this downscaling was a somewhat common phenomenon among public agricultural research institutes in Latin America in the 1990s, the situation in Guatemala has become troubling, with the country dedicating the lowest share of public funds to agricultural research in the region (USAID 2010). This lack of funding has led to serious limitations in the international acquisition and distribution/sharing of germplasm by public institutions, which are unable to cover the basic costs associated with these operations, and there are no special mechanisms or exemptions in place to facilitate the movement of materials for research purposes (Suchini). Furthermore, the decrease in international funding devoted to multi-country collaborative programmes and networks has greatly reduced the flows of germplasm, which had allowed for the generation of the majority of varieties and hybrids released in Guatemala over previous decades. CIATs' role in collaborative bean research has been less prominent since 2002, owing to the drop in international funding; the continuation of international nurseries and trials was made possible thanks to Zamorano's technical support, through financial contributions from USAID's bean/cowpea CRSP, together with the personal dedication of the few breeders still working in Guatemalan institutions. Indeed, from the late 1990s to 2010 it seems that not a single variety was released through international collaboration in Guatemala; following this gap, six new varieties were released within the framework of the bean/cowpea CRSP in 2010 and 2011.

The exchange of plant genetic resources to cope with the impact of climate change

Central America is considered to be a hotspot of climate vulnerability (Working Group II 2007), and the agricultural sector is naturally among the most affected, given its dependence on climate patterns. In Guatemala, the most serious impacts relate to irregularities in rainfall, which shift planting and harvesting times, as well as increases in temperature, which lead to greater incidence of pests and diseases (Nelson et al. 2009). Such vulnerability threatens the food security of 52% of the rural population, which depends on staples such as maize and beans (Baumeister 2010). A number of institutions in Guatemala are making efforts to develop solutions to adapt agricultural systems, particularly those of small-scale vulnerable farmers, to climate change. In the agricultural sector, projects tend to focus on technology transfer in basic grains such as maize and beans, which most often involves the generation and/or dissemination of adapted varieties. The Guatemalan Ministry of Agriculture, through ICTA and in collaboration with FAUSAC/USAC, has developed materials tolerant to drought and resistant to pests and disease for both maize and beans, and is engaging in dissemination efforts to get them into farmers' fields. Regional bodies such as the Instituto Interamericano de Cooperación para la Agricultura (IICA) and the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) are developing projects to rescue, characterize and promote potentially adapted landraces. In this context, the importance of facilitating the continued, if not increased, exploration and use of diverse materials is evident (CCAFS 2014).

To provide a picture of how, faced with future climate challenges, the adaptation of maize and beans in Guatemala may benefit from sourcing materials beyond the country's borders, we used the Climate Analogues modelling tool (CCAFS): by choosing a reference site of interest in Guatemala, the tool identifies areas that experience climatic conditions that are statistically similar to this reference site, but which may be separated temporally and/or spatially. In our case, the tool allowed us to glimpse into the future by locating areas whose climate today is similar to the projected future climate of the reference sites (i.e. we ran the analyses with the 'backward' scenario). We used the 'lag' option, in order to detect areas that experience similar climates in different times of the year; and, given the major influence of annual mean temperature and precipitation on the crops' productivity and adaptation, we ran the model using these parameters, assigning equal weight to each. We chose reference sites corresponding to important maize- and bean-growing areas in Guatemala, thanks to expert advice from the national team involved in the GRPI2 project: Chiantla, in the Huehuetenango department, for maize; and Jocotán, in the Chiquimula department, for beans. In order to restrict the search for similar climates to those occurring during the period of the year in which the crops are actually in the fields at the reference sites, we selected a growing season of April to September for maize, and a growing season of May to October for beans. We applied a threshold of 0.6 to the final results (i.e. only retained those areas with a 60% or greater probability of being similar to our reference sites).

Figures 5 and 6 illustrate the 'future climate' or 'analogue' sites detected by the model, i.e. those areas where climate patterns similar to those expected to occur in our reference sites during the maize- and bean-cropping seasons in the future (by the year 2050) have already been occurring over the last 50 years.

Figure 5. Analogue sites for maize, using Chiantla in the Huehuetenango department as a reference site (15°22'0"N; 91°27'0"W). Only sites with a similarity greater than 60% were retained. Redder areas denote greater similarity (i.e. have a lower probability of being dissimilar)

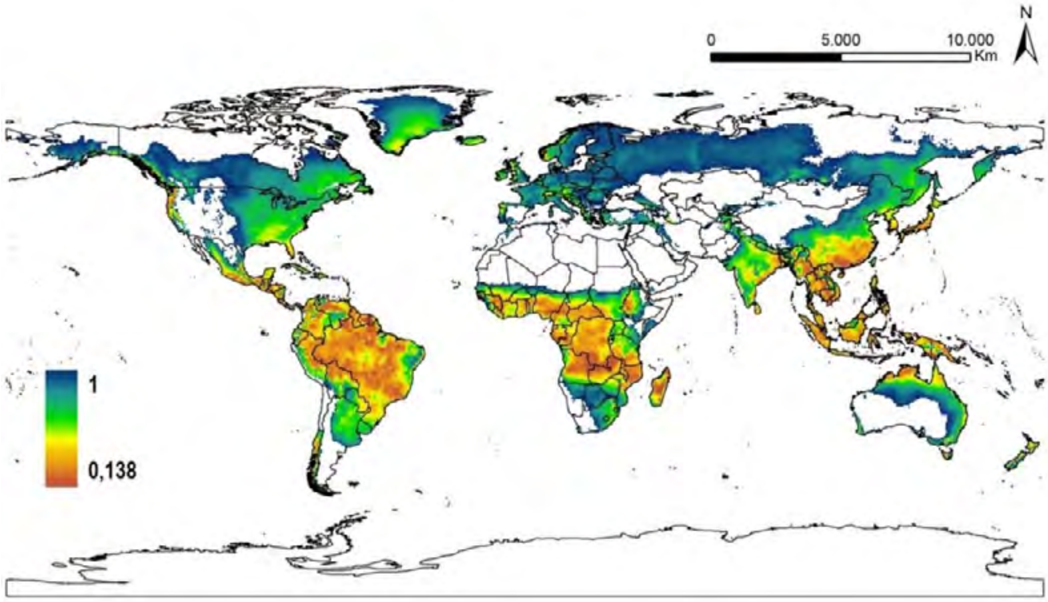
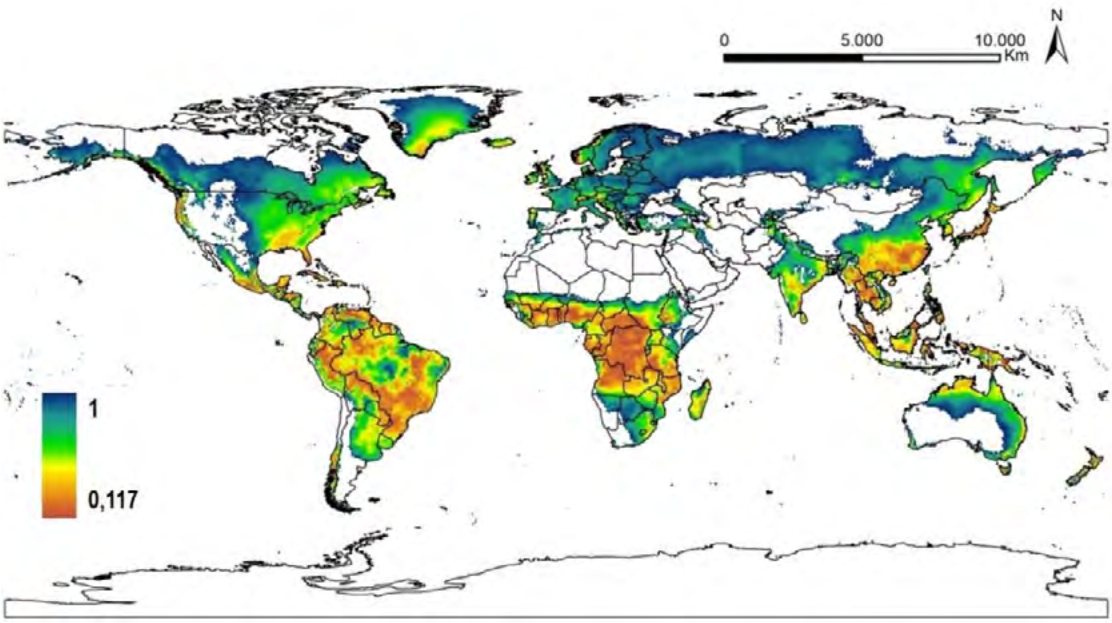


Figure 6. Analogue sites for beans, using Jocotán in the Chiquimula department as a reference site (14°49'0"N; 89°23'0"W). Only sites with a similarity greater than 60% were retained. Redder areas denote greater similarity (i.e. have a lower probability of being dissimilar)



Given the geographical proximity of the two reference sites chosen here, and considering the fact that maize and beans have partially overlapping climate requirements, growing seasons and areas, the analogue sites detected around the globe for the two species are rather similar. The 'future climate' areas identified are not necessarily traditional maize- or bean-growing areas. However, if sites can be found in these areas where maize and beans are thriving, obtaining germplasm from those sites may be a strategy for introducing materials with adaptive potential into Guatemalan breeding programmes. By overlaying geo-referenced observation data related to the maize and bean accessions deposited in international collections (purple dots on the maps below) (Genesys 2014), it was possible to locate those materials that were originally collected in 'future climate' areas. Since these accessions are included in the multilateral system of the ITPGRFA, they are available under a facilitated access regime that makes them easy to obtain by interested breeders working towards climate adaptation of maize and beans. Figures 7 and 8 list some of the maize and bean accessions that were collected from analogue sites, and which are available through the MLS.

Figure 7. Selected maize accessions collected from analogue sites and deposited in international or other collections. Point data refer to geo-referenced materials available in the collections hosted by CGIAR centers or other important collections (Genesys 2014)

Species	Accession number	Type of material	Country of origin/occurrence	Holding institute
Zea mays	CIMMYTMA-BANK-015334	Traditional landrace	Peru	CIMMYT
Zea mays	CIMMYTMA-BANK-004330	Traditional landrace	Suriname	CIMMYT
Zea mays	CIMMYTMA-BANK-022742	Traditional landrace	Ecuador	CIMMYT
Zea mays	CIMMYTMA-BANK-020471	Traditional landrace	Colombia	CIMMYT
Zea mays	CIMMYTMA-BANK-014698	Traditional landrace	Brazil	CIMMYT
Zea mays	CIMMYTMA-BANK-026393	Traditional landrace	Bolivia	CIMMYT
Zea mays	CIMMYTMA-BANK-002855	Traditional landrace	French Guyana	CIMMYT
Zea mays	PI 485674	Traditional landrace	Chile	CIMMYT
Zea mays	CIMMYTMA-BANK-005136	Traditional landrace	Brazil	CIMMYT
Zea mays	CIMMYTMA-BANK-016620	Traditional landrace	Cuba	CIMMYT
Zea mays	CIMMYTMA-BANK-009259	Traditional landrace	Mali	CIMMYT
Zea mays	TZm-398	?	Republic of the Congo	CIMMYT
Zea mays	TZm-361	Traditional landrace	Chad	CIMMYT
Zea mays	PI 532780	Traditional landrace	Zaire	CIMMYT
Zea mays	TZm-29	?	Tanzania	CIMMYT
Zea mays	CIMMYTMA-BANK-011519	Traditional landrace	Angola	CIMMYT
Zea mays	TZm-1057	?	Malawi	CIMMYT
Zea mays	PI 478297	Traditional landrace	Madagascar	CIMMYT
Zea mays	CIMMYTMA-BANK-009243	Traditional landrace	Nepal	CIMMYT
Zea mays	CIMMYTMA-BANK-023355	Traditional landrace	Thailand	CIMMYT
Zea mays	VI055772	Traditional landrace	Laos	AVDRC
Zea mays	VI056151	Traditional landrace	Cambodia	AVDRC
Zea mays	CIMMYTMA-BANK-020305	Traditional landrace	Vietnam	AVDRC
Zea mays	CIMMYTMA-BANK-020329	Traditional landrace	China	AVDRC

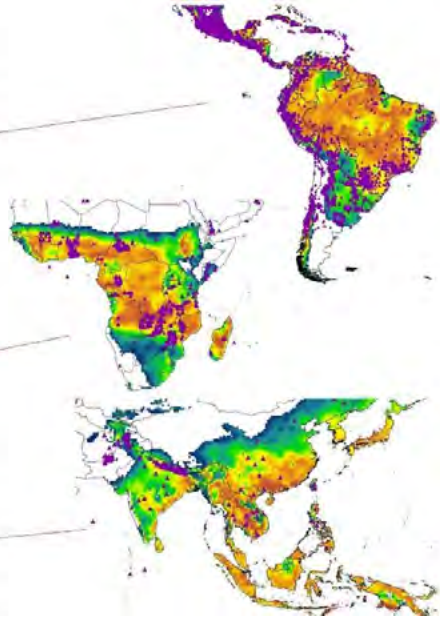
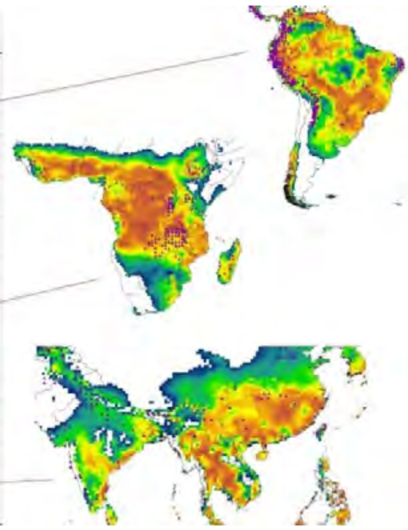


Figure 8. Selected bean accessions collected from analogue sites and deposited in international or other collections. Point data refer to geo-referenced materials available in the collections hosted by CGIAR centers or other important collections (Genesys 2014)

Species	Accession number	Type of material	Country of origin/occurrence	Holding institute
Phaseolus vulgaris	G4576	Traditional landrace	Colombia	CIAT
Phaseolus vulgaris	G11564A	Traditional landrace	Ecuador	CIAT
Phaseolus vulgaris	G111A	Traditional landrace	Peru	CIAT
Phaseolus vulgaris	G11575	Traditional landrace	Peru	CIAT
Phaseolus vulgaris	G14500	Traditional landrace	Brazil	CIAT
Phaseolus vulgaris	G11306	Traditional landrace	Bolivia	CIAT
Phaseolus vulgaris	G6473	Traditional landrace	Brazil	CIAT
Phaseolus vulgaris	G11752	Traditional landrace	Peru	CIAT
Phaseolus vulgaris	G51055E	Traditional landrace	Colombia	CIAT
Phaseolus vulgaris	G24507	Traditional landrace	Guinea	CIAT
Phaseolus vulgaris	G737	Traditional landrace	Democratic Rep. Congo	CIAT
Phaseolus vulgaris	G50163	Traditional landrace	Tanzania	CIAT
Phaseolus vulgaris	G24179	Traditional landrace	Tanzania	CIAT
Phaseolus vulgaris	G20137	Traditional landrace	Ethiopia	CIAT
Phaseolus vulgaris	G22995	Traditional landrace	Malawi	CIAT
Phaseolus vulgaris	G22480	Traditional landrace	Madagascar	CIAT
Phaseolus vulgaris	G13106	Traditional landrace	India	CIAT
Phaseolus vulgaris	G13897	Traditional landrace	India	CIAT
Phaseolus vulgaris	G24312	Traditional landrace	China	CIAT
Phaseolus vulgaris	G24311	Traditional landrace	China	CIAT
Phaseolus vulgaris	G24308	Traditional landrace	China	CIAT

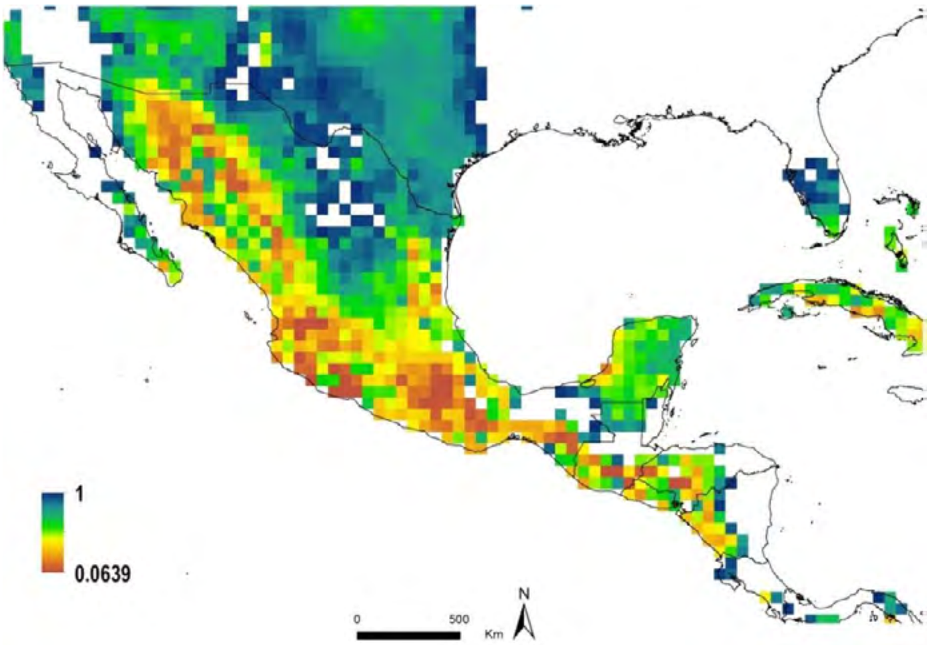


While some of the 'future climate' areas detected here appear to have been covered by collection missions, resulting in a significant amount of materials deposited in international genebanks and hence in the MLS, few maize and bean samples have been collected from other analogue sites: MLS samples from Africa and Asia are much fewer than from Latin America, and different areas of Latin America have been sampled with different intensities.

This is largely to be expected, since collection missions tend to focus primarily on the regions of origin and/or diversification of the crops of interest, where diversity is expected to be highest; furthermore, the two crops are not necessarily part of the agricultural systems of *all* of the analogue sites. However, it may also be that additional genetic resources exist from analogue sites where the crops *are* grown, but are stored in national genebanks or other collections within countries rather than in international institutes; these countries may either not be parties to the ITPGRFA, or they may not yet have taken active steps towards identifying the collections under their management and control and in the public domain, and deciding about their inclusion in the MLS. This scenario would imply a narrowing of the potential range of options available to Guatemalan researchers, and others, for addressing the climate adaptation needs of their key staples through exploration of materials from 'future climate' sites. Of course, the opposite scenario, i.e. the presence in Guatemalan collections of materials from areas that have climates similar to the future projected climates of sites in other countries, may also be true, restating the importance of fully implementing the MLS at national level.

The map below (figure 9) provides one such example, by showing the distribution of analogue sites for a reference site chosen within the maize-producing uplands of northern Vietnam (in the Bac Giang province). The present-day climate of analogue areas in Central America, including parts of south-western Guatemala, resembles that which is expected to hit this important maize-growing area in Vietnam in the future, suggesting that Guatemalan materials could become an important source of traits adapted to the climate challenges that the maize upland cropping system in Vietnam may face (Thanh Ha et al. 2004).

Figure 9. Analogue sites for maize across Central America, using Bac Giang province in the maize-growing upland areas of Vietnam as a reference site (21°18'06"N, 106°9'14"E). Only sites with a similarity greater than 60% were retained. Redder areas denote greater similarity (i.e. have a lower probability of being dissimilar)



This example indicates how all countries are interdependent in relation to PGRFA in the face of climate change, and that the participation of as many parties as possible in the MLS makes it most effective and useful.

Outlook

This brief overview of the case of maize and beans in Guatemala highlights how even a country that is the centre of crop origin or diversification has greatly benefited from the exchange and introduction of foreign germplasm for the improvement and adaptation of its native staple crops. As the sharing of germplasm across borders becomes more and more politically charged, and climate change exacerbates the challenges faced by plant breeders, clear rules and procedures for exchanging PGRFA are needed, in order to allow for the continuing development of more resilient and sustainable agricultural and food systems. Over the past three years, Guatemalan researchers and policymakers have been working towards the national implementation of the ITPGRFA and its MLS, within the framework of GRPI2, led by Bioversity International. During this time, the preliminary results of this brief were discussed and will hopefully continue to be instrumental in raising awareness on these topics.

By setting up clear and efficient mechanisms and procedures, international exchanges of germplasm, which have supported innovation in agriculture for many years, can be enhanced and put to use in addressing the increasing interdependence of countries on PGRFA, and fostering climate change adaptation.

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