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

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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 Burkina Faso as a case and millet, rice and maize 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 Burkina Faso is dependent upon germplasm from other countries for its food security, and how, in a complementary manner, other countries rely upon germplasm from Burkina Faso. 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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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, even 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 rules). 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 of all other countries, along with those in the collections held by international organizations that have signed agreements with the Governing Body of the ITPGRFA. 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. Those funds are 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 was the main reason for creating the multilateral system. An appreciation of the extent to which any ITPGRFA party 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.

The data presented in this working paper should contribute to increased awareness among stakeholders about the extent to which Burkina Faso is dependent upon germplasm from other countries for its food security, and how, in a complementary manner, other countries rely upon germplasm from Burkina Faso. The analyses include a retrospective element, tracing back the history of domestication or introduction of key crops in Burkina Faso and their subsequent adoption/diffusion; a present-day snapshot of important achievements based on international PGRFA exchanges; and an investigation of future potential germplasm needs that are required to respond to the likely impacts of climate change on Burkinabe agricultural production.

The paper begins with a general overview of Burkina Faso's agricultural system. Thereafter, most of the in-depth analyses focus on pearl millet and rice, and to a lesser extent on maize and grain legumes (cowpea and groundnut), in an effort to present a picture of the contrasting dynamics of crop genetic resources both inside and outside of the country over past 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 Burkina Faso, the project was led by the Commission Nationale de Gestion des Ressources Phytogénétiques, partnering with a range of organizations, including the Institut de l'Environnement et Recherches Agricoles (INERA), the Université de Ouagadougou, Direction Générale des Productions Végétales, the Conseil National pour l'Environnement et le Développement Durable and the Direction de la Valorisation des Résultats de Recherche.[1]

Overview of agriculture in Burkina Faso

Burkina Faso's economy is largely based on crop production and livestock, which engage 90% of the workforce and contribute to 39% of the gross domestic product. A variety of food crops occupy the cultivated area in the country (which amounts to around 13% of the national territory), and are mostly grown in subsistence systems, usually characterized by a dominant cereal such as millet, sorghum, maize, rice or fonio. Millet and sorghum contribute to over 60% of the average diet of the population. Some of Burkina's staple foods originated from within the country and the West African region (sorghum, millet, African rice, fonio, yam, cowpea, Bambara groundnut), while others have been introduced from elsewhere (rice, maize, groundnut, soybean, potato, sweet potato, cassava, tomato, onion, cabbage). The country also produces a number of introduced commodities (such as cotton and sugarcane), and fruit species (citruses, mangoes, bananas). Forages, some of African origin (*Brachiaria* spp., *Pennisetum* spp.), some introduced from other continents (*Crotalaria* spp., *Stylosanthes* spp.), are also of great importance for livestock rearing. The introduction of foreign crops and new technologies accelerated considerably in the 1920s, as part of the efforts of colonial officials and European missionaries to orient local agricultural systems towards commercial production and trade.

At present, the estimated reliance of Burkina Faso's food system on crops whose centre of origin and diversification lies elsewhere is estimated to be between 23% and 32%, which is a

[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 Bioversity International publications page at https://www.bioversityinternational.org/e-library/publications/ and the CCAFS working papers page at https://cgspace.cgiar.org/handle/10568/5468

relatively low index compared to other countries in West Africa, where foreign resources comprise between 35% and 81%, with the exception of Niger and Guinea Bissau[2](Flores Palacios 1998). However, this significant reliance on local crops for national food security in Burkina Faso has not meant self-sufficiency in terms of the germplasm of these crops that is required for the continued improvement of agricultural production. Indeed, germplasm introductions from other countries, often mediated through genebanks and breeding programmes of international institutions such as the CGIAR, have always been very important for sustaining the country's productive base of native crops as well as those that were not domesticated in the region. It has indeed been reported that a number of varieties of native crops such as millet, cowpea, yam, Bambara groundnut and sorghum, have disappeared from Burkina Faso, and if needed in local breeding programmes have to be sourced from foreign institutions. The need for sourcing foreign germplasm is at least partly due to limitations in Burkina's conservation infrastructure (e.g. genebanks) and funding strategies (e.g. little investment in on-farm conservation), as well as to the rapid socio-economic changes that cause traditional crops and varieties to be displaced by others. The erosion of local diversity, not all of which will be conserved in other countries' or international genebanks, affects not only the development of Burkina's agricultural system, but also those systems of other countries that may depend on similar crops and varieties. All these issues contribute to making the case for the country's participation in the MLS and will be expanded on in the following sections.

Millet, rice, maize and grain legumes: origins, dispersal and present-day importance in Burkina Faso

Pearl millet

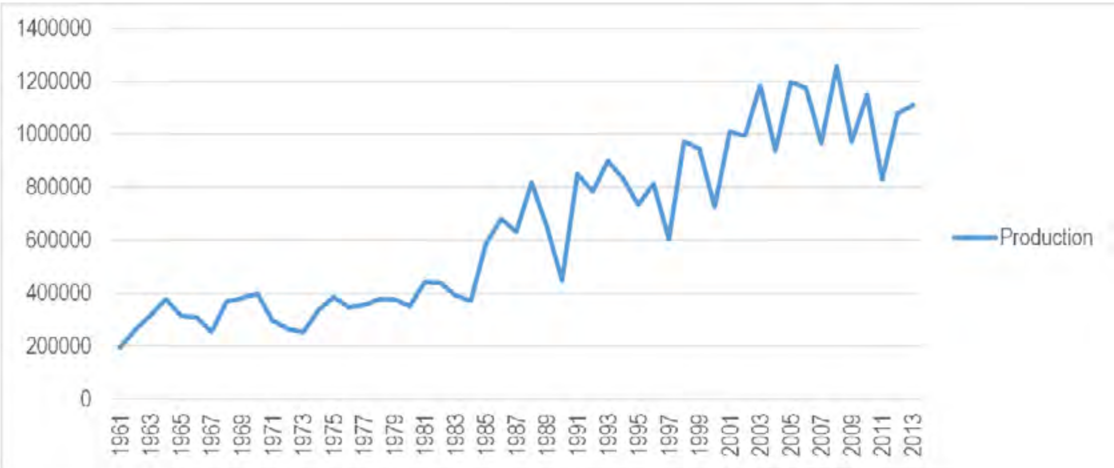
Considering the diversity and present-day distribution of pearl millet (*Pennisetum glaucum*), it has been suggested that the species' domestication occurred across a defused belt stretching from western Sudan to Senegal (Harlan 1971; Harlan 1975). The greatest morphological diversity occurs in West Africa, south of the Sahara desert, and north of the forest zone (Clement 1985; Tosiain et al. 1987); the timing of pearl millet's domestication is placed around the third millennium BC, after the drying of West African climatic conditions (approximately 3500 BC). This climatic change likely forced existing human populations and their herds to move south, where some appear to have taken up cultivation: by the early second millennium BC widely dispersed populations in West Africa were cultivating morphologically domesticated pearl millet (D'Andrea et al. 2001).

Although the exact timing and pathways of pearl millet's dispersal after domestication are not entirely clear, the species rapidly distributed across the semi-arid tropics of Africa and had already been introduced into southern Asia by around 1700 BC (Fuller 2002). It owes its success as a cereal to the fact that its domesticated form retained tolerance to heat and drought stress, as well as to its considerable landrace diversity, which allows its adaptation to a broad set of environments (Harlan 1975; Clement 1985; De Wet et al. 1991).

[2] This estimate is based on the Food Energy Supply criterion (in calories) that determines which crops contribute most to human nutrition, coupled with information on where these crops originated.

Because of its plasticity, millet is still today a fundamental element of production systems and diets in the Sahel countries, with most people preferring it to sorghum for culinary purposes. Millet can be treated as most other cereals, i.e. ground into flour for making flat bread or dumplings or pounded and cracked in a mortar to make a gruel, a sort of liquid porridge (Harlan 1975). After sorghum, millet is the second most produced commodity in the country, reaching a domestic production estimated at just over a million tonnes during the 2012 harvest. According to FAOSTAT data on millets in Burkina Faso (more than 95% of which can be considered pearl millet (FAO 2014)), yields have experienced large yearly fluctuations over the last 20 years, but on the whole have increased (figure 1): this increase is mostly due to an expanding production area coupled with a yield increase of 1.6% per year (ICRISAT 2014a).

Figure 1: Pearl millet production in Burkina Faso over the 1961-2013 time period (FAO 2014)



Burkina Faso is almost totally self-sufficient in millet, with very small imports; exports from Burkina are also very small(FAO 2014). Pearl millet is one of the most nutritious of cereal grains (Harlan 1975) and has a high protein content (11% to 12%) with one of the best amino acid profiles; it also is high in iron (from 60 to 80 ppm). Pearl millet has a relatively high fat content, which in turn leads to a high energy content [10]. Average daily millet consumption *per capita* in Burkina Faso is around 70 gr, and it has been growing over the last 40 years.

Rice

West Africa is home to a species of domesticated rice, *Oryza glaberrima*, whose distribution and use has remained restricted to West African countries; it was most likely domesticated some 2,000–3,000 years ago in the upper Niger delta, from the annual *O. barthii (*previously *O. breviligulata*), which in turn derived from the perennial *O. longistaminata* (Fuller 2002). The annual progenitor is adapted to water holes that are filled with water during the rainy season and dry up in the dry season; it was harvested in enormous quantities a century ago and is still harvested to some extent today (Harlan 1975). While genetic diversity in *O. glaberrima* would appear to be lower than in *O. sativa* (Second 1982; Second 1985; Wang et al. 1992), *O. glaberrima* harbours a reservoir of genes that have allowed the species to survive and prosper in West Africa with minimal human intervention (Jones et al. 1997a).

There are believed to be three centres of domestication for *O. glaberrima*, in Mali, Gambia, and Guinea (Portères 1970), and this may have contributed to the broad ecological adaptation of African rice cultivars today.

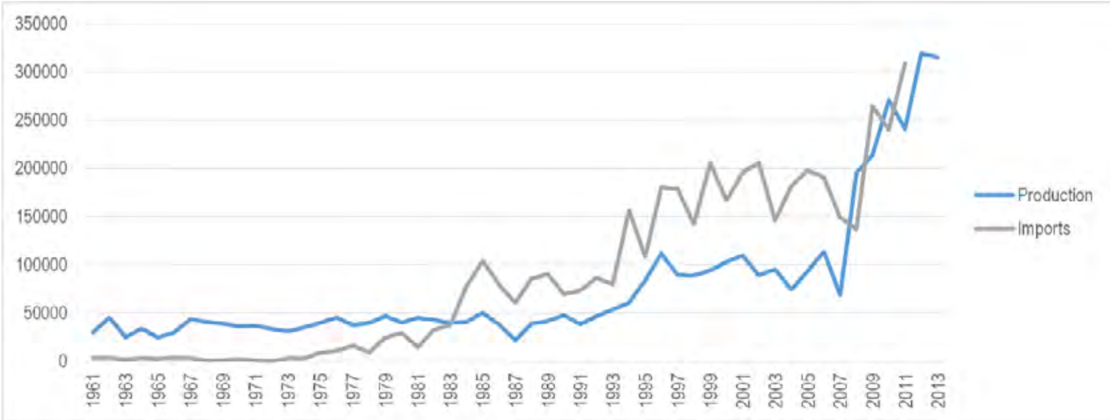
Compared to its African cousin, Asian rice (*Oryza sativa* L.) has reached global distribution after its initial domestication in Asia thousands of years ago. Its immediate wild relative, still found today, is *Oryza rufipogon*. In-depth genetic analyses have revealed that the *japonica* subspecies of rice was first domesticated from a specific population of *O. rufipogon* around the middle area of the Pearl River in southern China, and that the *indica* subspecies was subsequently developed from crosses between *japonica* and local wild rice as the initial cultivars spread into south-east and southern Asia (Huang et al. 2012).

Today, *O. glaberrima* is grown in a zone extending from the delta of the River Senegal in the west to Lake Chad in the east. To the southeast, its range is bordered by the river basins of the Benue, Logone and Chari, but it has also been recorded growing in the islands of Pemba and Zanzibar (Tanzania). Asian rice spread from the foothills of the Himalayas to western and northern India, to Afghanistan and Iran, and south to Sri Lanka, where it was a major crop as early as 1000 BC. The rice crop may well have been introduced to Greece and neighbouring countries of the Mediterranean by returning members of Alexander the Great's expedition to India in 324 BC, but only became an established crop in Europe around the fifteenth or sixteenth centuries. Between the fifteenth and seventeenth centuries, Portuguese priests introduced the tropical *japonicas* from Indonesia into Guinea Bissau from where they spread to other West African countries. Thus, most upland Asian rice varieties grown in West Africa are tropical *japonicas* (Portères 1976).

Both *O. glaberrima* and *O. sativa* are commonly grown in mixtures by West African farmers in upland and rainfed lowland environments (Harlan 1975). Only slight morphological differences separate the two species, making them difficult to tell apart in the field. African *O. glaberrima* varieties have certain negative features compared to Asian O. *sativa* varieties: the seed scatters easily, the grain is brittle and difficult to mill, and, most importantly, the yields are lower. But the *O. glaberrima* types also offer distinct advantages: the plants have luxurious wide leaves that shade out weeds and the species is more resistant to diseases and pests than its Asian cousin. Moreover, African rice is better at tolerating fluctuations in water depth, iron toxicity, infertile soils, severe climates, and human neglect (Pham 1992; Besançon 1993; Adeyemi and Vodouhe 1996; Semon et al. 2005). Some *O. glaberrima* types also mature faster than Asian types, making them important as emergency food (Linares 2002).

Asian rice (*O. sativa*) has gained prominence in the food baskets of Burkina Faso over the last two decades, particularly in urban areas where households have shifted their preferences away from traditional cereals faster (Halewood et al. 2014). While African rice remains a marginal food (its growing areas were reported to be less than 20% of the total cultivated area allocated to rice in West Africa (WARDA 1996)), Asian rice has been emerging as a major staple food in Burkina Faso with demand growing at an annual rate of 3% between 1973 and 1992 (WARDA 1996). Since the 2000s, in-country production covers about 60% of the demand, whilst 40% is met from imports (Randolph 1997). Rice production data from FAOSTAT (the 'rice' commodity reported in the database can be assumed to be almost entirely Asian rice) suggests that in recent years domestic production has picked up; however, imports have also increased, indicating that national production is still unable to meet internal demand (FAO 2014) (figure 2).

Figure 2: Rice production and imports in Burkina Faso over the 1961-2013 period(FAO 2014).



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. 2002). 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* subspecies *parviglumis*) also comes from the Balsas river basin at the convergence of Michoacan, Mexico and Guerrero States (Matsuoka et al. 2002). 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).

Linguistic evidence suggests that maize came to tropical Africa from the western coast; while the Portuguese are likely to have played an important role thanks to their sailing and trading routes connecting Africa and the New World, it may also be that maize was introduced to Africa at more than one point and at different times. As early as the sixteenth century, maize is reported as growing extensively along the West African coast, from the River Gambia to Sâo Tomé, and around the mouth of the River Congo. It was described as an important foodstuff and a major provision for slave ships between Liberia and the Niger Delta during the seventeenth century (Miracle 1965). By the 1930s, maize had become important in smallholder agriculture in Africa, both as a subsistence crop and as a cash crop (Shiferaw et al. 2011).

Maize is grown in the south-western cotton-growing areas (being part of the cotton rotation), extending to the central part of the country and occupying around 9% of the overall agricultural area (Somé et al. 2013). Maize consumption has increased for both rural and urban consumers, but the demand is shifting to higher quality products and processed products in cities, where maize flour has become an important source of starchy food that is quick to prepare. The most current form in which maize is consumed is as a paste, obtained after milling the grains and cooking the flour. Maize can also be germinated and then reduced to flour to obtain alcoholic and non-alcoholic beverages (though either lactic or alcoholic fermentations) (Kaminski et al. 2013).

Grain legumes: cowpea, peanut and Bambara groundnut

It has long been believed that cowpea (*Vigna unguiculata*) was domesticated in Africa due to the fact that wild cowpea plants are found only in tropical Africa and Madagascar, and not in Asia (or in any other continent) (Fuller 2003). However, where in Africa the crop was first domesticated is still uncertain and different centres of diversity and origin have been proposed, i.e. Ethiopia (Vavilov 1926; Steele 1976), West Africa (Vaillancourt and Weeden 1992; Pasquet 2000), and eastern and southern Africa (Ng 1995). A 'diffuse' domestication in the savanna following the dispersal of cereals has also been considered (Harlan 1975; Baudoin and Marechal 1985). After its rapid diffusion into Sub-Saharan Africa, cowpea is thought to have reached the Middle East by around 2000 BC and India by 1500 BC. The crop was introduced into the Mediterranean before 300 BC and into North America only with the slave trade in the sixteenth and seventeenth centuries (Fuller 2003). Today, cowpea is the most important grain legume in Burkina Faso (cultivated on around 12% of the total cultivated area with an annual production estimated at more than 350 000 tonnes) (Tropical Legumes II 2012); its seed is the primary source of plant proteins in the Burkinabe diet (22% to 33%, including a high proportion of lysine, which tends to be deficient in cereals (Fuller 2003)).

The origin of peanut (*Arachis hypogaea*) is placed in the primary region of occurrence of the wild *Arachis* species, and where the species' greatest diversity is found today, in an area stretching across southern Bolivia and northern Argentina (Smartt 1990). However, the retrieval of archaeological wild pod samples in the Casma Valley on the Pacific coast of Peru, which have been dated to 3500 and 3800 BP (Krapovickas and Gregory 1994), suggest that home gardens of ancient peoples there may have also served as a possible site for the origin of *A. hypogaea*. Peanut (*Arachis hypogaea*) is grown on about 7% of the total cultivated area in Burkina Faso; it is rich in oil, protein and vitamins, has a high energy value and is recommended for fortifying the nutritionally poor porridge gruels made from cereals in most of West Africa (Tropical Legumes II 2012).

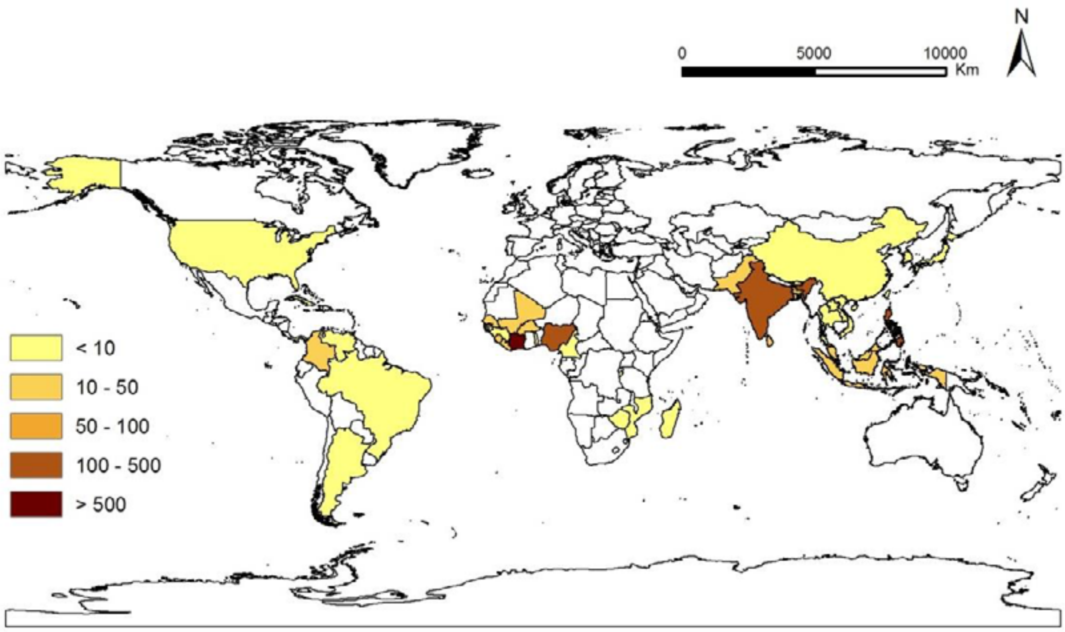
Bambara groundnut (*Vigna subterranea*) is believed to have been domesticated in West Africa, more precisely in an area between north-eastern Nigeria and northern Cameroon, from its presumed wild ancestor, *Vigna subterranea* var. *spontanea* (Herms) (Harlan 1971). While the species is classified as part of the genus *Vigna*, its morphological characters are very different from other *Vigna* species. A single pod of Bambara groundnut contains only one or two seeds and the pods are set underground, as in peanut (*Arachis hypogaea*). Bambara groundnut was already well established as a crop across dryland tropical Africa in the seventeenth century (National Research Council 1996), and has a large number of morphologically and genetically diverse landraces (Goli et al. 1997). In the seventeenth century, Bambara groundnut was introduced into South America, where Linnaeus recorded it growing in Suriname. Later, it was carried to the Philippines and Indonesia (Amadou et al. 2001). In Africa, Bambara groundnut is usually intercropped with cereals, roots and tubers on marginal lands, but it has also been heavily substituted with peanut (*Arachis hypogaea*), introduced by Europeans from the Americas in the 1500s. Peanut caught on quickly because it is similar to native Bambara groundnut but at the same time easier to harvest, and more productive and nutritious (Brouk 1975). Bambara groundnut is the third most important legume in West Africa but still a relatively neglected crop. It is highly nutritious with its seed containing 49% to 63.5% carbohydrates and 15% to 25% protein (Murevanhema and Jideani 2013). National production in 2011 was just below 60 000 tonnes.

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

Burkina Faso's Institut de l'Environnement et des Recherches Agricoles (INERA) is the main actor for agricultural research in the country. It hosts research programmes on traditional cereals (including millet), grains, horticultural crops, rice and cotton. Another government agency actively involved in agricultural research and development is the Institut de Recherche en Sciences Appliquées et Technologies (IRSAT). In 2008, 19% of INERA's investment in crop and livestock research was dedicated to rice, whereas millet only accounted for 7%, reflecting the growing demand for rice in the country. INERA's mandate is also to ensure the conservation and availability of plant genetic resources for utilization both nationally and internationally, and to broaden the genetic base through on-farm conservation. INERA has its main long-term germplasm storage facilities for crops at the Farako-Ba research station, where 333 millet and 802 rice accessions are held (the most represented crops are maize with over 12 000 accessions, and sorghum with over 10 000) (Stads and Sawadogo Kaboré 2010). However, serious technical and institutional limitations affect the conservation and use of these nationally held *ex situ* collections, especially the lack of adequate infrastructure for conservation and regeneration, limited documentation accompanying the germplasm, and unclear procedures for distributing samples to users. Introductions of germplasm from external sources have always taken place in Burkina Faso, as they have done in all other countries engaged in breeding programmes that require the input of lots of diversity from different origins and carrying different traits. International exchanges have taken place thanks to INERA's long-standing collaboration with a number of international partners. In addition to allowing the country to receive promising materials, these collaborations have also allowed duplicates of materials from Burkina to be safely conserved in international genebanks from which they are made available to Burkinabe researchers, which is particularly relevant given some of the infrastructural limitations of national conservation systems, and to the rest of the world. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is possibly the most relevant international partner for INERA when it comes to millet. Surprisingly, Burkinabe researchers have requested few *P. glaucum* accessions (of whatever origin) from the genebank at ICRISAT, which could be explained by the fact that they are mainly interested in accessing improved materials or finished varieties that are more frequently conserved and exchanged by breeders' and breeding programmes rather than genebanks (see later sections on variety development). Regional exchanges of germplasm of millet and other species of importance to the region routinely take place between Burkina Faso's INERA and the national research organizations of Mali and Niger, which are not as well documented as those involving an international organization. On the other hand, ICRISAT holds 860 pearl millet accessions *from* Burkina in its genebank (Ministere de l'agriculture de l'hydraulique et des Ressources Halieutiques 2007); it has sent samples of 712 of those accessions to researchers in other countries, particularly in India, given the importance of millet-based production and food systems there, throughout the 1979-2009 period (Genesys 2014).

Compared to the scenario of few requests for millet samples by Burkina Faso's researchers, a more significant number of rice genetic resources from international genebanks, such as the International Rice Research Institute (IRRI) and AfricaRice, have been shipped into the country for research and development purposes, suggesting a relatively greater investment in rice research: between 1979 and 2009, IRRI shipped 230 samples of rice, all belonging to *O. sativa*, to Burkina. Over half of these had been originally obtained in Burkina Faso itself, while the others came from at least 17 other countries, mostly in Asia. AfricaRice shipped 1934 samples to Burkinabe institutions over the same period of time; with the exception of two samples of *O. glaberrima* from the Cote d'Ivoire, the vast majority of the germplasm was again *O. sativa* (1799) or interspecific crosses (133), and had originally been collected or obtained in at least 29 foreign countries, mostly in Asia (Singer 2012) (figure 3).

Figure 3: Countries where the *Oryza* genetic resources that were sent to Burkina Faso from AfricaRice and IRRI's genebanks were originally collected or improved, with darker shades representing the greater number of accessions (1979-2009) (Singer 2012)



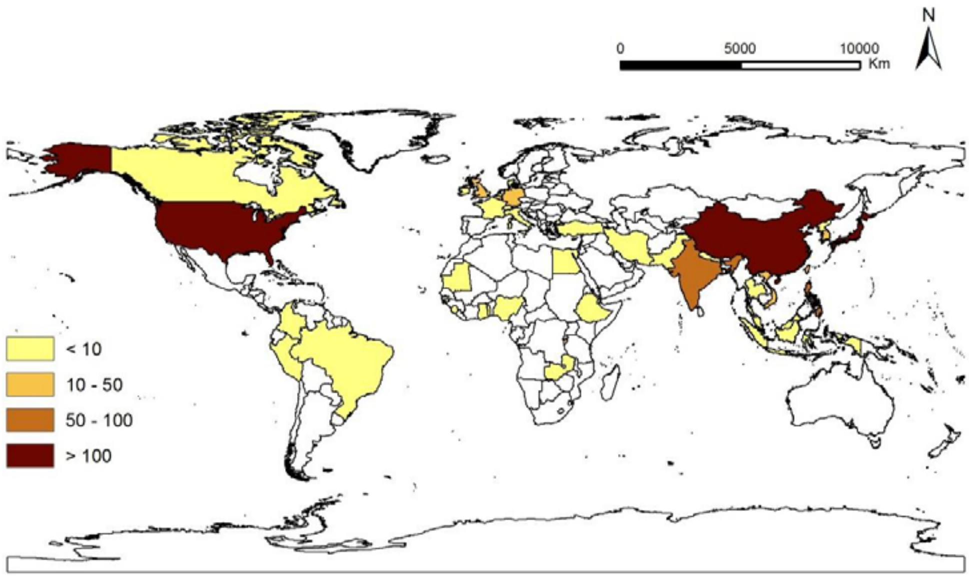
IRRI and AfricaRice maintain the following rice materials, from at least ten different species and three hybrids, originally obtained from Burkina Faso (Genesys 2014) (table 1).

Table 1. Rice accessions originally collected in or obtained from Burkina Faso, deposited in international genebanks (Ministere de l'agriculture de l'hydraulique et des Ressources Halieutiques 2007).

Species or hybrid	Collection	Number of accessions from Burkina Faso
Oryza glaberrima	AfricaRice	32
Oryza sativa	AfricaRice	64
Oryza barthii	IRRI	4
Oryza glaberrima	IRRI	113
Oryza longistaminata	IRRI	2
Oryza nivara	IRRI	4
Oryza officinalis	IRRI	4
Oryza rufipogon	IRRI	10
Oryza rufipogon x nivara	IRRI	1
Oryza rufipogon x spontanea	IRRI	3
Oryza sativa	IRRI	924
Oryza sp.	IRRI	7
Oryza spontanea x rufipogon	IRRI	2

A large number of rice accessions, mostly of Asian rice, among those originally obtained from Burkina Faso, have been distributed to other countries through these two international organizations, indicating that although *O. sativa* is not native to the country, its growing importance over the past decades has made Burkina a significant provider of diversity that may carry interesting adaptive traits (figure 4).

Figure 4: Countries to which *Oryza* genetic resources obtained in Burkina Faso from AfricaRice and IRRI's genebanks were sent, with darker shades representing the greater number of accessions received (1979-2009). Over 82% of these are *O. sativa* accessions (Singer 2012)



For grain legumes also, particularly cowpea, Burkina Faso has received germplasm from other countries through international germplasm flows facilitated by the genebanks of CGIAR centers: over the 1979-2009 period, 56 cowpea samples were introduced, originally sourced from Cote d'Ivoire, Ghana, Mali, Nigeria, Senegal, India, and the United States of America, and only four Bambara samples, all from Nigeria, reflecting the more limited research and development efforts in this orphan crop (Genesys 2014). Samples of these crops originally collected in or obtained from Burkina Faso are also being held in international collections: ICRISAT holds 62 peanut accessions while the International Institute of Tropical Agriculture (IITA) conserves 286 and 93 accessions of cowpea and Bambara groundnut respectively (Genesys 2014). As per millet and rice, some of these materials have been sent, upon request, to interested researchers and breeders in other countries: between 1979 and 2009, cowpea samples originally from Burkina were sent to a variety of countries from neighbouring Nigeria to far removed Korea; peanut materials contributed to research efforts in India, Indonesia and Mozambique; Bambara groundnut from Burkina was received by breeders from Zimbabwe all the way to Japan (Singer 2012).

In addition to direct requests from Burkina Faso institutions to international genebanks, considerable germplasm exchanges have occurred within regional or international collaborative networks focused on specific crops; in these cases, it is mostly advanced lines or finished materials that are exchanged. ICRISAT's millet research and development programme in West and Central Africa has released a total of 48 open-pollinated varieties (OPV) in the region (ICRISAT 2014b). Most of those that were most successfully adapted to Burkina Faso's conditions (SOSAT-C88, GB 8735, ICMV-IS 89305, IKMV 8201, Misari 1 and Misari 2) were developed at ICRISAT from non-Burkina germplasm (Camara et al. 2006): one example is variety IKMV 8201, which was developed in 1995 from an accession of Malian origin. This particular OPV has been consistently adopted by farmers living in areas with annual rainfall between 400 and 900 mm. The International Sorghum and Millet Collaborative Research Support Program (INTSORMIL 2015) was established in 1979 as one of nine collaborative research support programmes supported by the United States Agency for International Development (USAID 2004); throughout its 34-year history (1979-2013), it supported scientists from different disciplines working at a number of US universities to collaborate with national research programmes in 15 African and three Central American countries. Over the course of the programme, huge numbers of breeding lines, parental stocks, germplasm and cultivars were released around the world (INTSORMIL 2015). Other important international networks for germplasm exchange and variety release of the crops of interest here include the Réseau Ouest et Centre Africain de Recherche sur le Mil (ROCAFREMI) for millet, established in the early 1990s; and the Reséau Ouest et Centre Africain du riz (ROCARIZ), for rice, established in 2000. Both these networks were funded by USAID and the Swiss Agency for Development and Cooperation (SDC). The networks conducted a systematic strategic planning process to identify the major constraints of regional nature that hinder increased yields and production. These constraints became the objects of targeted and intensive collaborative research, germplasm exchange, and regional trials sponsored by the networks. The breeding, selection, and exchange of traditional germplasm and improved varieties with resistance to the main pests (insects, diseases, and the parasitic weed *Striga*) and drought occupied much of the earlier networks' research agenda. One of their major achievements was the generation and testing of hundreds of improved varieties, followed by their release (dozens at most) in member countries. From a heavy emphasis on plant breeding, the networks then moved much more toward technology transfer, post-harvest processing and new product development, including through the use of participatory approaches (USAID 2004). In 1975, IRRI launched the International Rice Testing Program (IRTP), a systematic global programme for the collection, distribution and testing of rice genetic materials, which later became the International Network for Genetic Evaluation of Rice (INGER). The overall objectives of INGER have been to link national rice improvement programmes and international centres, and to promote genetic diversity for different ecosystems through the global exchange, evaluation and utilization of improved breeding materials originating from sources worldwide.

The African wing of INGER was created in 1985 at IITA in Nigeria. In 1990, the mandate for all rice research in West and Central Africa was given to the Africa Rice Center (formerly known as the West Africa Rice Development Association) and in 1991, the Africa Rice Center (AfricaRice) and partners in the national agricultural research systems (NARS) established varietal improvement task forces (mini-networks) comprising upland, lowland, irrigated and mangrove swamp rice-breeding activities (mostly focused on Asian rice). Both before and during the operation of INGER and INGER-Africa, Burkina Faso received a significant number of rice varieties from other countries, for adaptation to local conditions and for national release (table 2).

Table 2: Rice varieties introduced and adapted in Burkina Faso from 1970 to the mid 1990s.

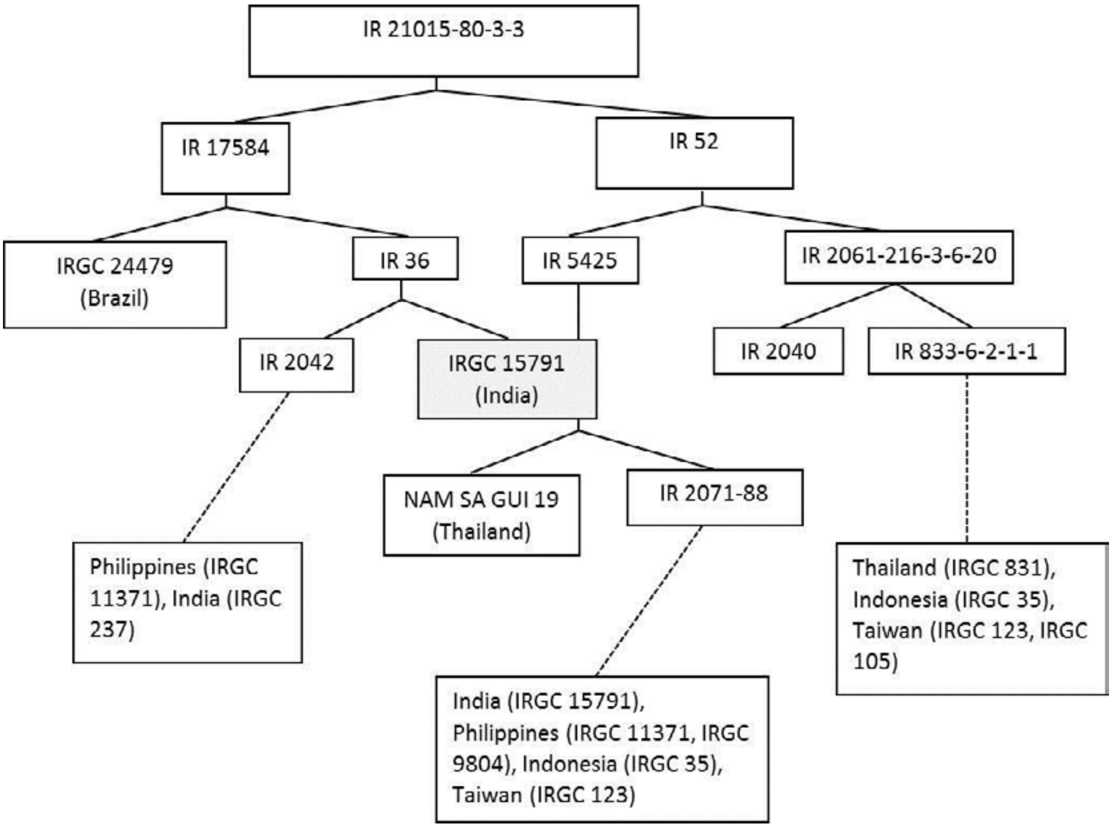
Variety	Year of introduction	Year of release	Cycle (days)	Origin
FKR 1 (Early Dourado)	1970	1972	98	Brazil
FKR 5 (IRAT 144)	1976	1983	103	Burkina Faso
FKR 13 (IRAT 147)	1976	1983	96	Burkina Faso
FKR 9 (IRAT146R)	1981	-	97	Burkina Faso
FKR11 (IRAT146B)	1981	-	96	Burkina Faso
FKR 25 (DJ 11-509)	1981	-	100	Senegal
FKR 27 (1215-5-5)	1982	1990	100	Burkina Faso
FKR 29 (1215-1-5)	1982	1990	95	Burkina Faso
FKR 31 (1083-1-1)	1982	-	100	Burkina Faso
FKR 33 (1195-5-2)	1982	1993	98	Burkina Faso
FKR 23 (DJ 12-539-9)	1987	-	110	Senegal
FKR 17 (ITA 150)	1988	-	100	IITA Nigeria
FKR 15 (ROK 16)	1990	-	111	Liberia
FKR 39 (TOX 1011-4-A2)	1992	-	98	IITA Nigeria
FKR 43 (CNA 6675)	1992	1998	95	Brazil
FKR 4 (SintaneDiofor)	1960	1972	120	Senegal
FKR 2 (Gambiaka)	1970	1972	145	Gambia
FKR 6 (IR 20)	1970	1972	125	Philippines
FKR 26 (C 74)	1970	1972	135	Philippines
FKR 8 (IR 8)	1970	1972	130	Philippines
FKR 10 (IR 1529-680-3)	1973	-	130	Philippines
FKR 12 (Vijaya)	1973	-	145	India
FKR 14 (4418)	1976	1993	125	India

FKR 16 (4456)	1976	-	120	India
FKR 20 (IET 2885)	1976	1983	130	India
FKR 24 (BR 51-319-9)	1977	-	126	Bangladesh
FKR 18 (SC 27)	1981	-	135	Burkina Faso
FKR 28 (ITA 123)	1983	-	125	IITA Nigeria
FKR 30 (IR21015-8-3-3)	1983	-	125	Philippines
FKR 19 (TOX 728-1)	1984	1990	115	IITA Nigeria
FKR 32 (ITA 222)	1984		127	IITA Nigeria
FKR 34 (RP 1125-1526-2)	1984		129	India
FKR 38 (BW 295-5-7)	1984		115	Sri Lanka
FKR 36 (ITA 304)	1985		125	IITA Nigeria
FKR 42 (IR 64)	1989		123	Philippines
FKR 48 (4418*IR6115-1-1-1)	1990		114	Burkina Faso
FKR 50 (4456*IR1529-680-3)	1990		115	Burkina Faso
FKR 44 (IR 13240-108-2-2-3)	1992		120	Philippines
FKR 46 (RP 1125-156-1-1-1)	1993		130	India

Since the inception of the new INGER-Africa at AfricaRice, the level of interaction and participation of national breeders in regional germplasm exchange has increased; greater collaboration with ROCARIZ (Ouedraogo and Ouedraogo 2003) over the past two decades has also contributed to this increase. NARS scientists in Africa have increased their use of the INGER-Africa network to develop, exchange and evaluate their own materials in a wide range of environments. This improvement in NARS participation clearly indicates that germplasm exchange and evaluation in Africa is no longer a one-way flow from international centres to national programmes (USAID 2004). From 1994 to 2000, significant progress was made in the identification and spread of improved rice varieties across all the agro-ecological zones of the entire region. Among the most outstanding irrigated rice varieties identified and released in Burkina Faso through INGER-Africa during that period, are IR 21015-80-3-3, ITA 304, IR 64, IR 13240, RP 1125-156-1-1-1, FKR 48, FKR 50 (WARDA 2002). A look at the pedigrees of some of these successful varieties shows the contribution of far-sourced germplasm: IR 21015-80-3-3 is based on a number of crosses which involved rice landraces from Brazil (IRGC 24479), India (IRGC 15791 and IRGC 237), Thailand (IRGC 11462 or NAM SA GUI 19, IRGC 831), the Philippines (IRGC 11371, IRGC 9804), Indonesia (IRGC

35), and Taiwan (IRGC 123, IRGC 105) (figure 4). IR64 incorporates landrace parents from Thailand (IRGC 831) and Taiwan (IRGC 105), India (IRGC 237), the Philippines (IRGC 9804) and China (Tsai Yuan Chung landrace) (WARDA 2002; Genesys 2014; IRRI 2015).

Figure 4: Pedigree of rice variety IR 21015-80-3-3. The pedigree is shown in its complete form up to the first three branches; dotted lines lead to boxes summarizing the contribution of foreign genetic resources to the crosses that constitute the rest of the pedigree



An interesting development for the rice sector in Burkina was the Interspecific Hybridization Project (IHP), initiated in 1992 by AfricaRice and its partners, in an attempt to combine the useful traits of both cultivated rice species (*O. sativa* and *O. glaberrima*). The problem of hybrid mortality encountered in the initial stages was overcome through backcrossing with the *O. sativa* parent and through anther culture, resulting in the first interspecific rice progenies from cultivated varieties (Jones et al. 1997b; Jones et al. 1997c). These interspecific lines, which have high yield potential and a short growth cycle, were named New Rice for Africa (NERICA) varieties. Several of them possess early vigour during the vegetative growth phase and this is a potentially useful trait for weed competitiveness. Likewise, a number of them are resistant to African pests and diseases such as blast, rice stem borers and termites. They also have a higher protein content and a better amino acid balance than most of the imported rice varieties (Jones et al. 1997c).

To meet the demand of rice farmers and consumers, the rice research programme in Burkina Faso started evaluating intraspecific and interspecific lowland progenies obtained from AfricaRice in 2000, out of which the 60 most successful ones were named the New Rice for

African Lowlands (NERICA-l), and were released in Burkina Faso, Mali, Togo, Sierra Leone, Niger and Cameroon (WARDA/FAO/SAA 2008). By December 2006, lowland NERICA varieties were released in Burkina Faso, the most popular varieties among farmers being WAS 161-B-9-3 (TOG5681/4*IR 64); WAS 191-9-3 (IR 64/TOG 5681 // 4*IR 64); WAS 122-IDSA-1-WAS-1-1-B (TOG 5681/3*IR 64); and WAS 122-IDSA-1-WAS-6-1 (TOG 5681/3*IR 64) (WARDA/FAO/SAA 2008). The international composition of the IR 64 parent of most of these NERICA varieties has already been discussed; WAS 161-B-9-3 has a complex pedigree that includes genetic resources and breeders' materials from Vietnam (IRGC 11115), India (IRGC 10951, IRGC 101508 - *O. nivara,* IRGC 6663, IRGC 237), the Philippines (IRGC 10951 and IRGC 11374, IRGC 11371, IRGC 15762, IRGC 39, IRGC 9804), Korea (IRGC 5070), Thailand (IRGC 172), the USA (IRGC 6993, IRGC 134, IRGC 6310), Indonesia (IRGC 611, IRGC 35, IRGC 13530), Malaysia (IRGC 14468), and Taiwan (IRGC 123, IRGC 105, IRGC 139) (Genesys 2014; IRRI 2015).

Burkina has been involved in more recent collaborative programmes concerning other crops, including the Dry Grain Pulses Collaborative Research Support Program (Pulse CRSP), focused on bean and cowpea, and funded by USAID, and the Tropical Legumes II (TL II) project, focused on peanut and cowpea among others, funded by the Bill & Melinda Gates Foundation and jointly implemented by ICRISAT, the International Center for Tropical Agriculture (CIAT) and IITA, in collaboration with the NARS of African countries. In Burkina Faso, these programmes further supported the active collaboration between INERA and IITA on cowpea research. Thanks to this collaboration, a total of 21 new cowpea varieties were released between 1982 and 2011 (Tropical Legumes II 2012), including IT98K-205-8 and Melakh, released in 2006 and deriving from crosses between Senegalese and Nigerian IITA varieties [64]). Cowpea variety IT98K-205-8 has been successfully adopted in the centre-north, centre-west and north of the country, where annual rainfall does not exceed 800 mm. Farmers surveyed in three key cowpea-growing areas of Burkina Faso reported that the additional costs related to the introduction of this variety have been outrun by the benefits of consistent yields (on average between 480 kg/ha and 590 kg/ha depending on the locality). This has allowed improvements in the communities' food security and livelihoods, generating extra income that can be used for purchasing food or addressing other needs including schooling.

With regards to peanut, the TL project aims at increasing the diversity available in Burkina Faso, since only 13 varieties have been released since 1958, with the most recent releases taking place in 1994. Examples of varieties released in the 1980s and 1990s are QH 243C, E(104), SH 470P, SH 67A, and Fleur 11. Varieties such as Te 3 (released in 1958) and CN 94C (1960) are still in use. The importance of increasing the conservation and use of local materials is clear if we recall that resistance to groundnut rosette disease (GRD), a major issue in Africa for peanut cultivation, was discovered in the late 1950s in local landraces grown in Burkina Faso. Utilizing these local landraces, cultivars resistant to GRD, such as KH 149A, KH 241D, 69-101, RMP 12, RMP 91, and RG 1 were bred and released in the recent past in Africa. These cultivars are now used as sources of resistance and several GRD-resistant peanut varieties have been released around the world (Ndjeunga et al. 2003; Waliyar et al. 2007).

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

Farmers in Burkina Faso report that climate is increasingly becoming a risk factor for their activity, particularly in terms of more frequent water deficits, the late onset or premature ending of the rainy season, and anomalous rainfall distribution. In West Africa, a decline in annual rainfall has been observed since the end of the 1960s with a decrease of 20% to 40% (Dai et al. 2004). Global circulation models predict further increases in temperature and drought frequency for the Sahel over the next century (Dirmeyer and Shulka 1996), as well as an increase in occurrence of extreme events. Although millet, cowpea and Bambara groundnut are known for their drought tolerance, a recent review of climate change impact studies on crops indicates that many of the West African staples may suffer yield losses (for millet the estimate is around 10%). The projected mean yield change for rice in any area of Africa where is it grown, is not significantly different from zero, with some sources (40%) projecting an increase and others (60%) a decrease (Knox et al. 2012). While the limited yield losses expected for rice may be due to its positive response to increased CO_2 fertilization, it is also known that exposure to high temperatures (greater than 35 °C) for a few hours can greatly reduce pollen viability and, therefore, lead to spikelet sterility (Osada et al. 1973) and possible negative effects on yield.

To provide a picture of how, under the future climate challenges, the adaptation of crops of importance to Burkina Faso's agriculture may benefit from materials located beyond the country's borders, the Climate Analogues modelling tool (CCAFS) was used for the cases of pearl millet and rice: by choosing a reference site of interest in Burkina, the tool identifies areas that experience statistically similar climatic conditions to this reference site, but which may be separated temporally and/or spatially. In our case, the Climate Analogues offered a glimpse into the future by locating areas whose *climate today* is similar to the *projected future climate* of the reference site (i.e. we ran the analyses with the 'backward' scenario); we also used the 'lag' option, in order to facilitate the detection of areas that experience similar climates at different times of the year; given the main influence of annual mean temperature and annual precipitation on the crops' productivity and adaptation, we ran the model using these parameters, assigning equal weight to each. We chose references sites corresponding to important millet- and rice-growing areas in the country: Dori in the northern Sahel region for millet (Ingram et al. 2002), and Boulgou in the southern rice-growing belt for rice (FAO 2002). 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 June to September for millet, which corresponds to the rainy season in the Sahel (ICRISAT 2014b), and a growing season of May to November for rice (FAO 2002). 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 'analogue' areas detected by the model, i.e. those areas where climate patterns similar to those expected to occur in our reference sites during millet- and rice-cropping seasons in the future (by the year 2050) have already been occurring over the last 50 years.

Figure 5: Analogue sites for millet, using Dori in the Sahel region of Burkina Faso as a reference (14°02'07"N, 00°02'04"W). Only sites with a similarity higher than 60% were retained. Redder areas signify greater similarity (i.e. have a lower probability of being dissimilar)

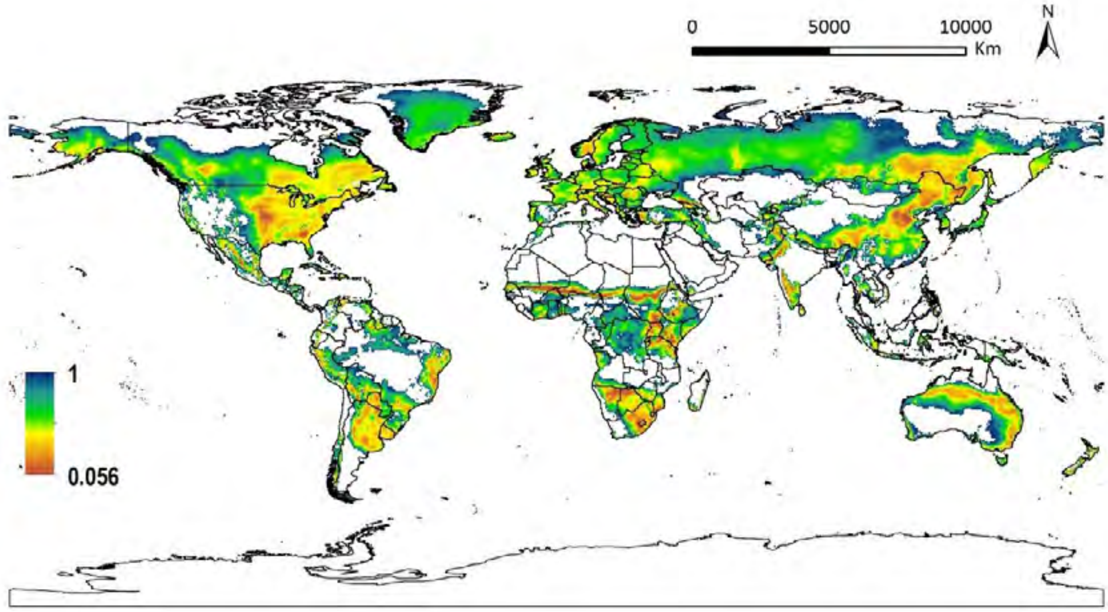
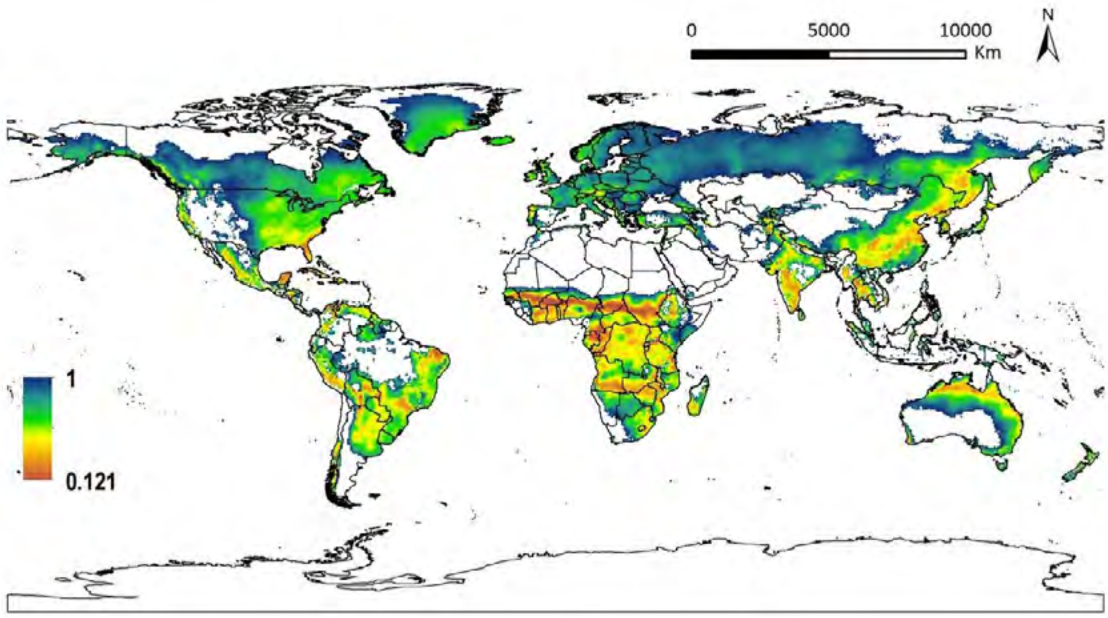


Figure 6: Analogue sites for rice, using Boulgou in the main rice-growing area of Burkina Faso as a reference (11°30'00"N, 0°25'00"W). Only sites with a similarity higher than 60% were retained. Redder areas signify greater similarity (i.e. have a lower probability of being dissimilar)



For millet, areas that currently have a climate similar to the future projected climate of Dori can be found in the narrow west to east Sahelian belt, and along other desert-like zones further south in Africa (including Namibia, where millet is already an important crop); in the hot and dry areas of western India; along a transition belt between desert zones and temperate-hot areas in eastern China; and in a few scattered areas of Latin America. For rice, areas that today have a climate analogous to the future projected climate of Boulgou can also be found in the Sahel, but extend over much larger areas in central and southern Africa, covering areas of high temperature; most of the Indian subcontinent, vast areas in eastern China and northern Australia; and smaller areas in the Americas.

Obtaining rice or millet germplasm that has been thriving in these ‘future climate’ areas could be a promising strategy for introducing materials with adaptive potential into breeding programmes for Burkina Faso’s conditions. By overlaying geo-referenced observations of millet and rice accessions deposited in international collections (purple triangles on the maps below) (Genesys 2014), it was possible to pin down those materials originally collected in sites that appear to be highly analogous to the reference sites chosen here. Since these accessions are included in the MLS of the ITPGRFA, or in institutions that make their materials freely available, they would be easy to obtain by interested breeders working towards climate adaptation. Figures 7 and 8 list some of the millet and rice accessions collected from potentially analogous sites, and available through easily accessible collections (here, they are all from ICRISAT, the main holder of millet accessions).

Figure 7: Selected millet accessions collected from analogue sites and deposited in international collections. Point data refers to geo-referenced materials available in the collections hosted by CGIAR centers or other important collections, based on data from Genesys

Species	Accession number	Type of material	Country of origin/occurrence	Holding institute
Pennisetum glaucum (L.) R. Br. americanum	IP 12412	Traditional cultivar/Landrace	Republic of South Africa	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 13343	Traditional cultivar/Landrace	Sudan	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 15833	Traditional cultivar/Landrace	Tanzania	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 18969	Traditional cultivar/Landrace	Namibia	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 5635	Traditional cultivar/Landrace	Niger	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 6383	Traditional cultivar/Landrace	Mali	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 8791	Traditional cultivar/Landrace	Botswana	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 9936	Traditional cultivar/Landrace	Sudan	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 15319	Traditional cultivar/Landrace	India	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 17913	Traditional cultivar/Landrace	India	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 18143	Traditional cultivar/Landrace	Pakistan	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 3230	Traditional cultivar/Landrace	India	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 3954	Traditional cultivar/Landrace	India	ICRISAT
Pennisetum glaucum (L.) R. Br. americanum	IP 4342	Traditional cultivar/Landrace	India	ICRISAT

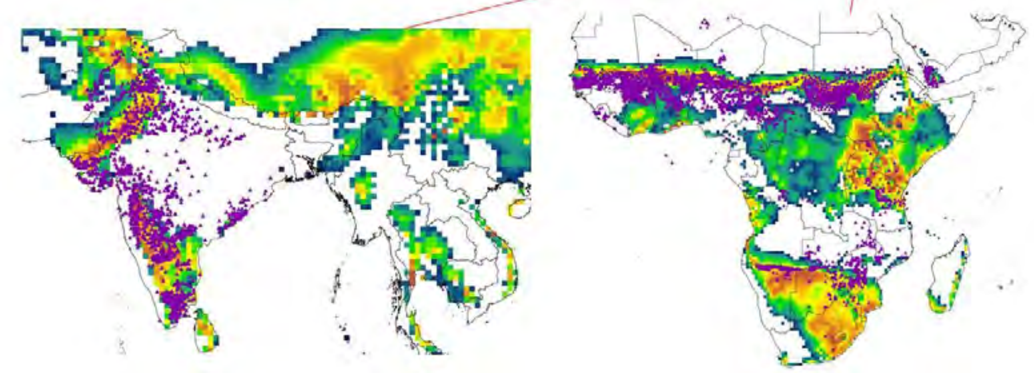
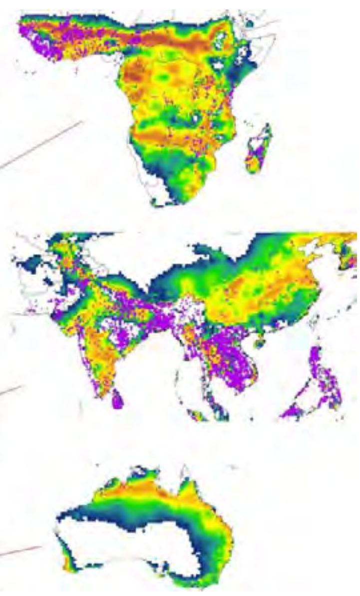


Figure 8: Selected rice accessions collected from analogue sites and deposited in international collections. Point data refers to geo-referenced materials available in the collections hosted by CGIAR centers or other important collections, based on data from Genesys

Species	Accession number	Type of material	Country of origin/occurrence	Holding institute
Oryza barthii	IRGC 104078	Wild	Nigeria	IRRI
Oryza longistaminata	IRGC 104127	Wild	Chad	IRRI
Oryza longistaminata	IRGC 105070	Wild	Republic of the Congo	IRRI
Oryza barthii	IRGC 106225	Wild	Mali	IRRI
Oryza sativa	IRGC 47058	?	Ivory Coast	IRRI
Oryza sativa	IRGC 73033	Advanced/improved cultivar	Ethiopia	IRRI
Oryza sativa	IRGC 79908	Traditional cultivar/Landrace	Tanzania	IRRI
Oryza eichingeri	IRGC 89245	Wild	Uganda	IRRI
Oryza glaberrima Steud.	PI 450521	Other	Cameroon	USDA-ARS
Oryza sativa	WAB0009210	Breeding/Research Material	Senegal	Africa Rice
Oryza sativa L.	Clor 12038	Other	China	USDA-ARS
Oryza sativa	IRGC 16825		Russia	IRRI
Oryza sativa	IRGC 28476		China	IRRI
Oryza sativa	IRGC 28591		India	IRRI
Oryza sativa	IRGC 52307	Traditional cultivar/Landrace	India	IRRI
Oryza sativa	IRGC 62125	Traditional cultivar/Landrace	Thailand	IRRI
Oryza sativa	IRGC 77659	Traditional cultivar/Landrace	Republic of Korea	IRRI
Oryza sativa L.	PI 160394	Traditional cultivar/Landrace	China	USDA-ARS
Oryza sativa L.	PI 428353	Other	China	USDA-ARS
Oryza sativa L.	PI 439086	Other	India	USDA-ARS
Oryza australiensis	IRGC 103303	Wild	Australia	IRRI
Oryza australiensis	IRGC 103318	Wild	Australia	IRRI

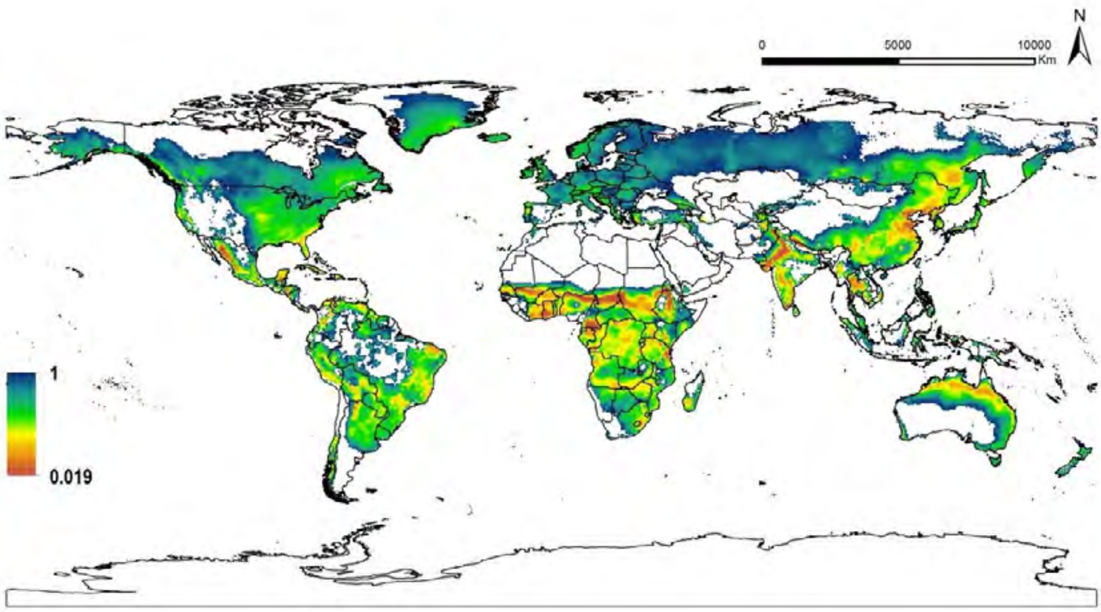


The overlay of analogue sites and geo-referenced accessions also allows to tentatively rule out areas where the crops of interest or their wild relatives are unlikely to be found, even if the temperature and rainfall conditions would allow it: pearl millet materials have been collected almost exclusively from central and southern Africa and India, while no accessions from the potential analogue sites in Latin America are available. This makes sense given the specific occurrence and adaptation of pearl millet to the dryland areas of Africa and India and its relative underuse elsewhere in the world (see earlier sections of this paper). The geographical spread of rice accessions deposited in the system is much broader, given the major importance and wide adaptation of the crop to different climates and agricultural and food systems. Genebanks whose data appears in Genesys seem to contain potentially interesting rice materials originally collected in analogue sites from three continents: Africa (including wild and African rice), Asia and Oceania. While there are a number of rice accessions of Latin American origin, the climate analogy of their collection sites is not as high as with the sites in other areas and were thus not considered here.

As figures 7 and 8 show, there already appears to be a good representation of materials of potential interest for adapting Burkina's crops to the conditions ahead in the institutions whose collections are listed in Genesys. Some of these will be in international genebanks of the CGIAR (hence with collections in the MLS) or in genebanks such as the United States Department of Agriculture (USDA), which make materials easily accessible. However, it is likely that additional genetic resources from analogue climates are stored in national genebanks or other collections within countries, rather than in international institutes or institutes with an open policy with respect to sharing; this may be more relevant for pearl millet than rice. Pearl millet is of regional importance and has a more restricted distribution; consequently, international collection and conservation efforts for pearl millet are limited compared to other crops (beyond the important work of ICRISAT, whose genebank conserves over 25 000 accessions, which is less than 1% of the centre's total holdings (Genesys 2014)). National collections may be in countries that are either not ITPGRFA parties, or may not have yet taken active steps towards identifying the collections that are under their management and control and in the public domain, and to deciding about their inclusion in the MLS, accompanied by the much needed characterization and evaluation data.

While this scenario may limit the range of germplasm options available to Burkinabe researchers, it is also true that until Burkina Faso itself takes steps towards implementing the MLS, researchers elsewhere may experience similar difficulties in accessing germplasm conserved within the country's borders, which could hold promise for the climate adaptation needs of other countries. The map below (figure 7) provides one such example, by showing the distribution of analogue sites to a reference chosen within the millet producing drylands of northern India (Chatarganj, in Rajasthan); the present-day climate in most of the Sahelian belt, including parts of Burkina Faso, resembles that which is expected to hit this important millet-growing area in India in the future, suggesting that the West African area, including Burkina, may become an increasingly important provider of germplasm for strengthening India's food systems.

Figure 9: Analogue sites for millet, using Chatarganj, located in the millet-growing area of Rajasthan in northern India, as a reference (25°32'21"N, 75°31'42"E). Only data from sites with a similarity higher than 60% were used. Redder areas signify greater similarity (i.e. have a lower probability of being dissimilar)



This millet-based example indicates how all countries are interdependent on 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 overview of the research and development dynamics of key crops in Burkina Faso has highlighted the tremendous amount of germplasm that has been flowing into and out of the country over the past thirty years, illustrating the extent to which the country has benefited from external inputs of germplasm (and associated technologies), while providing samples of its own diversity to users elsewhere. Most of the exchanges took place either when the circulation of PGRs was not such a politically charged issue as it is today, or through the operation of international institutions which, even after the inception of the CBD and its more restrictive, bilateral rules for accessing and exchanging germplasm, have continued to operate under a regime of facilitated access and free distribution.

As the sharing of germplasm across borders becomes more controversial, and climate change exacerbates the challenges faced by plant breeders, clear rules and procedures for maintaining and enhancing international exchanges of PGRFA are needed, in order to allow for the continuing development of more resilient and sustainable agricultural and food systems, particularly in areas of the world with a growing population and demand for food. The complex international scenario surrounding access and benefit sharing; uncertainties on how to deal with genetic resources at national level, with the CBD-inspired bilateral rules and the ITPGRFA's multilateral approach; and a lack of trust in how potential recipients may be interpreting these rules, has led to an increasing reticence among Burkinabe breeders and other PGRFA stakeholders to share and distribute germplasm. However, if the MLS is implemented properly, the country's obligations and those of its research partners would be clearly defined, allowing for the continuation and enhancement of Burkina Faso's role as provider and recipient of germplasm, and facilitating its participation in collaborative crop improvement projects like those presented here. In this direction, the work of the dedicated team of researchers and policymakers in advancing the process of ITPGRFA implementation in Burkina Faso within and beyond the GRPI2 project is crucial, and it is hoped that the results and reflections presented here may be of use in such a process.

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