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The demand for Bioversity's banana germplasm in Africa and Asia

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Abstract

Understanding how germplasm is utilized is of great importance to the development of accurate tools and methods by genebanks and enhances their response to the needs of farmers and consumers. Bioversity's International Musa Germplasm Transit Centre (ITC), based at the Katholieke Universiteit Leuven, Belgium, hosts the world's largest collection of banana germplasm, with more than 1,500 accessions. Currently, the ITC uses both *in vitro* and cryopreservation methods and are investing in conserving seeds of wild *Musa* species. Besides ensuring long-term conservation, for many users in numerous countries, the ITC is the only source of clean and healthy *Musa* germplasm. The ITC therefore plays a very important role in the mobilization, improvement and adaptation of *Musa* germplasm. Access to safe and healthy germplasm has enabled and facilitated a large body of research and development projects to support the *Musa* (banana) diversity, which is fundamental for ensuring production today and in the future. This study explores the value added to this process by various stakeholders. We analyzed the ITC *Musa* germplasm distribution data among recipients in Africa, Asia and the Pacific regions, followed by a requestor survey. We found that local institutions are important in the dissemination and adoption of germplasm and knowledge across researchers and other stakeholders in the community. Also, culture and tradition have a great influence in producers' and consumers' adoption preferences.

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Acronyms

eBSVs	Banana streak viruses
GDPR	European General Data Protection Regulations
GIS	Geographical Information Systems
ITC	The Bioversity International <i>Musa</i> Germplasm Transit Centre
LAC	Latin America and the Caribbean
MGBMS	<i>Musa</i> Genebank Management System
MGIS	<i>Musa</i> Germplasm Information System
MUS	<i>Musa</i> Usage Survey
TGSMG	Technical guidelines for safe movement of germplasm
WCR	Wild Crop Relatives

1. Introduction

Dessert and cooking banana (*Musa* spp.) are of great importance to the subsistence and the livelihoods of people in developing countries (FAO 2018). Around 300 million people under the poverty line¹ in developing countries depend on roots, tubers, and banana crops for food security and income (Thiele et al. 2017). Banana is also considered to be the most produced and consumed fruit globally; the latter is especially true for the European Union and North America which are the largest banana importers (FAOSTAT 2018). The crop originated in Southeast Asia and Melanesia and has diversified and spread out through Asia and the Pacific, Africa, and Latin America and the Caribbean (LAC) regions. Nowadays there are 75 species of banana wild relatives and more than 1,000 cultivars in the world² (MusaNet 2016). However, the genetic diversity of banana is threatened by various factors such as pests and disease, and environmental change. Narrowing of the crop's genetic exploitable base for poses a risk for agricultural production and food supply of present and future generations (Garming et al. 2010, Iriondo et al. 2008). Therefore, the conservation of *Musa* genetic diversity is a very important task.

Bioversity's International *Musa* Germplasm Transit Centre (ITC) is a major contributor to this task. The ITC is based at the Katholieke Universiteit Leuven, Belgium, and is the world's largest banana genebank with more than 1,500 accessions. The genebank has the goal of ensuring that 90% of its germplasm is available for distribution. For many users in numerous countries, the ITC is the only source of clean and healthy *Musa* germplasm. Currently the ITC uses both *in vitro* and cryopreservation methods and is investing in conserving seeds of wild *Musa* species. The ITC, therefore, plays a very important role in the mobilization, improvement and adaptation of *Musa* germplasm.

Garmin et al. (2010) provided an overview of the impacts created through the conservation and distribution of germplasm and presented an evaluation of the ITC services based on a survey of its users. However, the process by which ITC generated the impact, how stakeholders were involved, and how requestors used accessions was not elucidated. In order to further understanding of impacts, Bioversity International decided to develop an in-depth study of the usage and impact of ITC

¹ Based on World Bank estimations, the poverty line is defined as earning less than US \$1.25 at 2005 purchasing power parity (World Bank 2015).

² Cultivars are grown in many places over the world and some of them have many different local names. Unfortunately, the lack of standardized cultivar nomenclature and of morphological taxonomy of all the cultivars there is not a precise number to describe a single harmonious system adapted to the special nature of edible banana diversity (MusaNet 2016).

accessions. Garmin et al. (2010) and the Global *Musa* Survey³ served as a baseline and provided the conceptual background.

Two databases were considered in this study. The first is a database of ITC accessions distribution from 2000-2017. The second is the data collected by the *Musa* Usage Survey (MUS). The MUS was sent to ITC material requesters and aimed to identify how *Musa* genetic resources were used once they were received, the reasons for maintaining or not maintaining the accessions, and if they have been further distributed to other users. Among the four main regions where *Musa* is produced, the MUS had already been conducted in LAC and results are summarized by Montalvo-Katz and colleagues (2018). This study presents findings from the survey of requestors in the Africa, Asia and the Pacific regions.

Contextual background is presented in the following section. Section 3 describes the methodology. Analysis of the 2000-2017 distribution data and the findings from the MUS survey are presented in the fourth section. The closing section offers recommendations concerning further study on this topic.

2. Context

Musa diversity can be conserved through the complementary *ex-situ* and *in-situ* (including on-farm) methods. *In-situ* conservation is especially important for the preservation of Crop Wild Relatives (CWR), traditional varieties and landraces because it maintains the evolutionary process under natural pressures and farmer selection practices (MusaNet 2016). There are over 60 institutions around the world that maintain *Musa* collections *ex-situ*. Although the accessions are maintained in *in vitro*, in greenhouses and in cryopreserved collections, the majority of the germplasm is conserved *in vivo*, in field collections.

The Bioversity International *Musa* Germplasm Transit Centre (ITC) hosts the world's largest collection of banana germplasm, with more than 1,500 accessions, using both *in vitro* and cryopreservation methods and now also investing in conserving seeds of wild *Musa* species. In addition to managing the genebank, Bioversity has developed different initiatives to improve the conservation and use of *Musa* genetic resources. MusaNet⁴, for example, coordinates and strengthens the conservation and related research efforts of a worldwide network of *Musa* genetic resources and breeding experts from the public and private sector. In 2016, MusaNet updated its Global Strategy for

³ The Global *Musa* Survey was conducted in 2012-2013. This survey was sent to key *Musa* collections around the world to gather information to facilitate the update of the MusaNet Global Strategy for the Conservation and Utilization of *Musa* Genetic Resources and to increase support for crucial collaborative actions (MusaNet 2016).

⁴ The Global *Musa* Genetic Resources Network, www.musanet.org

the Conservation and Use of *Musa* Genetic Resources to be used as a roadmap for the *Musa* genetic resources community. Another initiative is the MGIS (for more information visit <https://www.crop-diversity.org/mgis/>), a database that provides accession-level information, including passport and characterization data, to the public and also facilitates requests of ITC germplasm.

Like other genebanks, the ITC has two mandates: 1) to ensure safe and long-term conservation of a broad range of *Musa* genetic diversity and 2) to distribute virus-free material that has confirmed genetic integrity and is well documented for the benefit of all users. The availability of germplasm for international distribution is determined by its health and genetic integrity status. The ITC has always adopted the most restrictive principle that only germplasm that is fully indexed, following the Technical Guidelines for the Safe Movement of *Musa* germplasm (TGSMG) (Diekmann and Putter 1996), updated in 2015 (Thomas 2015), and found to be free of virus and virus-like particles can be released for international distribution. The main viruses that limit ITC germplasm distribution are the *endogenous Banana Streak Viruses* (eBSVs), which are frequently present in *Musa* germplasm containing the B genome. The problem is that eBSV can be integrated into the genome and plants previously identified as eBSV-free can, when stressed, develop a symptomatic infection that can be easily transmitted. Consequently, many *Musa* accessions are not distributed under the current policy adopted by the ITC. In order to alleviate this problem and reach the performance target of 90% of germplasm availability, a task force recently developed a strategy for the distribution of B genome germplasm, while minimizing any associated risks to the recipient country (Thomas et al. 2015). Together with its partners, ITC is working on screening and cleaning this germplasm and developing a decision tree to facilitate the indexing and distribution of *Musa* germplasm.

The ITC uses a range of techniques to distribute the available *Musa* germplasm in order to address the needs of various requestors. These include: a) rooted plantlets, b) *in vitro* conserved proliferating tissue, and c) lyophilized leaf tissue⁵ (see Figure 1 for graphical representation)⁶. All ITC material has key data and information associated with the diversity of *Musa* germplasm, which is available in MGIS. Passport data, botanical classification, morpho-taxonomic descriptors, molecular studies, plant photographs and geographical information systems coordinates are reported⁷.

⁵ Lyophilized leaf tissue was only available for request since 2006

⁶ In addition to the means of distribution described above, a collection of 52 *Musa* accessions DNA samples is available for distribution. This type of material is frequently used for molecular studies (for more information please refer to the tab “*Musa* Genotyping Centre” in the following webpage <http://www.musanet.org/>)

⁷ This information is not only part of the ITC collection but from 4,937 accessions managed in 24 collections around the world, making it the most extensive source of information on banana genetic resources (MGIS 2018)

In addition to the two mandates, ITC continually generates new knowledge and promotes the exchange of knowledge and information among *Musa* germplasm users, as is illustrated in Figure 1. Therefore, ITC materials refer not only to the germplasm per se, but also to the information and knowledge package that is available for each accession.

Figure 1 describes a pathway of impacts generated, directly or indirectly, by the ITC from the genebank to end-users. The impact, depicted by the grey shade, refers to the impact of crop genetic material not only on the end-users (farmers and consumers), but on society as a whole. The double-way arrow indicates that achieving any of the impacts will also influence the others. For example, safeguarding *Musa* diversity for future generations, either for further development or future consumption, might improve bananas farmers' livelihood and income, and reduce food and nutrition insecurity in the future. Likewise, high yielding or nutritious *Musa* varieties that improved farmers' livelihoods will be worth enough to be safeguarded for future generations. In order to arrive at the ultimate impact, there are several stages of indirect and direct impacts that could occur, where different stakeholders are involved. So, one might ask – are there different impact pathways that an ITC accession has to follow to generate the ultimate impact and who are the stakeholders that need to be involved for it to happen? What is the value that the ITC has added to the generation of the ultimate impact? Are the pathways context-specific or are they the same everywhere?

A first step towards answering these questions is found in a study by Garming, Roux and Van den houwe (2010), who provided an overview of the impacts created through the conservation and distribution of germplasm and presented an evaluation of the ITC services based on a survey of its users. They identified that the main user groups are scientists in national agricultural research centres and advanced research institutes, including universities. Additionally, they confirmed that the distribution of guaranteed healthy ITC germplasm is a very important service among users, given that for many countries the centre is the only source of clean and healthy *Musa* germplasm. Access to safe and healthy germplasm has enabled and facilitated a large body of research and played an important role in the implementation of banana-related development projects (Garming et al. 2010). Lastly, Garming et al. identified the following three outcomes that generate a direct impact on users: 1) the ITC collection identified as a reference collection, 2) the distribution of healthy germplasm and facilitation of germplasm exchange free of charge and 3) the contribution of the ITC to the conservation of *Musa* germplasm, depending on the probability that the crop genetic resources would be lost if not conserved by the ITC. These outcomes depict direct impacts generated by the ITC on germplasm requestors (such as local research institutes), but not on end-users. There, additional investigation is needed to understand impacts on end-users and how ITC adds to the process.

3. Data and Methods

We used two datasets in this study. The first one contains the record of all ITC accessions distributed from 2000-2017. Generated by the genebank with a tool called the *Musa* Genebank Management System (MGBMS), the record shows the requestor, institute, country and date⁸ each time an accession was requested and shipped. We present summaries in a series of graphs and descriptive tables, and estimate a simple linear regressions to test for trends over the years included in the data. Regressions were not used for causal analysis because additional observable and unobservable factors were not taken into consideration and the magnitudes of the estimated coefficients might be biased.

The second dataset comprises the results from the “Musa Usage Survey” (MUS). The MUS is an online, structured questionnaire based on the survey conducted by Garming et al. (2010).⁹ The survey was sent to 81 institutes¹⁰ in Africa, Asia and the Pacific who had received ITC material from 2000 until 2017. Of these, 31 replied (see Table 1). To maximize the information gathered, the survey was sent to different individuals among the institutions. Once a response was obtained in a given institution, the remaining individuals were informed so that only one response per institute was recorded. The words institute, user or requestor will be used interchangeably across the document. In order to comply with the European General Data Protection Regulations (GDPR), users were contacted by e-mail and asked to accept and submit a Consent Form and a Privacy Notice (see Annex 1) prior to receiving the survey.

The MUS contained three sections. The first section covers three main topics: 1) accessions that have been maintained and why, 2) accessions that were not maintained and why and 3) how have these accessions been used (e.g. distributed, impacted the community, research). The aim of this section is to understand how requestors have utilized the accessions they received. The second section asks about common varieties grown in the survey regions and why are they considered to be special. The aim of this section is to identify patterns of demand *Musa* germplasm and their traits among communities and regions. The third section seeks feedback on ITC services, and consists mainly of open-ended questions. This section was designed to enable users to report their own experiences (both successful and unsuccessful) and identify particular problems. We created two versions of the survey

⁸ Also, the purpose of request has been documented since 2014

⁹ The survey was first conducted for the LAC region, although some minor modifications were made to the LAC version of the MUS, the results of all regions are comparable.

¹⁰ The entire requesters population comprises 115 known institutes, however some of them resumed their operations or we could not have access to their contact information.

– an online survey link and an excel file (see Annex 2) - so that respondents could choose their preferred option. The survey was offered in English and took between 15-20 minutes to complete. The findings from the first two sections of the MUS are summarized here.

4. Results and discussion

4.1 Distribution of ITC Germplasm in Africa, Asia and the Pacific 2000-2017

The ITC collection contains more than 1.500 accessions of edible and wild species of banana¹¹. Between 2000 and 2017, ITC shipped 5275 accessions to users based in 50 different countries of Africa, Asia and the Pacific. Users requested on average 310 accessions annually. As depicted in Table 2, these included 139¹² individuals in 115 institutes. Requests from Asia and Africa comprised the majority of the demand, with fairly similar shares, compared to the share of requests originated in the Pacific Islands.

There are no clear trends in the *Musa* germplasm distribution data from 2000 and 2017 in the three regions (Figure 2) combined, or when the number of accessions requested was segmented by region (Figure 3). We modeled the linear trend on distribution across the years and found a decreasing number of countries and institutes, for about the same aggregate number of accessions distributed (Table 3).

Information on the purpose of the request is only available from 2014. However, these data showed that the majority of the requests (70%) were for research purposes. Slightly over one-fifth (22%) of the distributed accessions were requested for the purpose of breeding or conservation programs (see Figure 4). Similar results are observed when the data are classified by region, where research still represents the larger share of requests (see Figure 5). Interestingly in Africa the difference between the share of breeding and research is smaller compared to Asia and the Pacific Islands. These results demonstrate that the contribution to research and the creation of knowledge are the most important outcomes ITC generates by distributing *Musa* germplasm.

¹¹ <https://www.biodiversityinternational.org/banana-genebank/>

¹² In total there were 185 individual requests from which 139 are from known individuals and 46 from unknown individual. There can be more than one individual from the same institute.

4.2 Results from the *Musa* Usage Survey

Table 4 shows the number of institutes that participated in the online survey in total and per region. Among the 81 institutes to which the survey was sent, 31 gave their consent and replied to the survey. Institutes in Africa and Asia represented the majority of the population surveyed (in similar shares), showing a pattern similar to the distribution data. The institutes that requested *Musa* germplasm were classified into seven types (see Figure 6); similar to Garming et al., (2010), the majority of the institutes belonged to the *Research institutes* and *Academic institutes* categories.

Although 27 of the institutes replied that they maintained the ITC accessions, only 18 of them have information about their collection on the MusaNet website (www.musanet.org) (see Figure 7 and Table 5). There is no verifiable information concerning whether the remaining institutes maintain their own *Musa* collections or whether they participate only in the dissemination of germplasm. Regarding the method of conservation, the majority of the institutes maintain the ITC accessions in field collections (see Figure 8), corresponding with what was mentioned above about *in vivo* conservation. The institutes also mentioned that the two principal reasons for not maintaining the ITC accessions are problems with diseases and the lack of space in their facilities. This finding reveals the need to train local institutes about the use of various conservation methods, other than *in vivo*, in order to reduce the chance of disease propagation and the space required. Such training offers the opportunity for ITC to collaborate even more with requestors.

In section 4.1 we discussed the purposes mentioned by users when requesting each individual accession. We were also interested in knowing the reason why institutes-maintained accessions. Figure 9 depicts the different reasons given by survey respondents for maintaining an accession, by region. Contrary to the purpose of the request, which was most frequently to conduct research, the majority of the institutes maintained the accession in order to evaluate its agronomic and other traits. In addition, as mentioned above, the majority of the *Musa* germplasm conserved *ex-situ* is in field collections. Therefore, the demand for conservation *in vitro* or in cryopreserved collections is low compared with the option to conserve in a field collection. This is especially evident for cryopreservation, which has the smaller share of responses. The field collections are particularly important for taxonomic characterization, evaluation, training and breeding purposes (MusaNet 2016). Nevertheless, when the three options related to conservation (*Conservation in field*, *Conservation in vitro* and *Cryopreservation*) are combined, conservation appears to be the most common purpose for maintaining an accession. These results show the importance of local institutes in achieving the ITC's first mandate, which is to ensure safe and long-term conservation of a broad range of *Musa* genetic diversity.

Among respondents who maintained the germplasm received from ITC, the important trait when requesting germplasm that was most frequently mentioned was *resistance to disease* (see Figure 10), and the most frequently mentioned diseases were Tropical Race 4 (TR4)¹³ and Black Sigatoka. Interestingly, from the six respondents who mentioned TR4, five were located in Asia and the Pacific, suggesting that there is a greater interest from this region's users for resistance to TR4 compared to the ones in Africa. If compared with the distribution of TR4 cases in the world (see Figure 11), one can infer that many of the research and breeding programs in Asia and the Pacific are focusing on finding or developing varieties resistant to TR4. As depicted in Figure 11, by the end of 2000, TR4 was found in several locations in southern Asia and parts of the Pacific Islands and since then the number of cases has increased exponentially throughout the region (ProMusa 2018). On the other hand, the only case reported in Africa was in 2013, indicating that TR4 is not the main disease for which institutes in that region are seeking resistance. Additional studies and trials are planned to identify the risks of TR4 across regions. Lastly, the diseases most frequently mentioned by the African institutes surveyed were Black Sigatoka, Banana Bunchy Top Disease and Banana Xanthomonas Wilt.

Culture appears to have a greater influence on the selection of *Musa* varieties in Asia and the Pacific Islands compared to Africa. Despite that *Resistance to disease* and *Productivity* were reported to be the most important traits to maintain in an accession, characteristics of the fruit were also taken into consideration. Traits related to the fruit's taste, color, size, texture and nutritional value were found to be more important for requestors in Asia and the Pacific than to the ones in Africa (see Figure 10). Resistance to drought, salinity, cold and wind were some of the other traits mentioned by the requestors.

The main outcomes achieved by the users after receiving ITC accessions were reported to be the generation of knowledge through research, local adoption (perceived), and further distribution (see Table 6). Regarding research, the results showed that 13 of the institutes have used the ITC accessions for research and developed a total of 20 articles (including both peer- and none peer-reviewed publications). Table 6 describes the number of accessions used for research according to the type of cultivar, showing that the majority of the research is driven by advanced or modern varieties, but that landraces and wild varieties are also important in to knowledge generation.

¹³ Tropical race 4 (TR4) is the name given to a strain of the fungus *Fusarium oxysporum* f. sp. *cubense* (Foc) that causes Fusarium wilt in Cavendish cultivars.

The local adoption of foreign and modern varieties is an important outcome that generates impact. Hence, we wanted to observe how the different users perceived the adoption of ITC varieties in their local communities. Adoption is difficult to measure because it can be defined in numerous ways, is time-dependent, and conditional on many observed and unobserved factors. Therefore, the indicator reported here should be considered with caution. Ten requestors (see Figure 12) perceived that some of the ITC accessions received from 2000 onwards have been “adopted” into local markets of Burundi, Cameroon, Madagascar, Indonesia, Tanzania, Egypt, Uganda, India, Taiwan and Hawaii. Users from Asia and the Pacific Islands reported that five different accessions had been adopted in local markets, three of them landraces (see Table 6). For example, AAcv Rose (ITC0712), was originally from Indonesia and subsequently adopted in Taiwan.

Lastly, 15 institutes reported that they had further distributed ITC germplasm material (see Figure 13). As depicted in Table 6, 10 landraces, six advanced and three wild varieties were further distributed by the users across the Africa, Asia and Pacific regions. The most common purposes for distribution were the evaluation of agronomic or other traits and conservation. Only one of the requestors declared that the distribution was to return the plants to farmers or the community of origin. According to the users, *Musa* germplasm was usually distributed to farmers, universities and research institutes.

5. Conclusion

This study has contributed to a better understanding of the patterns of demand for ITC germplasm, its uses and the relationship between the genebank and its users. The analysis of distribution data and user survey considered institutes who requested germplasm from the ITC from 2000-2017 and are located in the regions of Africa, Asia and the Pacific islands. ITC records indicate that 5275 accessions were distributed to 50 different countries in those regions over that time period. This, combined with the fact that ITC hosts the world’s largest collection of banana germplasm (over 1,500 healthy accessions), demonstrates the important role it plays in not only in the conservation, but also the global mobilization of *Musa* germplasm.

The user survey provides illustrative information about the current use of accessions originating from the ITC in recipient countries. Out of 81 institutes with verifiable contact information from the original roster of 115, 31 responded. The majority of the institutes (27) stated they maintained the accessions they had received, although only 18 of them reported their collections in MusaNet. Despite that the most popular purpose for requesting ITC material was research, the primary purpose for maintaining the accession was related to breeding, evaluation of traits and conservation (*in vivo*). The most important conservation methods were field collections followed by tissue culture. Problems with diseases and lack of space suggest a need for additional training in techniques of conservation in order

to ensure the long-term conservation of *Musa* germplasm in local institutes. This finding underscores the potential for further collaboration between the ITC and its users.

Survey findings also demonstrate the important role that local institutes play in achieving the ITC's mandate and contributing to end-user impacts. In terms of knowledge generation, respondents reported a total of 20 research articles involving ITC accessions. In addition, local partners are crucial for incentivizing the use of introduced or advanced *Musa* varieties since culture and tradition clearly influence the acceptance and adoption of varieties in communities. Finally, the relationship between ITC germplasm local institutes and end-users is very important for maintaining the equilibrium between *ex-situ* and *in-situ* conservation.

After evaluating the results some questions remain unanswered. In this study, we have depicted the relationship between the ITC and local institutes that request *Musa* germplasm. What pathway does a *Musa* accession need to follow to generate impact among growers? What value is added by the ITC in the process of generate such impact?

Further research should address the adoption of introduced and modern varieties and its determinants in key locations, linking this information directly to accessions received from the ITC. Institutes that reported use of the materials distributed to them could be contacted in order to identify specific communities or groups of producers. Ideally, we would like to compare communities that adopted with those that did not, in order to measure any benefit that was delivered with a counterfactual. By using the MUS results, the first author of this study selected a list of case studies from which potential successful stories can be drawn (see Annex 3). These case studies could be used to build impact pathways and assess the impact on growers and consumers (end-users) and the contribution of the ITC. Another avenue of research would be to utilize the collected data about common varieties in each country or region, track their pedigrees, and identify which are related to accessions received from ITC.

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Tables

Table 1. Institutes surveyed per country.

Region	Country	Name of Institute	Type of Institute
Africa	Burundi	AGROBIOTEC, Gitega, Kinindo-Bujumbura	Seed System
	Burundi	IRAZ (Institut de Recherches Agronomiques et Zootechniques)	Research Institute (National Collection)
	Cameroon	CARBAP (Centre Africain de Recherche Sur Bananiers et Plantains)	Research Institute (National Collection)
	Congo DRC	UNIKIS (University of Kisangani)	Academic Institute (National Collection)
	Egypt	Minia University	Academic Institute
	Kenya	University of Agriculture and Technology	Academic Institute
	Madagascar	DRA/FOFIFA (Centre National de Recherche Appliquée au Development Rural)	Research Institute
	Mauritius	FAREI (Food and Agricultural Research and Extension Institute-Reduit)	Research Institute (National Collection)
	Mozambique	IIAM (National Agrarian Research Institute of Mozambique), Maputo	Research Institute
	South Africa	University of Pretoria and Stellenbosch University	Academic Institute
	Tanzania, United Rep of	IITA C/O AVRDC, Arusha or IITA, Arusha, Duluti	CG Center
	Tanzania, United Rep of	Kizimbani Agricultural Training Institute, Zanzibar	Training Institute
	Uganda	KARI (Kawanda Agriculture Research Institute)	Research Institute
Uganda	NARO (National Agriculture Research Laboratories), Kampala	Research Institute (National Collection)	
Asia	China, Mainland	GDAAS (Guangdong Academy of Agricultural Sciences Institute of Fruit Tree Research Banana Research Centre), Guangzhou, Guangdong Province	Research Institute (National Collection)
	China, Mainland	Haikou Experiment Station, CATAS, Haikou	Academic Institute

	China, Mainland	SCAU (South China Agricultural University College of Agriculture)	Academic Institute (National Collection)
	India	ICAR-NRCB (National Research Centre for Banana)	Research Institute (National Collection)
	India	NBPGR Division of Germplasm Exchange New Delhi	Public Institute (National Collection)
	Indonesia	ITFRI (Indonesian Tropical Research Institute)	Research Institute (National Collection)
	Japan	Amami Biodiversity Gardens, Oshima-Gun, Kagoshima-Ken, JPN	Botanical Garden
	Malaysia	MARDI, Klang Selangor, Serdang	Public Institute (National Collection)
	Malaysia	University of Malaya Unit of Genetics and Molecular Biology Kuala Lumpur	Academic Institute
	Nepal	Agribiomaterial and Truffle Research Center, Tribhuvan University, Kirtipur, Kathmandu	Academic Institute
	Philippines	Dole Philippines Inc., Davao	Seed System
	Taiwan, ROC	TBRI (Taiwan Banana Research Institute)	Research Institute (National Collection)
	Thailand	Kasetsart University Center for Agricultural Biotech Kamphaengsaen Campus Bangkok Nakornpathom	Academic Institute
The Pacific Islands	Australia	Daf-Maroochy Horticulture Research Station Department of Primary Industry and Fisheries Nambour Qld	Research Institute (National Collection)
	French Polynesia	Service du Développement Rural, Dpt Recherche Agronomique Direction Del'agriculture, Papeete	Research Institute (Pacific Regional Field Collection)
	Hawaii	University of Hawaii at Manoa Tropical Plant and Soil Sciences	Academic Institute
	Papua New Guinea	NARI-Papua New Guinea National Agricultural Research Institute	Research Institute (Regional Collection)

Source: Authors

Table 2. Requestors of ITC germplasm according to region, 2000-2017.

	Number of known institutes	Number of unknown institutes	Number of individuals	Number of different countries
Africa	54	12	69	22
Asia	53	5	62	21
Pacific Islands	8	2	8	7
All the regions	115	19	139	50

Source: ITC germplasm distribution dataset

Table 3. Linear trend model, number of accessions across the years per region.

	Y1=number of accessions		Y2=number of countries		Y3=number of institutes	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Africa	2,44	2,96	-0,15	0,10	-0,28**	0,13
Asia	-2,50	5,21	-0,18*	0,10	-0,31*	0,16
Pacific Islands	1,56**	0,63	0,02	0,55	0,02	0,55
All the regions	0,17	6,11	-0,38**	0,14	-0,64***	0,21

Source: Authors

Note:

- 5,276 accessions in 17 years
- All the series are series non stationaries, according to Dickey-Fuller and Phillips-Perron tests for unit root
- Significant and negative trends for: all regions y2*, all regions y3*
- Significance: *10%, **5% and ***1%

Table 4. Online survey respondents, by region.

	Number of respondents (institutes)	Number of different countries
Africa	14	11
Asia	13	9
Pacific Islands	4	4
All the regions	31	24

Source: Authors, based on survey

Table 5. Maintenance of ITC accession and collections reported in MusaNet.

	Institutes that maintained an ITC accession	Collection reported in MusaNet
Yes	27	18
No	4	13

Source: Authors, based on survey and MusaNet

Table 6. Number of accessions used by the requestors to achieve different types of outcomes by type of accessions.

		Types of cultivar		
		Landrace	Wild	Advance
Institutes' outcomes after receiving ITC accessions	Research	3	3	5
	Local adoption (perceived)	3	1	1
	Further distribution	10	3	6

Source: Authors, based on survey

Figures

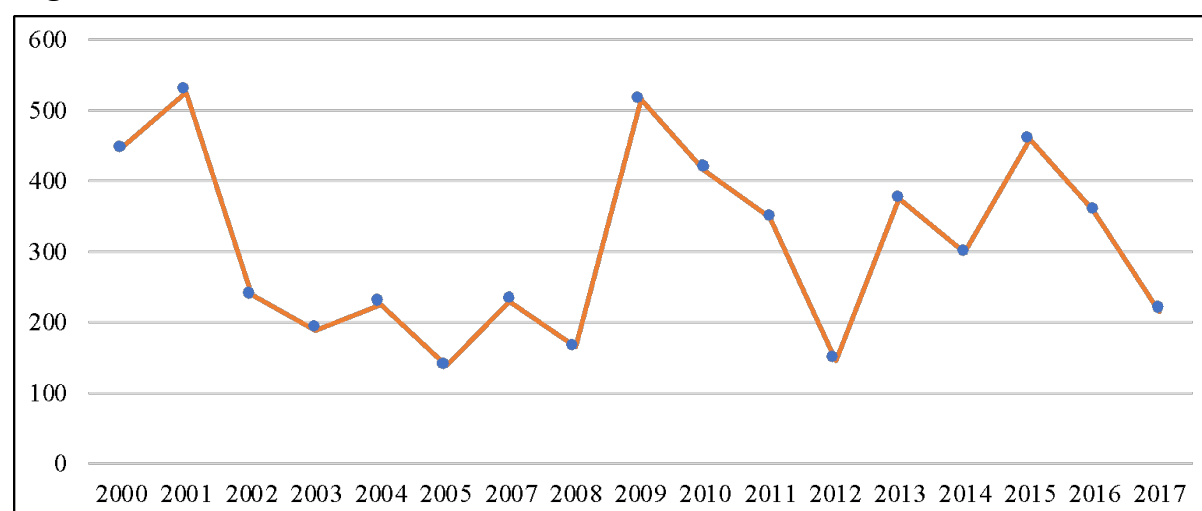


Figure 2. Total number of ITC accessions requested, 2000-2017.

Source: ITC germplasm distribution dataset

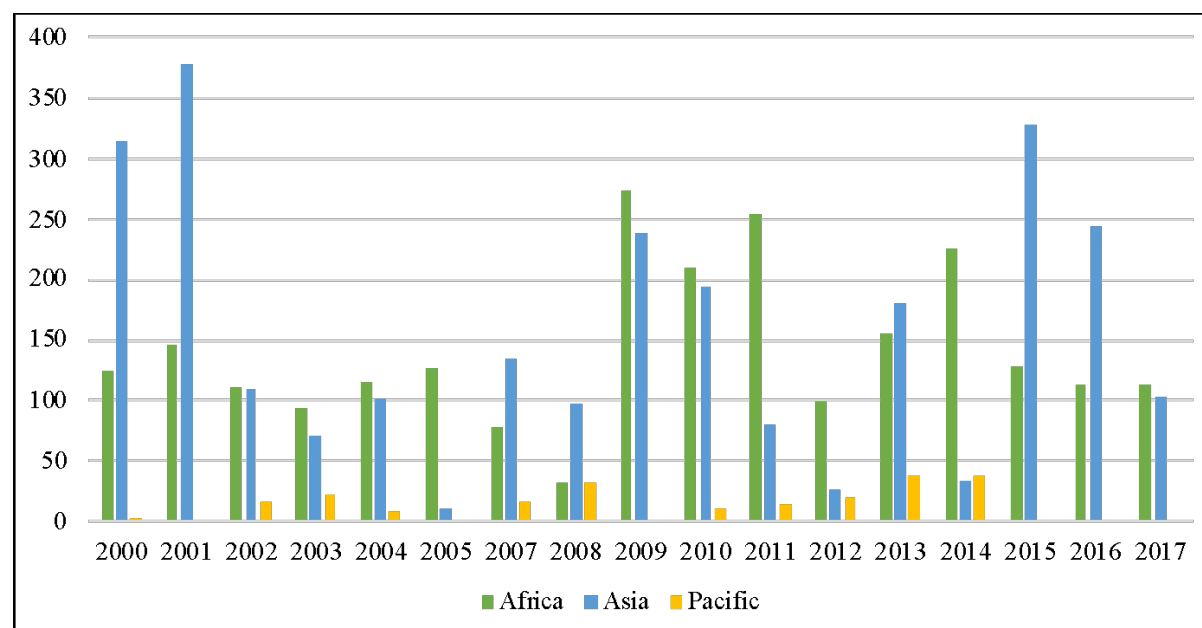


Figure 3. Number of ITC accessions by region, 2000-2017.

Source: ITC germplasm distribution dataset

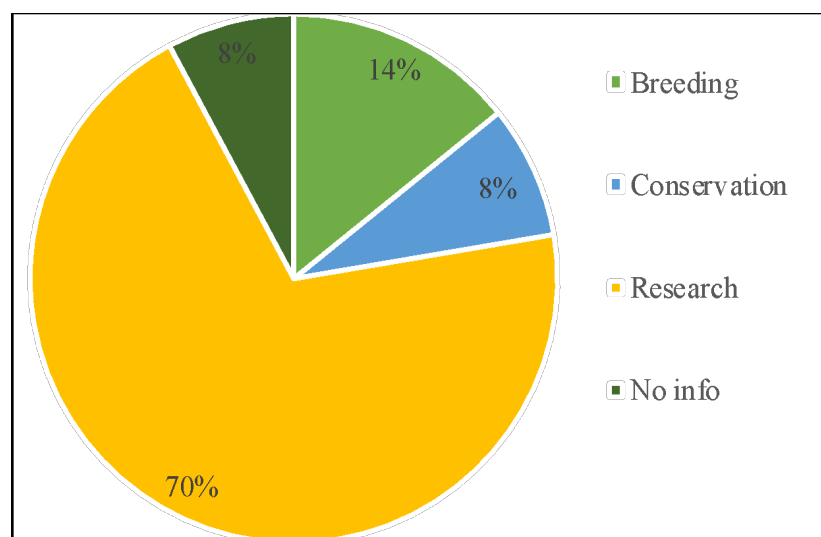


Figure 4. Total *Musa* germplasm requests according the purpose of use, 2014-2017.

Source: ITC germplasm distribution dataset

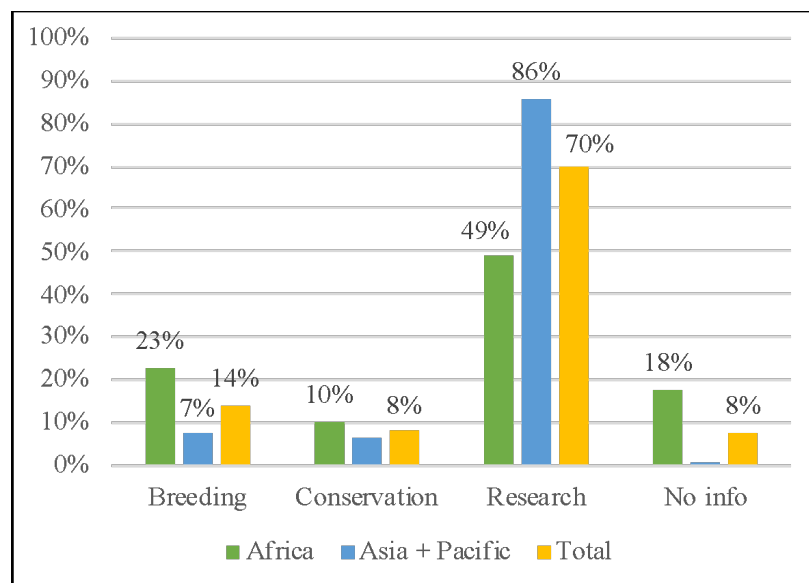


Figure 5. *Musa* germplasm requests according the purpose of use by region, 2014-2017.

Source: ITC germplasm distribution dataset

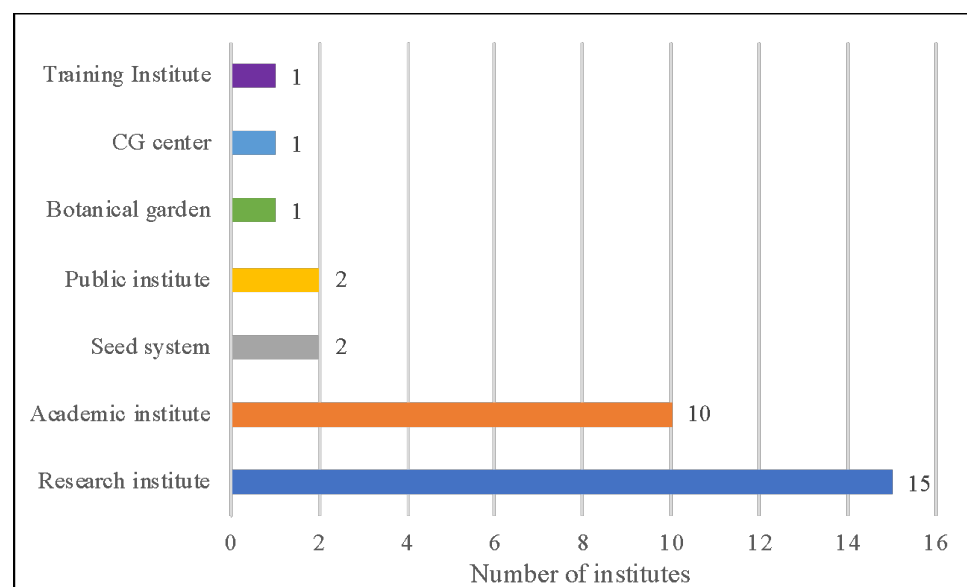


Figure 6. Types of institutes that requested *Musa* germplasm, 2014-2017.

Source: Authors, based on survey

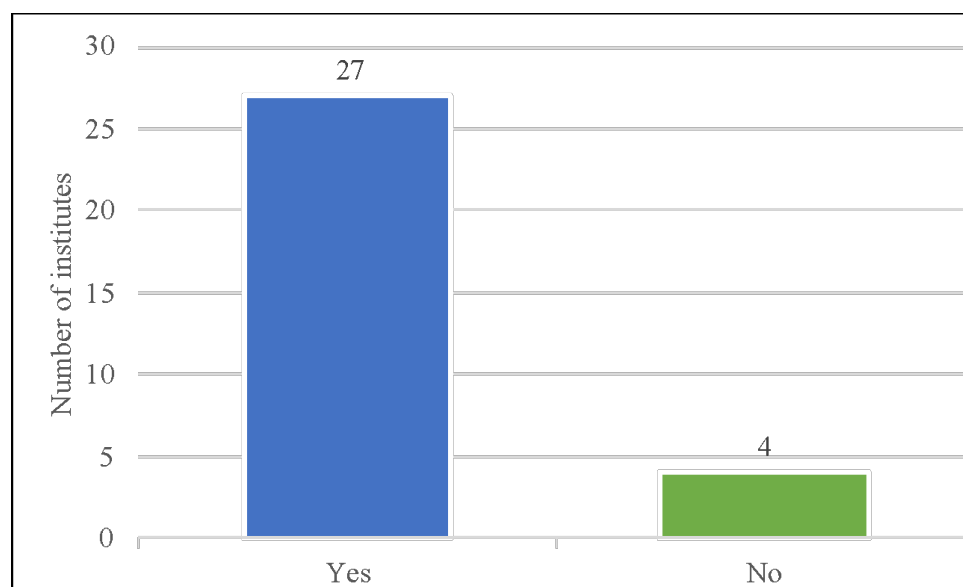


Figure 7. Institutes that have maintained ITC germplasm, 2000–2017.

Source: Authors, based on survey

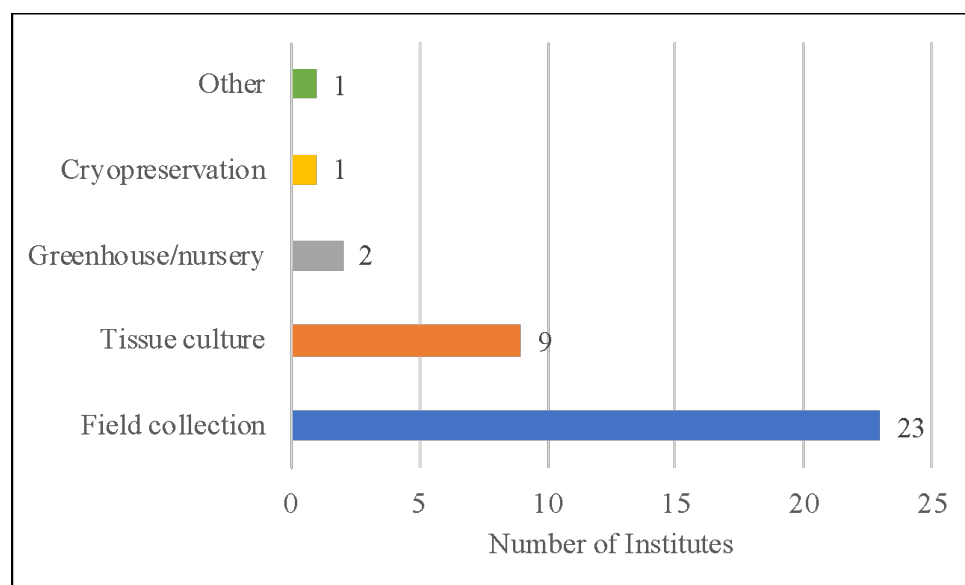


Figure 8. Methods of conserving of ITC accessions received by requestors, 2000–2017.

Source: Authors, based on survey

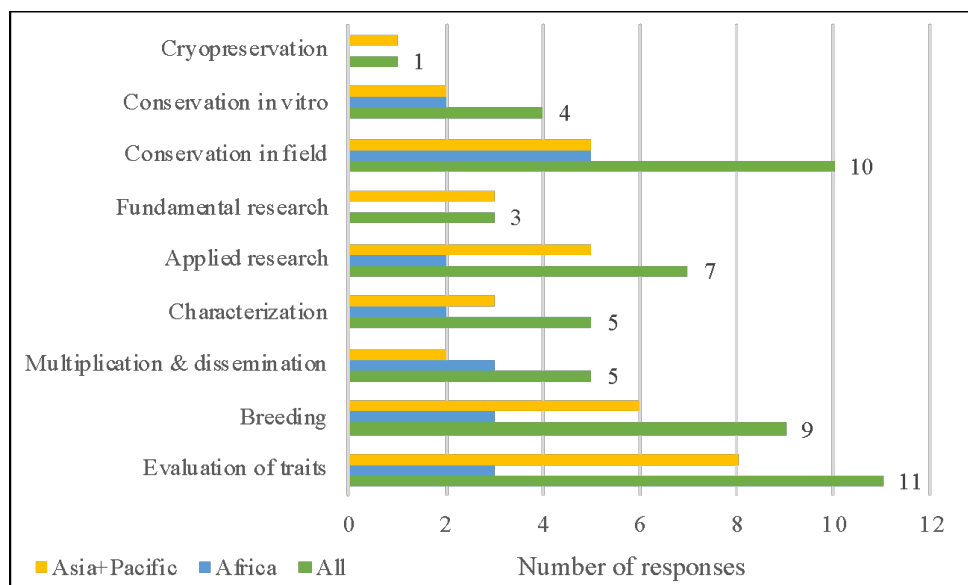


Figure 9. Purpose of maintaining ITC accessions by region, 2000–2017.

Source: Authors, based on survey

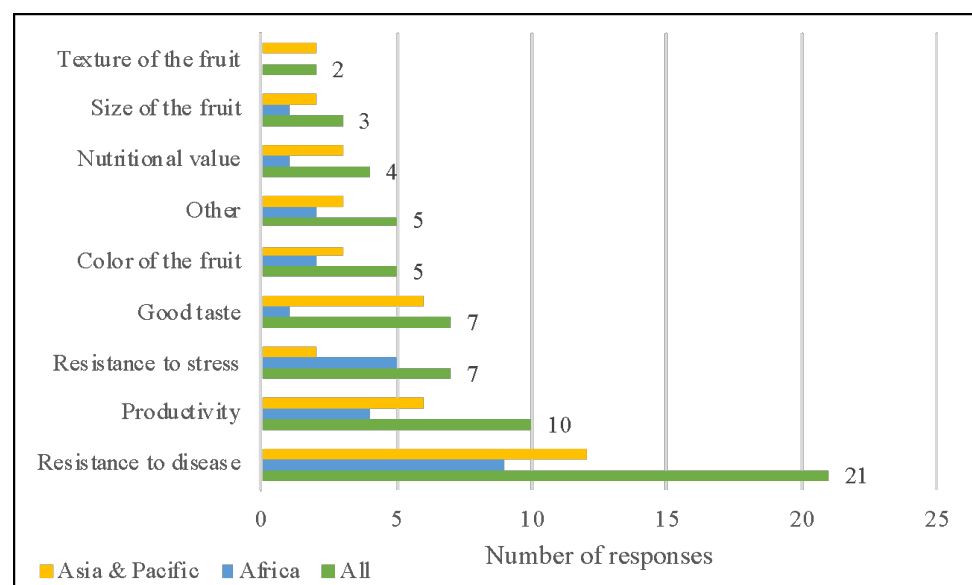


Figure 10. Most important traits when requesting ITC material, 2017–2018. (multiple answers possible). Source: Authors, based on survey



Figure 11. Reported cases of TR4 in the world.

Source: (ProMusa 2018)

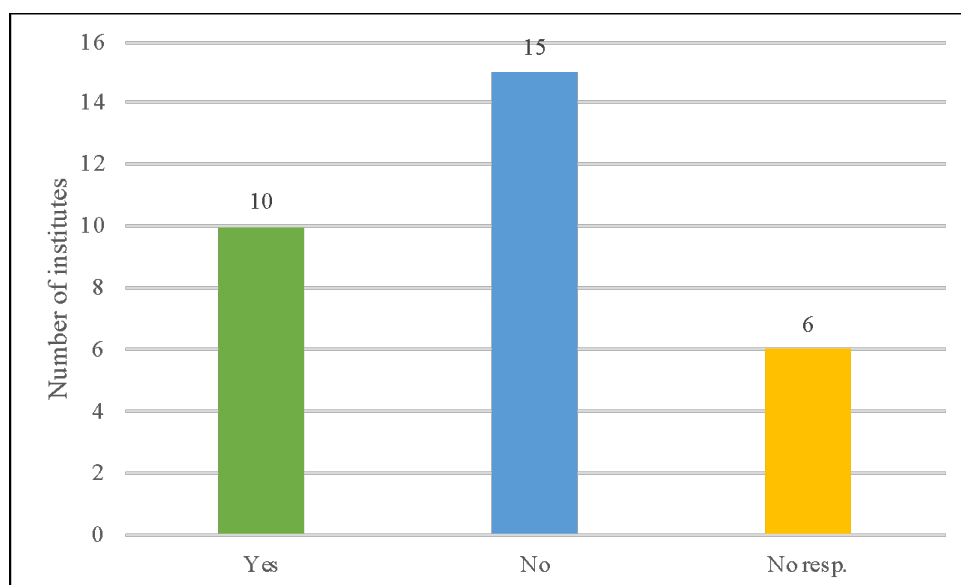


Figure 12. Requestor's perception of the adoption of ITC varieties in the local markets.

Source: Authors

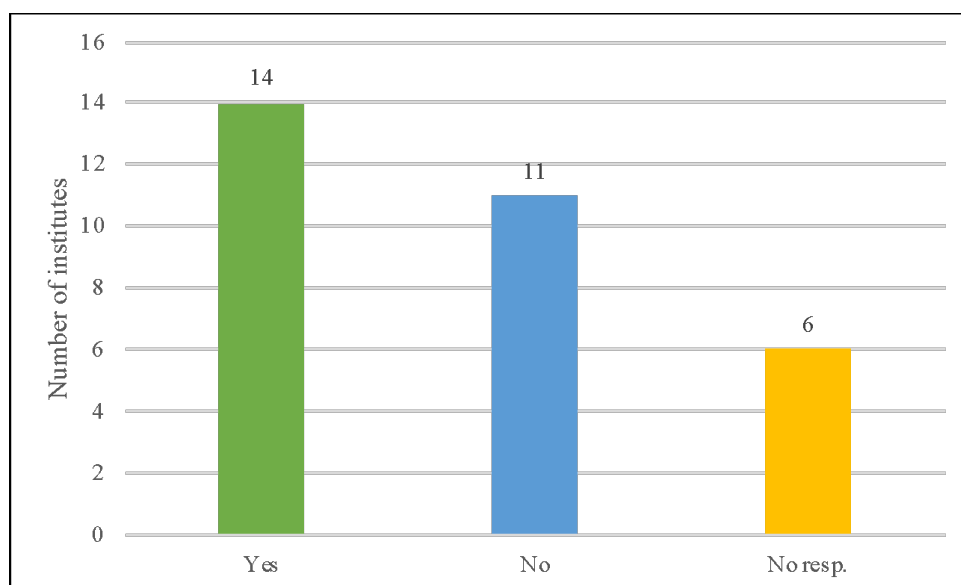


Figure 13. Requestors that have distributed accessions.

Source: Authors

Annexes

Annex 1. Consent Form and Privacy Notice



Dear [name of the ITC requester],

Thank you for requesting banana plant material from Bioversity's International *Musa* Germplasm Transit Centre (ITC). In order to better understand your needs, and to identify what have the users done with the received *Musa* genetic material and how this material has impacted the recipient communities, we are collecting your feedback and kindly invite you to support this effort by completing **The *Musa* Usage Survey**. The survey is directed to institutes and individual users who requested *Musa* genetic material during the period from 2000 to 2017.

If you wish be part of the *Musa Usage survey*, please confirm your consent [here](#)

After giving your consent you will receive an email with the survey. Please confirm by Friday November 30th, 2018. If you do not confirm, we will assume that you would not like to be part of the survey.

As a reminder of your previous requests, please find attached a table with the lists of ITC accessions that you have requested since 2000.

Why are we doing this?

At Bioversity International, we are keen to build a strong network with all the stakeholders that work with *Musa* genetic resources and to promote the exchange of knowledge and ideas. We believe that the more information we share, the easier collaboration becomes among researchers, collections and different types of users. This is why we, together with all the stakeholders, developed *the Global Strategy for the conservation and use of Musa genetic resources* (to see the strategy please click [here](#)), and as a mean to implement the agreed strategy we are now coordinating the network [MusaNet](#).

Why you should participate?

By being part of the **Musa Usage Survey**, you will help to provide information on how *Musa* genetic resources are used and what are the tendencies within your institute, country or local communities. The more we know the easier is to generate impact on communities and sensitize people on the importance of conserving banana diversity in the world.

If you have any questions and/or comments, please contact Vanessa Ocampo via email or Skype at v.ocampo@cgiar.org

Thank you in advance for your contribution and time.

With best regards,

Dr. Nicolas Roux, PhD

Senior Scientist, *Musa* Genetic Resources Team Leader

MusaNet Coordinator

Effective Genetic Resources Conservation and Use
Initiative Bioversity International

Email: n.roux@cgiar.org

Vanessa Ocampo

Musa Usage Survey Collaborator

Consultant for Bioversity International

Email: v.ocampo@cgiar.org

To know about our services and global collaborative framework, visit the following websites:



<http://www.musanet.org>

Global*Musa* Genetic Resources Network



<http://www.bioversityinternational.org/banana-genebank/>

**Bioversity's International *Musa* Germplasm Transit
Centre**

Privacy Notice – Musa Usage Survey

This privacy notice tells you about the information we collect from you when you agree to participate in our study the **Musa Usage Survey**

1. Project description

Bioversity International is collecting users' feedback from the users of its Bioversity International Musa germplasm Transit Center (ITC), to identify the usage tendencies of the Musa genetic resources. The survey is directed to the institutions and individual users who requested Musa genetic material during the period from 2000 to 2017. By being part of the **Musa Usage Survey**, you will provide information on how *Musa* genetic resources are used and promote the exchange of knowledge within the *Musa* genetic resources network. We believe that the more information we share, the easier collaboration becomes among researchers, collections and different types of users.

The survey comprises the three following sections: I. Follow up in distributed ITC accessions, II. Common varieties in the regions and III. User's feedback on ITC services. On average, the survey will take between 10-20 minutes to complete. The participation of the research subjects is entirely voluntary, refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled, and the subject may discontinue participation at any time without penalty or loss of benefits to which the subject is otherwise entitled. In addition, the subject is free to modify and remove his/her personal data at any time.

In case you have questions please contact Vanessa Ocampo at v.ocampo@cgiar.org

In collecting this information, we are acting as a data controller and, by law, we are required to provide you with information about us, about why and how we use your data, and about the rights you have over your data.

2. Who are we?

We are Bioversity International. Our address is Via dei Tre Denari 472/a, 00054, Fiumicino, Rome, Italy. You can contact us by post at the above address, by email at bioversity-ds-requests@cgiar.org or by telephone on +39(0)61181.

We are not required to have a data protection officer, so any enquiries about our use of your personal data should be addressed to the contact details above.

3. What personal data do we collect?

In order to participate in the **Musa Usage Survey**, we will only ask you for your email, as personal data.

4. Why do we collect this information?

The aim of the **Musa Usage Survey** is to identify what have the ITC users done with the received Musa genetic material and how this material has impacted the recipient communities. Bioversity would like to understand some of the drivers and tendencies of the Musa genetic resources use so that they can provide a better service in the future and strengthen the Musa global collaborative framework. In addition, the data collected will be used for information noted above in order to identify the people that are involved in our study. Your personal data will be used in order to contact you when the final report is made publicly available or if we need to request further clarification regarding the information that you submit to us.

5. What do we do with your information?

All the personal information collected will be encrypted at rest and in transit in compliance with the European General Data Protection Regulations (GDPR). The final report will be shared with project stakeholders.

The collected data will only be used for research purposes and to improve ITC services and materials. The collected responses will be used to create a database, which will be included in the CGIAR publicly available open access database¹⁷. In addition, the database will be part of a research project that aims to identify how Bioversity international is impacting communities and end-users of Musa genetic material. The results from the research project will be part of a report that will be shared within the Musa genetic resources community and posted in the Bioversity International web page.

6. How long do we keep your information for?

¹⁷ <https://www.bioversityinternational.org/e-library/library-services/open-access-at-bioversity-international/>

The data will be retained for 10 years, however, you can request at any time for us to remove it from the database by sending an email to bioversity-ds-requests@cgiar.org.

7. Your rights over your information

By law, you can ask us what information we hold about you, and you can ask us to correct it if it is inaccurate.

You can also ask for it to be erased and you can ask for us to give you a copy of the information.

You can also ask us to stop using your information – the simplest way to do this is to withdraw your consent, which you can do at any time, either by emailing, writing or telephoning us using the contact details above.

8. Your right to complain

If you have a complaint about our use of your information, you can contact the Italian Data Protection authority at http://www.garanteprivacy.it/web/guest/home_en

Annex 2. Musa Usage Survey

Welcome to the Musa Usage Survey

Please follow these instructions

1. Filling out the survey: Write the answers in the gray box that corresponds to each question
2. End of the survey: send the excel file to vacampo@cgiar.org

The purpose of the Musa Usage Survey is to collect and share information on which accessions of Musa are being used in different countries and to learn about the traits that make those accessions so important. This will help us to provide the Musa community better and more complete information and improve the way Bioversity's International Musa Germplasm Transit Center (ITC) impacts users.

Your participation is entirely voluntary, and you may choose to not complete the survey or to not answer specific questions.

Please find the Privacy Notice for the study in the following link: [Privacy Note](#)

If you have any questions and/or comments, please contact Vanessa Ocampo via email or Skype at: vacampo@cgiar.org

We greatly appreciate your time and participation in this initiative, which will help us improve the collaboration among Musa users. The results of the survey will be shared with you in due course.

1. Follow-up information: ITC material

Please write your email							
1.1] What are the common purposes when requesting ITC accessions? (i.e., What were you planning to use the material for?) (you may select more than one option)	Purpose 1	Purpose 2	Purpose 3				
	SELECT FROM LIST ▼	SELECT FROM LIST ▼	SELECT FROM LIST ▼				
		not applicable					
Accessions that were maintained:	SELECT FROM LIST ▼						
1.2] Do you maintain any of the accessions received from ITC?	SELECT FROM LIST ▼						
1.3] What is the total number of ITC accessions you have maintained?							
1.4] How do you maintain the ITC accessions you received?	Option 1	Option 2	Option 3				
	SELECT FROM LIST ▼	SELECT FROM LIST ▼	SELECT FROM LIST ▼				
		not applicable					
1.5] What are the main purpose(s) for maintaining these accessions?	Purpose 1	Purpose 2	Purpose 3				
	SELECT FROM LIST ▼	SELECT FROM LIST ▼	SELECT FROM LIST ▼				
		not applicable					
1.6] What are the most important traits of the accessions you maintained?	Trait 1	Trait 2	Trait 3				
	▼	▼	▼				
		not applicable					
		not applicable					
		not applicable					
Accessions that were not maintained:	SELECT FROM LIST ▼						
1.7] Do you discard any of the accessions received from ITC?	SELECT FROM LIST ▼						
1.8] Please fill out the following table with the name the ITC accessions that were NOT maintained and the reason why	Accession name or ITC code if available	Reason not maintained	Specify if required				
◆ > If you need more space, insert rows freely ◆ > If you do not have the information to fill out the following table please continue to question 1.9	a	SELECT FROM LIST ▼					
	b	SELECT FROM LIST ▼					
	c	SELECT FROM LIST ▼					
	d	SELECT FROM LIST ▼					
	e	SELECT FROM LIST ▼					
	f	SELECT FROM LIST ▼					
1.9] Please state what are common reasons for not maintaining an accession	Reason 1	Reason 2	Reason 3				
	SELECT FROM LIST ▼	SELECT FROM LIST ▼	SELECT FROM LIST ▼				
		not applicable					
		not applicable					
Accessions use and impacts							
1.10] Have any of the ITC accessions you received have been distributed?	YES						
1.10.1] How many ITC accessions have been distributed? (specify a number)							
1.11] Please fill out the following table with the information of the ITC accessions that were distributed	Name of the distributed accession (code if available)	ITC	To whom was it distributed? (specify location)	Purpose of distribution	Please comment on the yield of the accession	When was it distributed?	Current status
◆ > If you need more space, insert rows freely ◆ > If you do not have the information to fill out the following table please continue to question 1.12	a			SELECT FROM LIST ▼			
	b			SELECT FROM LIST ▼			
	c			SELECT FROM LIST ▼			
	d			SELECT FROM LIST ▼			
	e			SELECT FROM LIST ▼			
1.12] What are the common purposes for distribution?	Purpose 1	Purpose 2	Purpose 3				
	SELECT FROM LIST ▼	SELECT FROM LIST ▼	SELECT FROM LIST ▼				
1.13] To whom would you usually distribute the accessions?	Option 1	Option 2	Option 3				
	SELECT FROM LIST ▼	SELECT FROM LIST ▼	SELECT FROM LIST ▼				
1.14] Have any of the ITC accessions you received been adapted into the local market? Please specify the name of the accessions	SELECT FROM LIST ▼						
1.15] Does any of the ITC accessions you received have contributed to food security? 1.15.1] Please specify in what way do you think the accessions have contributed to food security in your region?	SELECT FROM LIST ▼						
1.16] Are there any ITC accessions that have been part of your research reports?	SELECT FROM LIST ▼						
1.17] How many ITC accessions, do you know, have been used in published or unpublished research? (specify a number)							
1.18] Please fill out the following table with the information of the ITC accessions that have been part in research reports	Name of the ITC accession used in research (ITC code if available)	Title of the research	Author	Is it published?	Year of publication	Publication link	
◆ > If you need more space, insert rows freely ◆ > If you do not have the information to fill out the following table please continue to section II.	a			▼			
	b			▼			
	c			▼			
	d			▼			

II. Common Musa varieties in the regions

2.1) Please list the most popular varieties in your country (they can include, but are not limited to, ITC accessions):

Variety name	Code (if known)	Which one is most common? please rank of the variety (consider 1 as the most common)	Is it included in your collection/institute/field site?	Where was this variety acquired?
a				
b				
c				
d				
e				
f				
g				
h				
i				
j				

2.2) Please specify use and trait of interest of each variety

Variety name	Current use in your country		Major trait of interest		Extra comments
	Use 1	Use 2	Trait 1	Trait 2	
a					
b					
c					
d					
e					
f					
g					
h					
i					
j					

III. User's feedback on ITC services

3.1) How do you qualify the state in which you received the requested ITC materials?

3.2) How do you qualify the quality of the information received with the ITC material?

3.3) Do you or your organization has a Musa collection?

3.4) Please describe if you have any specific difficulty in maintaining your collection? (e.g., a prevalence of disease, lack of materials, other)

3.5) Can you describe any contribution and/or impact the ITC accessions have had in your collection/research/institute?

3.6) Please describe how ITC services and materials can help in the future to improve your research or your collection in case you have one? (e.g., providing a specific ITC accession or providing technical guidelines)

Thank you!

Please remember to send the completed survey to v.ocampo@cgiar.org

II. Common Musa varieties in the regions

2.1) Please list the most popular varieties in your country (they can include, but are not limited to, ITC accessions):

Variety name	Code (if known)	Which one is most common? please rank of the variety (consider 1 as the most common)	Is it included in your collection/institute/field site?	Where was this variety acquired?
a				
b				
c				
d				
e				
f				
g				
h				
i				
j				

2.2) Please specify use and trait of interest of each variety

Variety name	Current use in your country		Major trait of interest		Extra comments
	Use 1	Use 2	Trait 1	Trait 2	
a					
b					
c					
d					
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3.6) Please describe how ITC services and materials can help in the future to improve your research or your collection in case you have one? (e.g., providing a specific ITC accession or providing technical guidelines)

Thank you!

Please remember to send the complete survey to v.ocampo@cgiar.org

Annex 3. Information provided in the MUS on seven institutes with potential impact stories.

Name of the institute (and origin)	Outcome(s)	Reason for the selection
NARI (Papua New Guinea)	Dissemination to farmers and Germplasm reintroduction	<p>Collection reported in MusaNet: yes</p> <p>Main purpose for requesting and maintaining accessions: conservation</p> <p>Further distribution of ITC accessions: yes, to Central & National Capital District, Port Moresby and people use the varieties as food source and income generation.</p> <p>Adopted varieties: 'Dwarf Kalapua' (ITC0812), for subsistence farming and food security. Important traits: good taste, drought resistance and acceptable height.</p> <p>Research: 14 accessions were used for research, no published article.</p> <p>Although they aimed to maintain the ITC accessions in their collection, several environmental events caused the loss of these accessions and some endemic ones. 154 accessions were lost because of the Laloki river flood and/or faulty irrigation pump during long dry period. 40 were not able to survive under dry conditions</p>
NRCB (India)	Breeding programs	<p>Collection reported in MusaNet: yes</p> <p>Main purpose for requesting and maintaining accessions: breeding and evaluation for breeding</p> <p>Most important traits are: resistance to disease and high productivity.</p> <p>Further distribution of ITC accessions: 3 accessions for evaluation of agronomic traits and one of them is in pipeline for release (name: Saba)</p>

<p>Haikou Experiment Station, CATAS (China)</p>	<p>Fundamental research and breeding</p>	<p>Collection reported in MusaNet: yes</p> <p>Main purpose for requesting and maintaining accessions: Breeding and Evaluation for breeding</p> <p>Most important traits are: resistance to disease</p> <p>Further distribution of ITC accessions: yes, with the purpose of breeding and evaluation for breeding and were distributed to Chinese academies</p> <p>Distributed accessions: 'Gabon 2' (ITC0017), 'Calcutta 4' (ITC0249), 'Cocos' (ITC0724), 'Dwarf Parfitt' (ITC0548), 'Balbisiana' (ITC0545)</p> <p>Research: yes, from 'Balbisiana' (ITC0545) they have an unpublished report and from 'Pahang' (ITC0609) they have a published report¹⁸</p>
<p>University of Malaya Unit of Genetics and Molecular Biology Kuala Lumpur (Malaysia)</p>	<p>Fundamental research</p>	<p>Collection reported in MusaNet: no</p> <p>Main purpose for requesting and maintaining accessions: fundamental research.</p> <p>Research: yes, two publications that are based on the 'Gran Enano' (ITC1256)¹⁹.</p>
<p>Kizimbani Agricultural Training Institute, Zanzibar (Tanzania)</p>	<p>Applied research and Dissemination to farmers</p>	<p>Collection reported in MusaNet: yes</p> <p>Main purpose for requesting and maintaining accessions: conservation in fields</p> <p>Most important trait is: the color and texture of the fruit.</p>

¹⁸ Z. Wang, J.-Y. Li, C.-H. Jia, J.-P. Li, B.-Y. Xu, And Z.-Q. Jin. 2016. Molecular cloning and expression of four phenylalanine ammonia lyase genes from banana interacting with *Fusarium oxysporum*

¹⁹ 1) Syarifah Aisyafaznim Sayed Abdul Rahman, Zulqarnain Mohamed, Rofina Yasmin Othman, Rony Swennen, Bart Panis, Dirk De Waele, Serge Remy, Sebastien Christian Carpentier. 2010. In planta PCR-based detection of early infection of plant-parasitic nematodes in the roots: a step towards the understanding of infection and plant defence.

2) Aisyafaznim Al-Idrus, Sebastien Christian Carpentier, Mohamad Taufiq Ahmad, Bart Panis, Zulqarnain Mohamed. 2017. Elucidation of the compatible interaction between banana and *Meloidogyne incognita* via high-throughput proteome profiling.

		<p>Further distribution of ITC accessions: yes, for conservation in the field</p> <p>*They reported that farmers have adopted varieties such as 'Williams', 'Yangambi Km5' (ITC1123), 'FHIA17' (TC1264) and 'Pelipita' and that they are used as food (subsistence production) and sell them in the market.</p>
UNIKIS-University of Kisangani (DRC Congo)	Applied research and Dissemination to farmers	<p>Collection reported in MusaNet: yes</p> <p>Main purpose for requesting and maintaining accessions: multiplication and further dissemination and for evaluation of agronomic traits</p> <p>Most important traits are: resistance to diseases (Black Sigatoka)</p> <p>Further distribution of ITC accessions: yes, high yield varieties (e.g., 'FHIAs') were distributed in the market and adopted by local farmers around Kisangani.</p>
AGROBIOTEC, Gitega, Kinindo-Bujumbura (Burundi)	Dissemination to farmers	<p>Collection reported in MusaNet: no</p> <p>Main purpose for requesting and maintaining accessions: multiplication and further dissemination</p> <p>Most important traits are: productivity, and resistance to disease (BBTV and BXW) and stress (especially drought)</p> <p>Further distribution of ITC accessions: yes, to farmers and research. Adopted in local communities in Burundi and in other African countries such as Rwanda, DRC and Comoros. High yielding varieties (e.g., 'FHIAs') have been adopted in the market and contribute to food security</p> <p>Direct quote: "AGROBIOTEC is one of the most important tissue cultures of East and central Africa. We can play a key role in developing an in vitro collection as part our mission of multiplication and dissemination</p>

		<p>of clean planting material. That needs support in collection maintenance and financial support. In particular, AGROBIOTEC in collaboration with ITC and the national research institute ISABU can develop a collection for the African highland varieties and the NARITA varieties for further use in Burundi, DR-Congo and Rwanda if these supports availed”</p>
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