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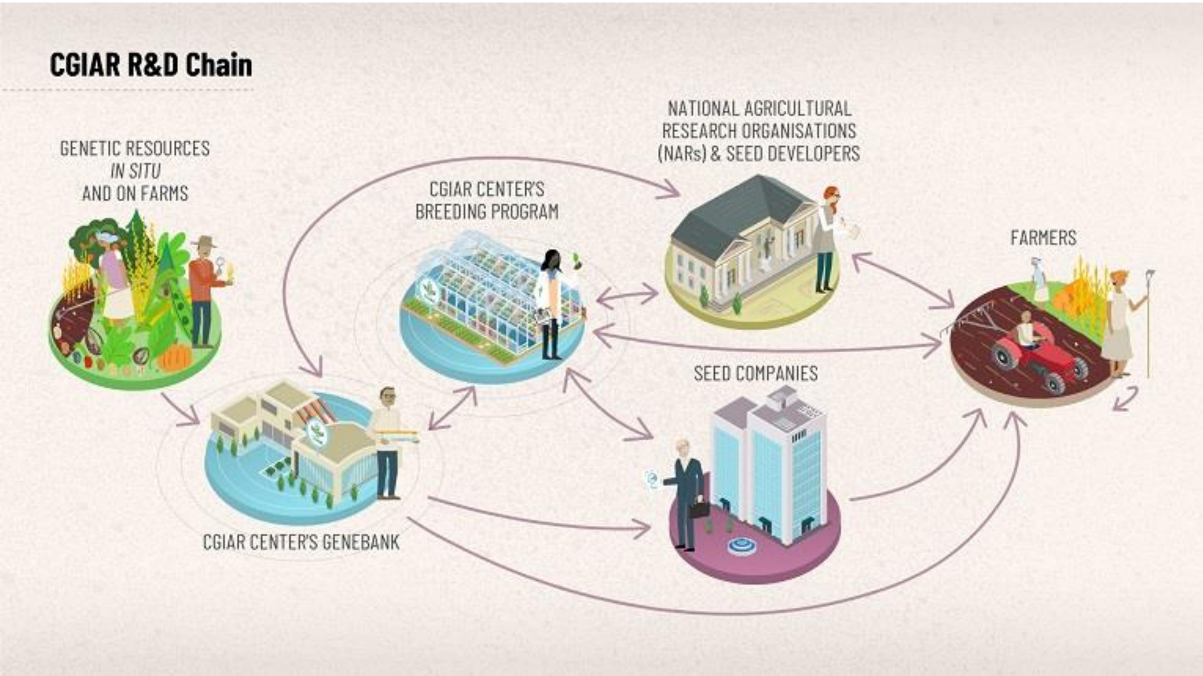
More fruit diversity for food security: conservation of local agricultural diversity and increasing the adaption of newly introduced climate smart bananas for different agro-ecozones in the African Great Lakes Region.

2022-2024

“This next phase project will build on **(i)** the **validation** of the high throughput banana phenotyping data through on station and on farm evaluation via a novel **citizen and farmer science methodology** and **(ii)** will further increase the representation of central and eastern African banana diversity in the international germplasm collection in Belgium by evaluating the characteristics and potential of local banana diversity for climate change adaptation of regional agro-systems prior to safely **conserving** the germplasm in the International Transit Centre (**gene bank gap filling**). The project will strengthen its capacity building component by **(iii) training** national organizations to safely conserve the banana biodiversity (germplasm) and to efficiently multiply banana varieties and landraces in order to build durable seed systems for smallholders.”



Introduction

The answer to the global hunger problem is multifaceted and must be multipronged. What is needed, above all, is a change in the government decision-makers' way of thinking. Agricultural development needs to become a priority in each country, and we **need more investments in research** in the food **and** agriculture sector with **training** campaigns, further development of animal and plant breeding, and equal access to land ownership for women and men (Laborde et al., 2020). UN's Food and Agriculture Organization (FAO) expects that the number of people facing hunger will grow to 840 million by 2030 – instead of reaching zero as pledged by the member states in 2015 in their pact on the world's future. Investments are needed toward farmers' alliances, enabling smallholders to work together and providing training for young people, for the cultivation of climate-resilient crops, and appropriate irrigation (Laborde et al., 2020). Small-scale food producers and food workers are often left out of economic growth, technological change, and political decision making. Globally, today's food systems are not producing affordable healthy diets for all in a sustainable way[1]. The climate crisis poses a mounting threat to food systems, while at the same time, the current food system is a major driver of climate change[2]. Governments acknowledged the central importance of ending hunger and committed to support the most vulnerable food producers, to preserve biological diversity and to better protect the resources and the ecosystems that our children will need to feed themselves into the future. To do so, it was modelled that an additional USD 33 billion a year is needed (Laborde et al., 2020). Climate change is also likely to facilitate the spread of new diseases. Often, smaller-scale producers in countries facing higher risks of extreme climatic events and pandemics of crop diseases, have limited access to adapted technologies, including access to seeds and crop diversity. The introduction and the **support of climate resilient crops** and the **increase of research on water scarce regions** were among the ten recommendations made by CERES (Laborde et al., 2020). Successful adoption is positively correlated with inclusive extension services, access to inputs, and varieties that are readily available and commercially viable. Access to diverse high-quality climate resilient seed is an crucial pathway out of poverty for smallholder farmers and is the basis of multiple development projects (Kilwinger et al., 2020). To provide smallholder farmers with high-quality seed, governments and non-governmental organizations (NGO) must engage in 'seed-systems'.

Geographic focus

This project will focus on the African Great Lakes region, which is one of the poorest areas in the world, encompassing **Burundi**, north-eastern **Democratic Republic of Congo** (DR Congo), western **Kenya**, **Rwanda**, north-western **Tanzania**, and **Uganda**. The region is also one of the most important banana-growing areas in the world, and is home to a unique group of banana varieties adapted to this distinctive highland environment. With an annual production of around 22 million tonnes, the region also has the highest per-capita banana consumption in the world that contributes to up to almost a third of total calorie intake, which is 15-fold the global average and 6-fold the Africa average (Karamura et al., 1998). The region is home to more than 200 million people with a 75% rural population at 153 million. The Great Lakes Region is a secondary center of banana diversity (Perrier et al., 2018), therefore highly diverse varieties associated with traditional/cultural, social and economic values are being used by farmers (Gold et al., 2002). Because banana plants are perennials which can be kept for over 50 years in a plantation (Kilwinger et al., 2019), the choice of banana varieties is key

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[1] The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets. FAO. http://www.fao.org/3/ca9692en/online/ca9692en.html

[2] Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://www.ipcc.ch/srccl/

to the necessary resilience to adapt to climate change. However, climate change as well as pests and diseases are putting banana diversity under threat (Ocimati et al., 2014). Banana seed systems are particular compared with other crops grown in the region because they are sterile and set no seeds. Therefore, banana is a perennial crop that is vegetatively propagated by uprooting the suckers, side shoots that grow from the mother plant. The higher occurrence of extreme temperatures and/or long drought periods will force farmers to replace the mother plants more often and even restart the whole plantation to synchronize with the most suitable moment in the season (Manners et al., 2021). Therefore, a proper ***in-situ* and *ex-situ* conservation of the local diversity** and easy access to locally-adapted banana varieties with good performance in the face of climate change is of **pivotal importance to sustain food and income security for smallholders**. In this context, there is an urgent need to help each country to **manage its own diversity** (the so-called genetic resources) and to foster effective use of local banana diversity for the benefits of their agro- and food-systems.

Objectives and scope

The overarching goal of the project is (i) to foster **food and nutrient security** especially in the view of climate change, and (ii) to **mitigate biodiversity loss** and **conserve the local diversity** by filling the gaps in the ITC collection in Leuven. We aim to achieve those goals by increasing the diversity on the farms and introducing banana varieties with important traits such as drought tolerance and disease resistance. Tolerant varieties introduced from the ITC will be adopted and grown to help close the yield gap in drought-prone areas of the African Great Lakes region and beyond. Ultimately millions of banana growers will adopt drought-tolerant and disease resistant banana varieties within their portfolio, boosting banana yields and associated livelihoods. For this to happen, all stakeholders, including breeders, agro-input traders and extension workers, will play their roles in delivering climate smart and disease resistant varieties to the seed systems. The loss of precious agricultural biodiversity will be achieved by collecting local varieties and assessing their value on our phenotyping platform.

The work will be implemented within DGD Strategy action areas of i) agriculture, food and poverty, ii) biodiversity, (iii) climate change, and (iv) gender. Improving agricultural systems are increasingly recognized to tackle the challenges of inequality, malnutrition, climate change, natural resource degradation, and biodiversity loss. The project supports Belgium's leverage development investment since it focuses on one of the priority regions for Belgium development support, i.e. the Great Lakes Region in Africa. Our partnership has a long-term presence in the Great Lakes Region and has continued to function effectively and support efficiently the farming communities through periods of unrest, insecurity, and the pandemic.

Bioversity, KU Leuven and local partners will implement the work in five linked work packages (WPs):

1. WP1 Gene bank gap filling: evaluation and conservation of local diversity
2. WP2 On station field evaluation
3. WP3 On farm evaluation
4. WP4 Documentation and capacity building
5. WP5 Data management

Research plan

The proposed work is a three-year project that will be executed in 2022-2025. While the previous projects dealt mainly with the high throughput screening for climate smart banana accessions from the banana ITC collection, this next phase will introduce those climate smart varieties in different regions and, by doing so, **validate** those results **in the field** and **assess the potential for adoption** through the on farm testing via a novel **citizen and farmer science methodology.** The said citizen methodology will build on the seed systems to distribute high quality climate smart banana varieties to individual farmers in order to directly involve them in the evaluation of the varieties. Because the selected farmers will grow the distributed accessions on their own farm, they will be able to compare the performance to the varieties already grown on site. This approach has proven very effective to provide robust variety assessment. Growing selected varieties on farmers' fields is also particularly instrumental to promote adoption and initiate dissemination of climate smart banana varieties. Feedback and variety performance can be directly collected by phone and field visits can help validating quantitative data. Our citizen approach consists of a large complex objective that is achieved by distributing small simple tasks to many farmers. With this innovative approach the challenging multi-variety evaluation in multi-locations can be subdivided into 'micro-tasks'. We will apply the tools developed by our digital inclusion team (Van Etten et al., 2019) to collect and analyze the data and to support the decision making for each particular region. The implementation of the key findings will take advantage of existing **farmer field schools initiatives** (for example Enabel in Rwanda) using dissemination tools such as Access Agriculture platform and in close collaboration with national agricultural research centers and cooperation agencies.

Banana is the most important crop in both Uganda and Tanzania (Marimo et al., 2021) and as stated above, the diversity in the whole Great Lakes Region is enormous yet threatened by global warming, anomalous dry seasons and upcoming diseases. The ITC collection is not the only source of valuable diversity. Many local varieties are not commonly known nor distributed across regions/countries, and are currently neither in the ITC collection nor in regional germplasm collection such as the one available in Mbarara (Kamira et al., 2016; Ocimati et al., 2014; Turner et al., 2016). In order to take full advantage from germplasm collections, robust assessment of variety specific characteristics, agronomical performance, and consumer preference is key and needs to be performed in diverse agro-ecological and cultural contexts. We will **collect** the local diversity that is not yet present in the ITC banana collection (**gap filling**) (Van den houwe et al., 2020) and we will assess their potential to enter the ITC through our phenotyping platform. We will **train** students and researchers from the national agricultural research organizations (NARs) in the **safe conservation** of their valuable germplasm collections, high-throughput assessment of tolerance to biotic and abiotic stresses as well as and in the rapid multiplication of healthy planting material. The capacity building activities will provide new expert knowledge to be fed into the stakeholder participation and to unlock the potential of local agro-systems with the implementation of sustainable seed systems that are locally adapted for large scale distribution of healthy and diverse planting material.

WP1: Gene bank gap filling: evaluation and conservation of local diversity

Climate change is more than ever a worldwide problem, affecting management related decisions at all levels from global to regional level. From agricultural to industrial business, all actions are in one way or another related to climate change and its mitigation. Based on current and future anthropogenic emissions, the Intergovernmental Panel on Climate Change (IPCC) reports four representative concentration pathways (RCP) scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) (Collins et al., 2013). However, irrespective of the scenario, global mean temperature will continue to rise by 2100, ranging from 0.3 to 4.8 °C relative to 1986-2005 period and with more hot temperature extremes. Nevertheless, these changes will exhibit substantial spatial variation around the globe (Collins et al., 2013).

Banana (Musa spp.) is a tropical C3 crop, cultivated in a wide variety of climates in tropical and subtropical regions (Calberto et al., 2015; Varma and Bebber, 2019). It provides a substantial amount of affordable energy in calories and food- and income-security (Lynam, 1996). Due to climate change, yields are predicted to decline especially in the currently largest producing, consuming and exporting areas, such as India, Brazil, Colombia, Costa Rica… (Machovina and Feeley, 2013; Varma and Bebber, 2019). Hence, geographic shifts in banana production are expected to occur. However, to sustain current yields and improve farming systems' resilience, intraspecific diversity, complemented with adapted farm management techniques, should be more exploited (Heider et al., 2020). **Mapping the current local banana diversity in function of the environment** is, therefore, urgently needed. Temperature cannot be controlled by farm management and is one of the main factors determining crop cycle duration in tropical species. As temperature and soil water balance are two of the most critical factors affecting plant development, growth, and production (Turner et al., 2016), growers will face immense challenges to sustainably feed the increasing population (UN, 2019) while local varieties are at risk to be permanently lost. Worldwide, a huge range of biodiversity is available. But up to now, a systematic evaluation has never been performed. Characterization and evaluation of the existing genetic diversity for genotypes better adapted to the current and future agro-environment, will give solutions to sustainably intensify agricultural production systems and to alleviate yield gaps. To systematically screen the uncharacterized local banana diversity, the collected varieties will be screened in our high-throughput phenotyping platform called the BananaTainer (Van den houwe et al., 2020). This lab model is essential in speeding up the process and help prioritizing which varieties should enter the ITC gene bank.

Local markets have specific demands and farmers often prefer traditional cultivars because of their superior consumption qualities, even if new/other cultivars display superior agronomic traits and better performance under stress conditions. A **deeper understanding of the local diversity and its potential to withstand current and future climate challenges** is therefore vital. We have proven that there is diversity within the different banana varieties in terms of growth retardation due to suboptimal temperatures (Gambart et al in preparation) and in terms of water use efficiency and drought tolerance (van Wesemael et al., 2019). Hence, there is an imperative need to understand the local diversity so that we can recommend the set of varieties that are suitable for the particular agro-eco zone now and in the future! Our modelling of the environment in the framework of the previous project showed that there are differences in suitability now and in the future (Manners et al., 2021). Within the 5 investigated regions, there were also differences in suitability (Figure 1). The intensity of cultivation and the specific cultivar profiles are not only steered by the agro-ecological conditions, but the local culture and other socio-economic forces are also found to play a role - significant difference were found according to region/ethnicity. Our research pipeline allows us to (i) select the relevant subsets, (ii) understand in a high throughput manner the potential and the weaknesses of the currently used diversity and identify varieties with improved traits, (iii) save time and money by developing a more targeted approach that reduces the costs associated with extensive field trials, and (iv) develop a demand-driven introduction of climate-smart varieties in specific areas for direct use by farmers or as parents in breeding programs.

So far during the 2017-2021 project, we studied the *on-farm* diversity of 5 different agro-ecological zones across Uganda and Tanzania[3].

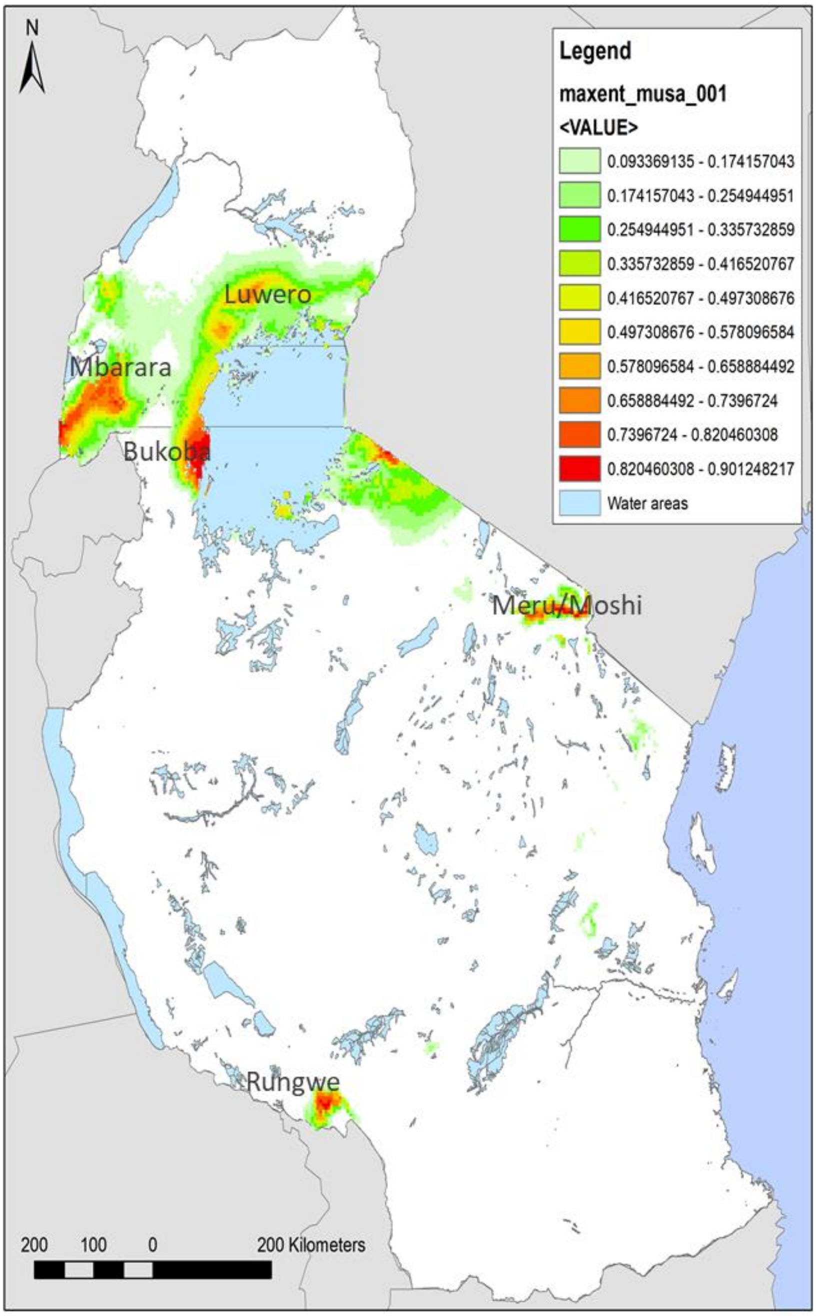

Figure 1: Climate map of suitability for the Great lakes region. With reference to the classification proposed by Yang et al. (2013), five classes of potential habitats were regrouped: unsuitable habitat (0–0.2); barely suitable habitat (0.2–0.4); suitable habitat (0.4–0.6); highly suitable habitat (0.6–0.7); very highly suitable habitat (0.7–1.0).

[3] This work is in support of the Bill and Melinda Gates project Breeding Better Bananas and is a collaboration between the CGIAR, the National Agricultural Research Organisation from Uganda (NARO), and the Tanzanian Agricultural Research Institute (TARI).

WP2: On field evaluation

Screening bananas in the field is challenging due to the changing non-controlled environmental conditions and the long crop cycle but absolutely necessary. It involves detailed and careful planning to accommodate different genotypes. A climate smart variety is a variety that has a good growth in the current and keeps or even increases its growth potential under a changing future environment (Figure 2). During the 2017-2021 project, we evaluated a strategic subset of the collection (146 varieties of which 41 East African Highland varieties) and our modelling identified 55 varieties with an optimal growth in the current zones of interest. To validate the traits observed in the lab models and to study in more detail the impact of heat and drought waves on later stages, we need to go to the field: six climate smart varieties selected from the lab-model phenotyping will be grown in close collaboration with local extension services and farmers. A detailed quantification of the traits maximal stomatal conductance, root/shoot ratio, hydraulic conductance photosynthesis, diurnal canopy movements as well as other relevant traits such as resistance to local diseases will be performed in relation to the main weather events. Yield, plant loss, extended crop cycle, and suckering behavior are exclusive field traits. Daily weather records for the past 10 years will be analyzed to determine the frequency of periods of extreme drought and heat.

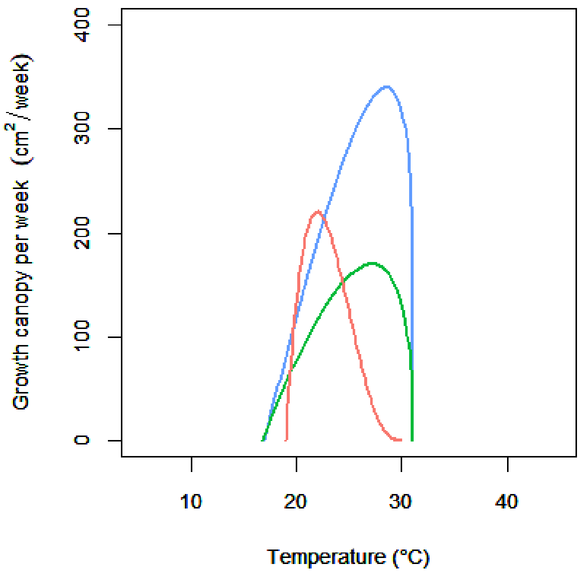

Figure 2: Growth curve of N'Dundu (red), a hybrid (green) and Guineo (bleu) in function of the temperature. Guineo (green) is a highland banana that has a good growth at the current average temperature of 21 °C and even increases its growth at elevated temperatures. The optimal growth of N'Dundu drops fast in a warmer environment.

Special attention will be given to tolerance traits during the critical stages in the life cycle (Gibbs and Turner, 2018). The life cycle of bananas can be divided into three phases: the vegetative, floral, and fruit phase. The vegetative phase begins after planting or when the dominant sucker starts growing and ends when the apex becomes reproductive. During the vegetative phase, any disturbing environmental factor like water deficit will delay the transition to floral phase (Carpentier and Eyland, 2020). The interaction between seasonal changes in temperature, photoperiod, and soil water balance influences the timing of the transition from vegetative to floral phase in bananas, contributing to seasonal variation in flowering and bunch harvest (Gibbs and Turner, 2018). At the start of the floral phase, the apex changes from leaf formation towards the formation of the inflorescence. Any effect of environmental conditions during this time will be reflected with variations in crop duration. A **deviation of the bunch emergence distribution** can be linked to different factors such as spatial heterogeneity in the field, farming practices or plant stresses (drought, root parasitism, plant nutrition, etc.)(Tixier et al., 2004). There is also a genetic difference in crop length cycle (Turner and Hunt, 1984). All these factors are complex require local scientific capacity and close collaboration with national partners and farmers.

WP3 On farm evaluation

In this WP, we will perform on station field testing of 21 promising varieties coming from the ITC banana collection in Leuven. However, it is crucial that there is a demand for them on the local market. Different varieties produce bananas with different properties. The adoption of improved planting material in developing countries is challenging despite their potential to increase agricultural productivity (Kilwinger et al., 2020). To better understand the adoption rates, it is necessary to identify the traits that are considered attractive. Given that smallholder farmers' seed sourcing practices are often influenced by social ties and cultural norms, **we need to understand where and why farmers seek to acquire planting material**. Not only should variety traits be tailored to farmers' preferences, but the sources from which farmers access planting material (Kilwinger et al., 2020) need to be, too. It is crucial that farmers and consumers are involved in the introduction of alternative varieties and the development of new hybrids, to prime high adoption (Nwachukwu and Egwu, 2006; Thiele et al., 2020). **Different varieties have different agronomical properties and** produce **fruits with different characteristics** that influence processing, storage, and other culturally relevant properties (Dury et al., 2002). We have conducted socio-economic and gender studies to **investigate the market potential** of alternative varieties to improve their distribution and adoption (Marimo et al., 2020).

We will build our project further around a farmer-centered approach. A novel citizen science methodology was successfully implemented by Bioversity in India, East Africa, and Central America: triadic comparisons of technologies or 'tricot' on barley, durum wheat, and common bean (van Etten et al., 2019b). This methodology involves **distributing agricultural technologies to individual farmers** who embrace these technologies and use them to evaluate their varieties on their own farm. This 'tricot' approach is relatively easy to execute . Farmers do not score the varieties, but rank them for different aspects of performance. The idea behind this choice is that ranking avoids any complication arising from the need to explain rating scales and precise yield measurements. This provides a more coherent dataset for subsequent analysis. It has been found that most people can correctly distinguish objects that differ 6% or more in weight (Weber, 1996). Feedback is simply collected by phone. The idea behind the recent citizen science approaches is that large tasks can be accomplished by distributing small simple tasks to many farmers. It creates a mechanism to break a large challenging task such as multi-variety evaluation on multi-locations into 'micro-tasks', and it generates mechanisms to retrieve and combine the results to accomplish the original complex task. Control over individual tasks is weak, and individual farmers will make mistakes. However, the built-in redundancy coming from the number of farmers minimizes this risk. Each task is executed more than once by several participants. Trial data analysis makes use of complementary environmental data. Since the data are digitally collected, the trial points are geo-located. This also makes it possible to combine the trial data with geospatial data from other sources. Another noteworthy advantage is that **many environments are being sampled**, as results from different participants at the same agro-zone are compared. The tricot approach provides interpretable, meaningful results and was proven in a pilot study to be widely accepted by farmers (Van Etten et al., 2019a). Hundreds of farmers become in this way our 'phenotypers'.

The tricot approach is:

- ✓ Simple: simplified trial format allows growers to easily participate; custom-built ClimMob software supports easy project design, data collection and analysis.
- ✓ Cost efficient: project staff does not need to closely supervise or visit all individual on-farm tests.
- ✓ Time saving: data can be collected remotely through telephone calls.
- ✓ Realistic: trials take place under real farming conditions.
- ✓ Comprehensive: growers make observations along the entire cropping cycle.
- ✓ Reliable: accurate and robust results are collected due to high number of observations.
- ✓ Effective: growers benefit immediately, as the new technology options are tested and available for their local farm conditions.

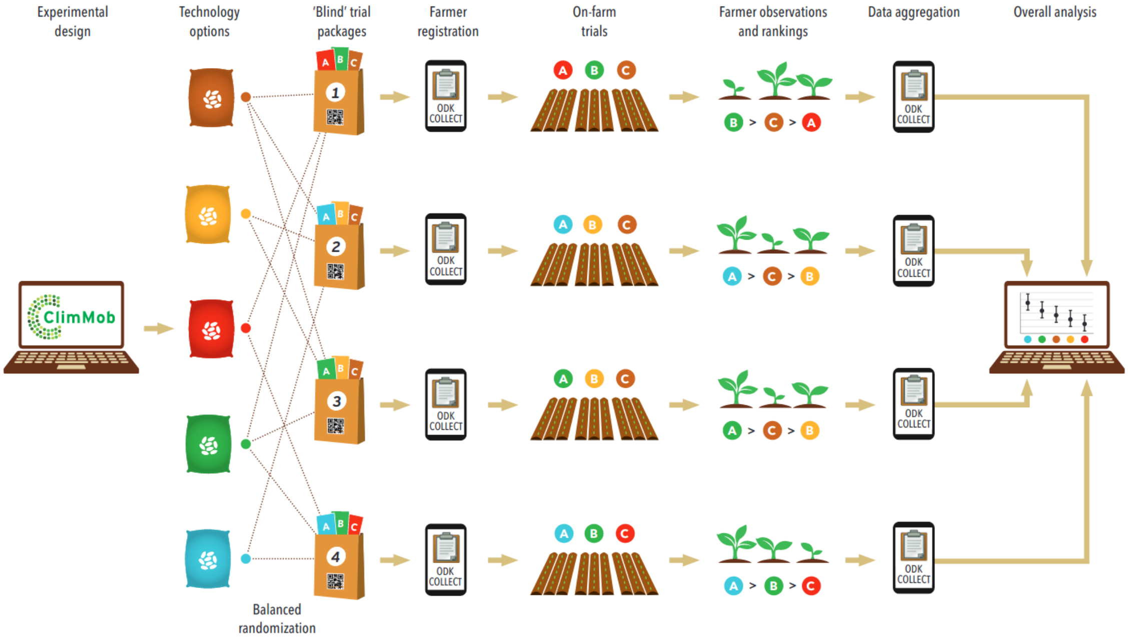

Figure 3: Ticot principle. Farmers receive 3 different varieties that they need to rank on their own farm.

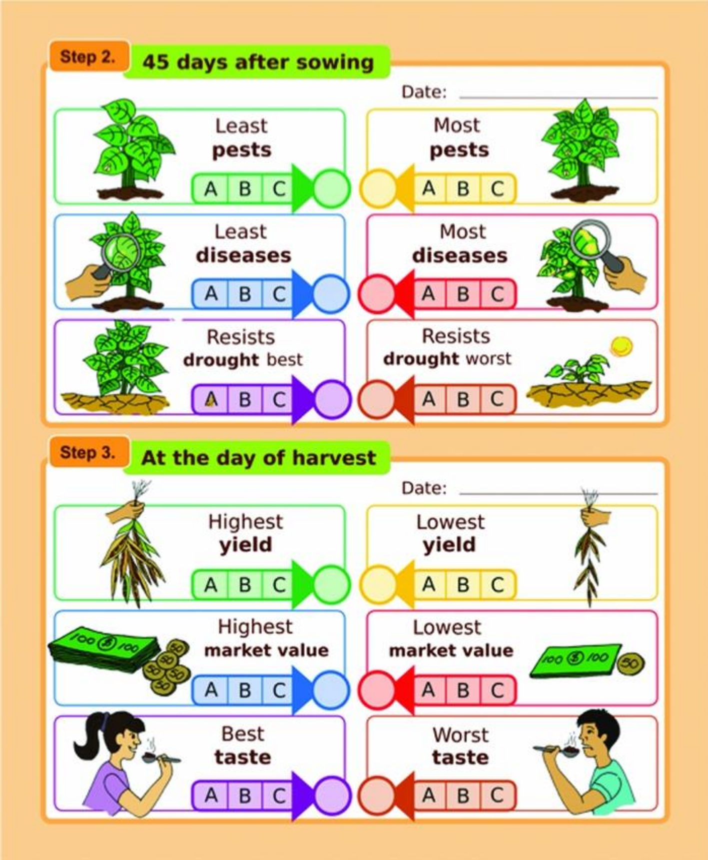

Figure 4: Excerpt from the data collection format. The format given to farmers is full colour. The idea is that farmers write the selected letter in the circle source (Van Etten et al., 2019a).

WP 4: Capacity building

The project builds on the **complimentary and multidisciplinary expertise** in the extensive banana research established and conducted in **Belgium** with partners in Africa **over the last 30 years**. The synergies between Bioversity, KU Leuven, and our African partners will warrant progress in the deployment of improved varieties for increased food security. The project targets small- and medium-sized farmers, producing bananas for home consumption and for local/regional markets in the African Great Lakes Region. Building on the experience and scientific excellence of the Bioversity - KU Leuven research team, the project will help to increase productivity and resilience of banana farms, through identifying varieties from the banana collection as well as from local environments that are better-adapted to climate related stresses. We anticipate that our experimental design will provide data to improve and optimize tools for future **farm management advice.** The project will support the decision-making in banana farming for agro-input suppliers, cooperatives, agricultural extension organizations, and NGOs. The project secures this unique expertise between Belgium and the Great Lakes Region, and its activities will directly reach out to smallholders. Several research components will be rooted in the partner African countries so that they will be able to safely conserve their local germplasm and use it to combat climate change. The project will also serve as a platform to build joint research projects with local African institutions and organizations (i.e. EU-Africa research program, VLIR-UOS, etc.).

In-situ conservation ensures **local capacity building** for easy **access of good and healthy planting material and production of 'seed' for local business** while the *ex-situ* conservation provides a secure backup in case of unforeseen natural disasters and anthropological conflicts. As previously demonstrated (Kilwinger et al., 2020), there is a considerable opportunity to improve the 'seed business' in the targeted region. The work will also contribute to the **pre-breeding workflow** where valuable sub-traits and genetic information on existing varieties will nurture the local breeding programs (NARO, TARI, IITA). We will take advantage of local research offices of Bioversity in the region as well as **existing collaborative networks[4] of NARs to disseminate knowledge and innovative agricultural practices to smallholders**. The generation and sharing of knowledge will help poor populations establish resilient banana production systems, reduce the vulnerability to the effects of current and future drought on banana production, and ultimately strengthen the adaptive capacity to climate-related hazards and natural disasters. The visibility of the efforts of the Belgian investments will be underlined by visits to the local farmers and local collections, and we will develop video capsules to facilitate knowledge dissemination and adoption of new varieties and agricultural practices by farmers.

WP 5 Coordination and Data management

Good data management is fundamental for high quality research and therefore research excellence. Therefore we will facilitate data sharing to ensure the sustainability and accessibility of data in the long-term and therefore their re-use for future science. All publications will be open access. All phenotypic traits will be incorporated into our institutional gene bank on line platform Musa Germplasm Information System (Ruas et al., 2017). The anonymised data from the citizen science experiment will be stored on the Climmob-platform and also mirrored on an encrypted backup server. Ethical approvals will be sought from respective countries and/or other ethical boards before implementation of any research activities with human subjects. We will share the data that we generate during the research process with the members of our research group. Before sharing the data, legal and ethical issues will be assessed in terms of data ownership (the researcher, the institution, the funder, farmer). Upon sharing data, attention will be paid that the data can be understood and interpreted correctly. This requires a good data description, good metadata, detailed data documentation and contextual information. Sharing research data has several benefits: encouraging scientific integrity, enabling scrutiny of research findings, leading to new collaborations and partnerships, encouraging the improvement and validation of research methods, promoting innovation and potential reuse of the data, increasing the impact and visibility of research and having a positive effect on the citation rate. We will ensure that the data meets requirements of funders and publishers.

STRATEGIC DIMENSION AND APPLICATION POTENTIAL

This project will focus on climate change related problems in banana cultivation in the African Great Lakes region, as described in section geographic focus. The issues related to climate change are: higher temperatures leading to a higher water demand, heat stress, anomalous dry seasons and risk of disease pandemics caused by plant pathogens (i.e. viruses, bacterial and fungal pathogens). This more fruit diversity for food security project builds further on our previous DGD-funded projects titled: 'Adding value to the ITC collection' "Phenseedata" and more fruit for food security'. It also links well with other work in the region, including the banana improvement work funded by the Bill and Melida Gate Foundation and the LEAP Agri project, Clismaban.

[4] MusaNet (www.musanet.org) including MusAfrica.

The project supports Belgium's leverage development investment since it focuses on one of the **priority regions for Belgium development support**, i.e. the Great Lakes Region in Africa. Our consortium has a long-term presence in the Great Lakes Region and has continued to function efficiently and support effectively the farming communities through periods of unrest, insecurity, and the pandemic.

The project targets small- and medium-sized farmers, producing bananas for home consumption and local/regional markets in the African Great Lakes Region. Building on the experience and scientific excellence of the Bioversity-KU Leuven research team, the project has great potential to help increase productivity and resilience of banana farms, through introducing banana cultivars that are better-adapted to drought- and climate-change related stresses.

The proposed project aligns with the Strategy and Results Framework 2016-2030 of the CGIAR in strategically addressing the three System Level Outcomes (SLOs), and in particular aiming to contribute to its Intermediate Development Outcomes (IDOs) on increased resilience of the poor to climate change and other shocks (SLO 1 - reducing poverty) and on increased productivity (SLO 2 - improving food and nutrition security). The CGIAR is committed to devoting a substantial part of its research for development activities to the cross-cutting theme of climate change, focusing on climate-smart agriculture based on urgently needed adaptation options for farmers.

The project contributes directly to a number of the UNDP Sustainable Development Goals (SDGs), as articulated below:

- The identification of banana cultivars with high water use efficiency directly **addresses SDG** target 1.5, SDG target 2.4 and SDG target 13.1, by helping poor populations to establish resilient banana production systems, thereby reducing their vulnerability to the effects of current and future drought stress on banana production and ultimately strengthening their adaptive capacity to climate-related hazards and natural disasters;
- The potential expansion of banana production to drier areas with lower disease pressure will contribute to SDG target 12.4, by reducing the dependency on pesticides and setting up more environmentally friendly banana production systems;
- Improved characterization of the ITC collection and enhanced data management will support SDG target 2.3 and SDG target 12.2, by providing access to vital information on banana cultivars that form the backbone of sustainable banana-based food and value chains.

Our research pipeline allows us to (i) select from the International Transit Centre the relevant subsets of banana accessions, (ii) **understand** in a high throughput manner the potential and the weaknesses of **the currently used diversity** and **identify varieties with superior traits**, (iii) save time and money by a more targeted approach that reduces the costs associated with extensive field trials, (iv) setup a rigorous **prebreeding workflow** that will accelerate future breeding programs, (v) understand the bottle necks of the current and **future seed systems** and (vi) develop a **demand-driven introduction of climate-smart varieties** in specific areas for direct use by farmers. We will **add value to the ITC collection** in the sense that National Agricultural Centres and breeders from all over the world will have access to this information and will be able to select the **right varieties for the right agro-ecological zone**. Moreover, they will be able to order disease free accessions free of charge and bring them into their own collections, where they can be distributed as healthy seed material. Several thermo- and drought tolerant and sensitive accessions will be identified and a link with the genetics will be made. This will not only lead to **open access publications** in top peer reviewed journals. This information will also be crucial for **breeding programs** and will give breeders insight into with parents and offspring they need to select to breed for more climate resilient varieties. The citizen science approach will judge the **potential for introduction and adoption in different agro-ecozones**.

The “one CGIAR” is in full development and an Alliance between Bioversity International and CIAT has been made as a first important step. Its mission is to advance agricultural science and innovation to enable poor people, with special attention to the right of women. We aim to better nourish families, improve productivity and resilience so economic growth can be shared and **natural resources managed in the face of climate change** and other challenges. A CGIAR disbursement has been found to translate to benefits twice the costs, when harvested over the lifetime of projects (Renkow and Byerlee, 2010).

We believe that planting the right variety at the right agro-eco zone and applying good seed systems with healthy planting material will definitely contribute to this. As leaders at the UN, the World Health Organisation, and WWF International have recently warned, pandemics such as the COVID-19 outbreak resulting in major social, financial and health devastation, are more likely under the current rampant destruction of the natural world. Conversely, agri-food system research, specifically climate-smart agriculture, is an effective investment to end poverty and hunger, and will at the same time improve natural resources and ecosystem services. In some cases, 75% of the total monthly household income for smallholder farmers is attributed to banana farming. When smallholders have **access to a broad scale of the banana varieties** most suited for specific growth conditions, a greater quantity of banana as an affordable staple food source is produced, impacting on the micro- and macroeconomic systems.

Gender and other social & cultural considerations

In the Great Lakes region, banana cultivation has strong cultural and symbolic associations. Owning a banana plantation is an important status symbol for adult men. It is also seen as a guarantee for food and income security. Women usually provide labour for their husband’s plantation (e.g. weeding). Requirements for additional labour investment in the cultivation of newly introduced varieties, might therefore negatively affect women. In female-headed households women do sometimes control banana plantations. Such households are often disadvantaged, with fewer resources, and would benefit from specific targeting as they might not be reached through common male-dominated information-sharing networks nor do they have the necessary resource / asset base to engage.

In the Great Lakes region, where plantations can stand for decades, planting a banana is often considered as making a claim on land. This is often why landless women and youths who cultivate for their husband/family or on rented land, cannot easily engage in banana production. High altitude areas such as western Uganda highlands (1400-2000 m a.s.l.) are also characterized by lower pest and disease pressure, allowing banana plantations of preferred landraces to thrive for many years unlike for lower lying regions (1200-1300 m a.s.l.)(Gold et al., 2002). Plantations as old as 50 years have been reported to be common in these high altitude regions (Bekunda, 1999). With climate change, anomalous dry seasons, and increased demand, the life time of a plantation will also be reduced. This has implications for our proposal targets for variety adoption. In new cultivation areas, banana introduction will affect gendered divisions of labour as labour requirements of banana differ from those of most seasonal or annual crops. This is not necessarily negative but will inevitably be taken into account. The same holds for revenues from bananas; although harvest peaks occur in specific months in the year, harvesting and thus income generation is possible year-round. This has potential to considerably alter household income generating patterns.

Women and men might have differential preferences for specific banana varieties and traits. Where traits associated with market demand might be more important for men, cooking time might be a more important criterion for women. Gendered trait preferences of farmers will be taken into account during screening and selection. From the previous project, we have obtained evidence that female-headed households had less banana cultivar diversity compared to male-headed ones, stressing the need to conduct a detailed gender disaggregated analysis to understand the underlying reasons why this might be the case (Marimo et al, in preparation). Female-headed households may lack or have less access to resources, information, and planting material required to diversity.

In order to contribute to changing ideas about gender equality and appropriateness of women's engagement in male-dominated domains such as agriculture and bio-technology, this project proposal seeks to engage at least 50% women as partners and students.

Barriers to adoption of research outcomes

Our research involves the introduction of new climate smart varieties, therefore it is necessary to identify potential anticipated context specific barriers for implementing the research activities at all the stages and for all stakeholders in the target areas. This will help us to recommend mitigating measures. Implementation and adoption of our research outcomes will depend on various stakeholders which include farmers, local partners and local authorities.

Adoption of new innovations is dependent on various factors at the individual, household, community and institutional level (Marimo et al., 2020). Barriers include economic (e.g land size), social (e.g demograpic characteristics, social networks), institutional (information access, extension, policies), characteristics of the technology (costs vs. benefits) and agro-ecological factors. The diffusion and use of new technologies such as new crop varieties in smallholder farming systems can be slow due to vegetative propagation, low mat replacement rate and informal seed systems as the dominant sources of planting material (Kilwinger et al., 2020). Supply of clean planting material coupled with good agronomic practices is a necessity to warrant expected yield gains. In order to enhance adoption, continuous training and monitoring of farmers needs to be embedded in the dissemination process (Faturoti et al., 2006).

To deal with these barriers we will take the following actions:

1) Use of participatory mixed methods to understand the context and needs of heterogeneous end users in terms of varieties and planting materials.
2) Citizen science approach to increase the likelihood of adoption: the tricot approach allows to elicit farmer preferences for varieties under different climatic and socio-economic conditions. We will create a rich database using a citizen science approach that allows systematic analysis of variety performance and farmer preferences. The tricot approach introduces a participatory and more people-centred approach for innovation adoption and learning
3) We will combine the systematic data analysed through the citizen science data with "thick data": in-depth qualitative case studies will allow us to understand in a more nuanced fashion possible barriers to adopting new varieties among the different research sites and will give us a clearer picture about the challenges for the future seed system.
4) Using a citizen science methodology allows to reach and involve a more diverse set of farmers in the experimental data generation (Van De Gevel et al., 2020).
5) We have a multidisciplinary and gender-balanced team. We are working with national partners which will ensure that the ownership of solutions and innovations developed under this project will stay in the hands of national partners.
6) All our research products are public goods.

Sustained multidisciplinary collaboration is extremely important to understand the local context, exchange vital information and methodologies that will be essential in achieving the proposed outcomes.

Budget

The Alliance between Bioversity International and CIAT will coordinate this project in collaboration with KU Leuven and the NARS (NARO Uganda, TARI Tanzania).

Details	Year 1 2022	Year 2 2023	Year 3 2024	TOTAL BUDGET in EURO
Personnel	50,641	54,668	143,236	248,545
Supplies and Services	5,000	15,000	22,000	42,000
Training	10,000	-	-	10,000
Staff Duty Travel	3,000	5,000	5,000	13,000
Collaboration and Partnerships	175,000	168,000	53,000	396,000
Research Support Services	9,019	9,685	25,563	44,267
Facilities, IT	2,992	3,299	6,853	13,144
Indirect Costs	38,348	38,348	38,348	115,044
CSP 2%	6,000	6,000	6,000	18,000
TOTAL	300,000	300,000	300,000	900,000

Monitoring, evaluation and learning

Bioversity International is instituting a results-based management monitoring system, integrated into the One CG. The proposed project will fit within this system. This project is cross-referenced to the initiative Genebank within Genetic Innovation. The purpose of project monitoring is project learning and improvement, ensuring that the project is on track towards outcomes. Bioversity will present annual reports to DGD and include information on the project in reporting to the One CG Platform.

Upon project approval and inception, Bioversity, KU Leuven, and other project partners will verify and refine the indicators and targets. Monitoring data collection will be rolled down to project partners through Letters of Agreement for capture in Annual Technical Reporting, as well as integrated by Bioversity International into the overall project report.

Objective statement	Indicative Indicators	Targets and means of verification	Critical assumptions
Long-term impact in 10 years: Farmers of diverse social groups in drought-prone areas of the African Great Lakes region benefit from closing the banana yield gap.	Rate of adoption of the promoted cultivars per different established household types (based on gender household head and other social / farm characteristics) Expansion of the area under promoted cultivars in targeted, drought-prone areas	Farmers from diverse social groups in targeted areas commence or expand banana production with promoted cultivars by 20 % Method: Establishment of Household typologies on basis of baseline data; preliminary impact assessment at the project end	Extension workers and others who extend information to farmers about planting material and production practice, where such services exist, have adapted the climate smart varieties. Seed systems assess multiply and distribute the materials. Preliminary Impact Assessment subject to separate fundraising for after the project closes, therefore obtaining funding is a critical assumption for delivering the assessment.
Output 1: Local valuable diversity has been identified, collected and phenotyped.	Ranking of the growth potential of 50 banana genotypes under simulated dry highland conditions and identification of the climate smart varieties	Project records At least one publication	Countries and NARs are willing to exchange germplasm under the Plant Treaty or Nagoya protocol.

Objective statement	Indicative Indicators	Targets and means of verification	Critical assumptions
Output 2: Gaps are filled in the ITC collection and climate smart varieties are safely conserved.	The number of ITC accessions coming from the Great Lakes region that are characterized and phenotyped have increased.	Project records MGIS platform	Countries and NARs are willing to exchange germplasm under the Plant Treaty.
Output 3: Climate smart growth models validated in the field	Field validation of climate smart varieties Breeders and farmers have access to technical guidelines for field management.	Project records At least one publication	Data collection can be performed throughout the experiment
Output 4: Potential new climate smart varieties have been evaluated by farmers in the TRICOT approach	Number of farmers reached, number of varieties evaluated, number of varieties with potential for adaption	Project records At least one publications	A sufficient amount of farmers is willing to participate in the public experiment.
Output 5: New knowledge shared with breeders, researchers, agro-dealers and extension workers in the Great Lake Area	Improved understanding (over baseline) of the impact of climate change and mitigation possibilities	State of art statement at inception and final reporting Video capsule Factsheet to be distributed to extension services and farmer’s associations Number and gender of participants trained (sign-up sheets)	Continued demand from breeder/researcher/suppliers and farming communities in Great Lakes region

Objective statement	Indicative Indicators	Targets and means of verification	Critical assumptions
		Number and gender of students (and MSc and PhD dissertations) Scientific databases and information systems are up to date with data and information generated by the project	

PERIODS: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

WP	ACTIVITY	PLAN START	PLAN DURATION
1	**Baseline gender assessment of trait preferences and selection of potential local varieties**	1	12
1	**Collect and multiply a strategic subset of the local varieties**	8	14
1	**Climate simulation and phenotyping**	12	24
2	**On field phenotyping for 2 crop cycles**	1	36
3	**Multiplication and distribution of climate smart varieties**	1	12
3	**Farmer network training**	1	12
3	**Citizen science data aquisition**	12	24
3	**Data analysis**	24	12
4	**Farmer schools**	12	24
4	**Training in situ conservation**	1	15
5	**Coordination and Data management**	1	36

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