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Andean potato diversity conserved in the International Potato Center genebank helps develop agriculture in Uganda: The example of Victoria

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From the Andes to the East African highlands

Potato (*Solanum tuberosum*) is native to the Andean region of South America, where its wild relative species and cultivated varieties are enormously diverse (Srivastava et al. 2016). Potatoes have adapted to an immense variety of habitats, and have developed various levels of resistance to biotic and abiotic stresses. This diversity has become extremely valuable to potato breeders who can capitalize on it for varietal improvement.

HIGHLIGHTS

- Two of the ancestors of Victoria, a popular improved potato variety in Uganda, are the wild relative species *Solanum bukosovii* and a Peruvian landrace belonging to the species *S. tuberosum* sub. *andigenum*.
- Based on the Relative Contribution of Provenance, the CIP genebank contribution to Victoria is 72%.
- The gross estimated benefit of Victoria in Uganda is $1.04 billion dollars in 2016 US$ over a 25-year period (roughly $42 million per year).
- The total cost of running the genebank to conserve 16,718 accessions of potato, sweetpotato, and Andean roots and tubers is estimated at only $4 million per year, a fraction of the gross economic benefits derived from a single variety in one country.

The example of the potato variety Victoria illustrates how the genebank of the International Potato Center (CIP) enabled breeders to incorporate this diversity into an improved variety that benefits small-scale farmers as far away from Peru as Uganda. The CIP genebank safeguards potato germplasm, protecting it from loss and making it available for breeders and scientists. A large part of the CIP genebank materials have been available since 1972 and many accessions have been the source of desired traits for potato breeding.

The varieties developed have been used not only in South America, but also in Asia and Africa where potatoes have played an important role.

Demonstrating the benefits generated by CIP genebank activities in farmers'

BOX 1 The International Potato Center (CIP) Genebank

The International Potato Center (CIP) contributes to making the diversity of potato, sweetpotato, and other Andean roots and tubers available for food security. The CIP genebank, located in Lima, Peru, holds an *ex situ* collection composed of wild relatives, landraces, advanced lines, and improved varieties. The CIP genebank has one of the largest *in vitro* collections in the world, which is maintained and distributed thanks to the genebank know-how. Germplasm is distributed for research, training, and breeding, using the Standard Material Transfer Agreement (SMTA).

The CIP genebank employs various conservation strategies to conserve true-to-type potato germplasm. Potato plants produce true botanical seeds (coming from fruits) that are easily conserved, but the traits of the plants are extremely variable compared to their mother plant. On the other hand, potato tuber seeds are identical to the mother plant (clonal), but their conservation for very long periods is not feasible. Due to this scenario and to the importance of having true-to-type germplasm for different traits, the CIP genebank uses seed conservation, cryopreservation, and *in vitro* conservation and propagation. These strategies consist of processes that follow high-quality standards that guarantee the current and future availability of diverse true-to-type and pathogen-free potato germplasm.

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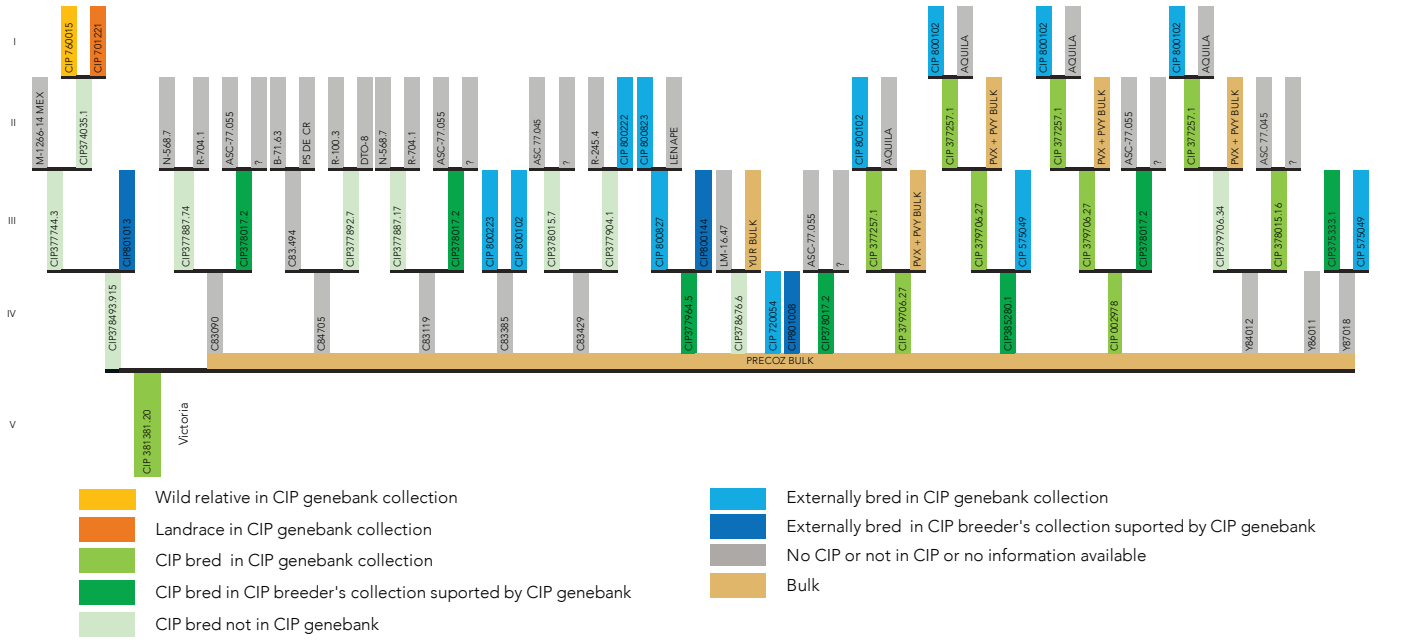

Figure 1. Pedigree of Victoria (CIP 381381.20). Source: Authors, based on CIP's pedigree book database.

fields poses challenges. The scarcity of detailed biological, agronomical, and historical information about the plant materials used in lengthy breeding processes makes it difficult to trace the germplasm's contribution to a new variety. On-farm yields are also influenced by multiple, confounding factors other than the new variety.

Robinson and Srinivasan (2013) calculated a large economic benefit from the use of the improved variety Cooperation-88 in China, but their effort included pedigree information that allowed only confirmation of an affiliation with the CIP genebank. Thiele et al. (2008) estimated a rate of return to CIP's investment in potato breeding of about 15% (in 1997) and 20% (in 2007), considering that a substantial part of the benefits was likely due to disease resistance traits present in the new varieties. They also recognized the role of the genetic materials carrying desired attributes (late blight resistance, high yield, market acceptance, cooking quality) as an important factor that may contribute to increase the area under a new variety. However, this study does not identify the benefits due specifically to the contribution of conserved germplasm.

In this study, we build on past work by employing a combination of detailed biological data, pedigree information, and an economic surplus model to estimate the contribution of accessions conserved in the CIP genebank to the economic benefits of growing the improved variety Victoria on farms in Uganda. Uganda is only one of the countries in sub-Saharan Africa where varieties based on the same germplasm as Victoria have been adopted under different names.

Figure 2. Victoria on a field in Uganda and harvested Victoria tubers. Photos: Pieter Wauters

Synopsis of methods

Victoria is an improved variety that corresponds to the clone CIP 381381.20 developed by CIP breeders in Peru. The pedigree for Victoria was constructed with the help of records provided by breeders considering only the period between the CIP genebank origin and 1981, the year the clone was developed. We evaluated the affiliation of each ancestor in the pedigree to the CIP genebank, and defined eight categories excluding "bulk" (Figure 1). Six out of the eight categories present a direct affiliation, which occurs when the germplasm of the ancestor is in the genebank's collection or its conservation is supported by the genebank.

Categories were used as criteria to calculate the contribution of the genebank using the Relative Contribution of Provenance (RCP) algorithm. The RCP quantifies the portion of the different categories that make up the attribute of "provenance" for a specific variety under the principle that each of the parents in each generation contributes half of the attribute. Provenance is related to origin or affiliation, such as a geographic region or a genebank. Although RCP gives an idea of the relative genetic contribution, it does not correspond to an absolute value because it does not account for bias like artificial selection from the breeding process. Applying the RCP algorithm and considering CIP genebank affiliation as the evaluated category, we then calculated the proportion of the contribution from the CIP genebank to Victoria based on its ancestors' affiliation to the

BOX 2 The Genebank Impacts Fellowship

The 2018 Genebank Impacts Fellowship program has been one of the most enriching experiences of my career. It has allowed me to explore how the use of conserved biodiversity can support international development. I had the opportunity to receive the guidance of several advisors from distinct disciplines at CIP, Virginia Tech, and the Crop Trust, and to interact with stakeholders with considerable knowledge and experience. The fellowship helped me appreciate how international collaboration is working to have a positive impact on the agriculture sector and food security.

I visited the CIP in Peru and received a warm welcome by the genebank and the social sciences group. The CIP genebank staff allowed me to immerse myself into genebank operations such as collection, identification, conservation, characterization and distribution of potato, sweetpotato, and other Andean roots and tubers germplasm. CIP genebank staff work with great dedication and passion to keep the CIP genebank as a world repository and reference for germplasm conservation and availability for breeding, research, and training. This work has a final goal of improving farmers' adaptability to a changing world and global food security.

As part of my project, I reconstructed and followed the flow of potato germplasm from the field in the Andes to the agriculture sector in Uganda. I learned of how Andean communities have a dynamic dialogue with the CIP genebank that allows for an exchange of potato germplasm. I saw first-hand how the genebank obtains this germplasm and identifies, conserves, and characterizes it by employing various biological methodologies (Figure 3). I also learned how CIP breeders use this germplasm and partner with the genebank to maintain, clean and distribute materials.

I could see in my visit to Ecuador how CIP genebank and breeders work together to provide new improved varieties to agricultural national programs of other countries (Figure 4). Additionally, thanks to the special guidance of George Norton at Virginia Tech (USA), I was able to connect the germplasm developed at CIP to an international economic context. We analysed the economic benefits produced by the adoption of one specific potato germplasm to the agriculture sector in Uganda. This experience has expanded my perspective, provided me tools to innovate in my professional path, and inspired me to work for improving food security.

Figure 3. Vivian Bernal and Ana Panta, Leader of the In-vitro conservation division at CIP genebank. CIP genebank maintain potato clones in the *in vitro* collection, which is disease-free conserved material that can also be distributed internationally.

Figure 4. Fripapa (CIP388790.24) is a potato variety developed by breeders at CIP Lima and conserved and distributed by the CIP genebank. It is currently planted in Ecuador.

CIP genebank and the relationships evidenced in the pedigree.

Applying an ex post model of economic surplus, we then estimated the gross economic benefits of Victoria in Uganda based on its adoption path over time, yield advantages compared to other cultivated potato varieties, and the economic value associated with productivity gains. Yield gains were based on farm survey data (Kaguongo et al. 2008). Information about market- and Uganda-related parameters, such as potato yields, agricultural gross production value, quantity of production, harvested area, and Uganda population changes, were collected from FAOSTAT and World Bank databases. Potato prices for Uganda were calculated based on the value of agricultural gross production and production quantity data.

Main findings

The total contribution of provenance of germplasm from the CIP genebank to Victoria is 72%, with the remaining 28% corresponding to germplasm that was not affiliated with the genebank (Figure 1). Among Victoria's ancestors, going back five generations, we also identified two of the ancestors of Victoria as wild relative species *S. bukosovii* (CIP 760015) and a Peruvian landrace belonging to the species *S. tuberosum* sub. *andigenum* (CIP 701221). Both are conserved and maintained in the CIP genebank.

The potato germplasm known as Victoria was released in Uganda in 1991 (Figure 2). The same germplasm has been distributed, released and cultivated under different names in several other African countries including Kenya, Congo, Rwanda, Madagascar, Burundi, and Malawi. Victoria's high yield, early maturity, and good marketability resulted in a high adoption rate (estimated at 53% of potato-growing area) after 19 years in the field (Kaguongo et al. 2008; Walker and Alwang 2015).

We estimate that the gross economic benefit of Victoria in Uganda was US$ 1.04 billion (2016 US$) over a 25-year period, corresponding to roughly US$ 42 million per year. Our method does not consider associated costs such as genebank, breeding, or extension costs, nor does it consider benefits from adoption in other countries or use values other than yield advantage. We estimate that 72% of the portion of the economic benefits earned on farms in Uganda from growing the improved variety Victoria are due to the CIP genebank contribution. By comparison, the current annual cost of operating

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the genebank (US$ 4 million) is less than a tenth of the economic benefits derived from a single variety in one country.

Conclusion and future considerations

This example highlights how conserving genetic resources in the CIP genebank plays a key role in the agricultural development of lower-income, potato-producing countries such as Uganda. The contribution of the genebank to the economic benefits of adopting a single potato variety in a single country far outweighs the annual costs of operating the existing collection. There are numerous improved varieties like Victoria and Cooperation-88 that include important genetic contributions from the CIP collection.

Complementary and more exhaustive studies could be conducted by making available more detailed information about a new improved variety of interest. Further historical information about the breeding process together with detailed biological information, such as the absolute genetic composition of the germplasm used – preferably associated with a trait description – would help to calculate a more precise ancestral contribution with more robust biological significance. Additional information about adoption, including the attributes that the variety presents in the field, in addition to yield, would provide insights into other types of benefits. More complete data about applied strategies, such as extension or seed program, and associated costs of the related processes, would help to estimate net economic benefits more accurately.

Further reading

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Additional details can be found in the paper on which this brief is based: Bernal-Galeano, Vivian, George Norton, David Ellis, Noelle L. Anglin, Guy Hareau, Melinda Smale, Nelissa Jamora, Jeffrey Alwang and Willy Pradel. 2019. Andean Potato Diversity Helps Agricultural Development in Uganda: Victoria and the Contribution of the CIP Genebank. Genebank Impacts Working paper No. 6. CGIAR Genebank Platform, CIP, and the Crop Trust.

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