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Revival and Survival of Repatriated Potato Landraces in the Andes – On-farm Maintenance and Benefits

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Abstract

Potato landraces (*Solanum* spp.) are not only crucial for food security and sustenance in Andean communities, but also deeply rooted in the local culture. The crop originated in the Andes, where a great diversity still exists despite the loss of certain landraces. Local communities and the genebank of the International Potato Center (CIP) partnered to re-establish some of these landraces by supplying clean seed potato to farmers. Over time, the genebank formalized a repatriation program, which is unique regarding its format and frequency. Repatriation is the process of returning native germplasm back to its place of origin, allowing a dynamic exchange between *ex situ* to *in situ* conditions. Between 1997–2020, 14,950 samples were distributed to 135 communities. So far, no comprehensive description of CIP's repatriation program, the changes it induced or its benefits, has been carried out. We address this research gap by applying duration and benefit analyses to a survey dataset of 301 households. While most household (56%) have abandoned the material in the fourth year after receiving it, the *in situ* survival of the material stabilizes in later years. Households headed by adults over 60 years are more likely to plant the landraces for longer times. Also, higher education, labor force, wealth, food insecurity and a location in the Southern part of Peru increases survival times. Most farmers reported nutritional and cultural benefits as significant reasons as to why they maintain the landrace material. The repatriated potatoes enable farmers to conserve potato diversity and hence re-establish and broaden culinary diversity and traditions. Our study provides an evidence base for continued support and funding for repatriation, supporting food security and livelihoods in the Andes and beyond.

Keywords

Peru, potato landraces, repatriation, International Potato Center, genetic diversity, agrobiodiversity, food security, household survey, duration analysis, survival, benefits, impacts

Suggested citation

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Contents

1. Introduction and motivation

Potato landraces (*Solanum* spp.) are not only crucial for food security and sustenance in Andean communities, but also deeply rooted in the local culture. The crop originated in this region and a great diversity evolved and is found there. Landraces of potato are locally adapted genotypes that are conserved by farmers in heterogenous Andean conditions. However, over time, these smallholder farming communities lost some landraces due to various reasons such as susceptibility to biotic and abiotic stresses, climate change, and terrorism (Ellis et al. 2020). The idea to return lost landraces to their places of origin evolved from the long-term partnership between the genebank at the International Potato Center (CIP) and the Andean smallholder communities which began in the 1990s. These redistribution activities are termed repatriation at CIP and have the primary goal for farmers to recover their lost landraces. The desired results are the improvement of food security and a general increase of infraspecific potato diversity managed on-farm amidst the local knowledge, traditions, and landscape in which the material evolved. To date, these activities, which started in 1997, evolved to a broader program which became part of the routine genebank work at CIP. Based on conversations with CIP staff, the repatriation program provides many benefits to the receiving communities, particularly culinary and cultural benefits (Anglin 2020; Ellis et al. 2020; Gomez 2020; Gomez 2020).

Our work is the first systematic description of the implementation, outcomes, and impacts for participating farmers of the potato repatriation program since it began 24 years ago. In this paper, we describe CIP's repatriation activities and document evidence of outcomes and impacts to farmers, including farmers' utilization of the repatriated materials.

Earlier studies modeled the choice to plant landraces in a static, applied economics framework (Meng 1997; van Dusen 2000). Other studies compiled and analyzed the large infraspecific diversity in Andean potato-intensive farming systems (de Haan 2006; de Haan 2009; Ochoa Neves 1990) or analyze the reasons for landrace loss on farmers' fields (Brush 1992; Brush 2004; McLean-Rodríguez et al. 2019). McLean-Rodríguez et al. (2019) underscore that it is crucial to understand the reasons behind *in situ* landrace loss at their centers of origin to pursue effective conservation strategies. McLean-Rodríguez et al. (2019) examined landrace abandonment over a 50-year period but could not model the on-farm survival of landraces over time. Instead, they used interviews and focus group discussions to investigate the loss process. They found that various interconnected changes in cultivation technologies, commodity markets, agricultural and land policies, cultural preferences, urbanization, intergenerational knowledge transfer gaps, and climate change, have created an disadvantageous environment for landrace maintenance (McLean-Rodríguez et al. 2019).

To overcome these research gaps and contribute to the literature about on-farm conservation of landraces, we first present a comprehensive description of the repatriation activities to date, drawing on passport data of the repatriated landraces and the expertise and experience of CIP staff. As a second step, we analyze a household survey that was designed to investigate outcomes and impacts from the program. We apply a duration model to identify household and community factors that influence the survival of the repatriated landraces on farms. Significant factors indicate which farmers are more likely to maintain the material for longer periods of time after the repatriation takes place. Long-term maintenance by farmers is a prerequisite for *in situ* conservation of landrace diversity and ultimately leads to an enhanced outcome of the repatriation. Further, *in situ* conservation ensures that the material remains at its place of origin so that it can adapt to new environmental conditions and local agricultural systems. Also, with long-term maintenance, the material remains in the local seed systems and can be further distributed throughout the local community. Finally, we present results from a benefit and change analysis. Here, we investigate the changes brought about by the repatriations to Andean smallholder farmer communities and their individual members. This analysis will further explain why farmers maintain and abandon the repatriated material and hence provide valuable insights on how the repatriation program produces benefits and how these benefits can be enhanced and upscaled.

We describe in the next section the repatriation activities carried out by the CIP genebank and its setting. Then we describe the data and methods in section 3. We present the findings for the genebank data analysis, duration model, and survival analysis, as well as the benefit and change analysis in section 4. Finally, these results are discussed section 5, before drawing conclusions and presenting possible ways to improve on CIP's repatriation program.

2. Background and research objectives

2.1. The concept of repatriation and dynamic conservation

The term *repatriation* is generally used to describe the redistribution of material from international or foreign genebanks to national genebanks. In the CIP context, it also refers to reintroducing landrace germplasm from the CIP genebank to their places of origin in the Peruvian Andes (Gomez 2020). The recipients are farming communities or local community genebanks. Thus, CIP's approach combines the definitions of *repatriation* and *rematriation* as defined in Ocampo-Giraldo et al. (2020). Within this context, the CIP genebank also engages with the community of indigenous farmers who will cultivate the material *in situ* and co-create a nurturing environment for the use of the landraces for inclusive and sustainable development. The cultural value plays a crucial role in these activities.

Such a dynamic model of *ex situ* and *in situ* conservation has a large intellectual legacy. Berthaud (1997) describes it as a modified version of the previously dominant linear model which means it was just a direct transfer from *in situ* material to *ex situ*. It is modified in such a way that interactions arise between conservation, evaluation, and utilization. This means that *in situ* conservation by farmers allows evolutionary forces, as selection and mutations can happen and hence new diversity is developed (Berthaud 1997). Smale, Bellon and Aguirre Gómez (2001) discuss the private and social value of landraces, emphasize the importance of both *ex situ* and *in situ* methods of conservation, and underline that *in situ* landraces continue to evolve due to human management and environmental changes. Negri and Tiranti (2010) assess the effectiveness of *in situ* and *ex situ* conservation methods and note that *in situ* conservation is the most effective way to conserve the diversity, which is present in a landrace's population, particularly because it allows evolutionary processes to occur and corresponding local knowledge systems to adapt. Nevertheless, the authors also highlight that *ex situ* conservation is the best option *if* it is not possible for the farmer to conserve the landraces *in situ* (Negri and Tiranti 2010).

The dynamic conservation model has been increasingly accepted and promoted starting with the works of Bellon, Pham and Jackson (1997) and Ortega (1997) in Maxted, Ford-Lloyd and Hawkes (1997) as well as Meng, Taylor and Brush (1998). Ocampo-Giraldo et al. (2020) recently described the dynamic model for maize landraces. Despite the growing literature, the incentives for smallholder farmers to grow landraces are not well understood and multiple researchers have explored this issue (McLean-Rodríguez et al. 2019; Meng 1997; Smale, Bellon and Aguirre Gómez 2001; van Dusen 2000). Brush, Taylor and Bellon (1992) were the first researchers to investigate on-farm crop diversity. Their work is an important basis for analyzing the *in situ* conservation of repatriated landraces.

2.2. The repatriation program at the International Potato Center

CIP's repatriation process embodies a dynamic and circular model of *ex situ* and *in situ* conservation (Figure 1). The sketched flow is continuous and the cycle between *ex situ* and *in situ* conservation is followed each year, while some activities occur simultaneously. The graph could be divided into two circles: (1) the large circle on the left hand-side describes the exchange between the CIP genebank and the Andean communities participating in the repatriations and (2) the smaller circle (in orange) represents the tuber multiplication, which occurs between the CIP genebank and the community of San José de Aymara, located in the Andean highlands.

The large circle starts with a formal written request of a community authority to the CIP director, genebank manager or potato curator. Then the potato curator and his team (or the repatriation team) review the request and initiate the administrative process. They check which accessions are collected from that region and the availability of tubers for repatriation in the genebank. In general, the repatriation team contacts the requester or people in the community to build a communication bridge with the community and understand the community's perspectives. They also advise about the suitable land area where the landraces will thrive based on the information provided by the community. In addition, the communities must agree to make the materials available for redistribution to all households in the community. Then the materials for repatriation are prepared and are either picked up (Figure 2) or sent to the Andean communities before the potato growing season starts in the Andes. Usually, 8 to 10 tubers are redistributed per landrace, but when there are supply constraints, five tubers are sent instead (Gomez 2021). After receiving the materials, the communities organize the communal multiplication of the material and the corresponding division of labor and plots. When the community has multiplied enough tubers, they are redistributed to individual farming households for inclusion in their own potato planting portfolios. When extreme events such as strong hail or rains occur during the cultivation period, the potato curator will usually call the participating communities to inquire on the status of the repatriated materials and give technical advice if needed.

The lower large arrow describes the flow of material between the *in situ* and *ex situ* conservation. Here it is important to note that the exchange is indispensable for the repatriation program. Since certain potato varieties have been grown in their place of origin for over 10,000 years, the Andes (Hawkes 1988; Popenoe et al. 1989) and therefore Andean farmers have conserved the landraces over time. Potato experts, among the CIP staff, have undertaken many collection trips over the last decades, for example the collections of Alberto Salas, Vargas Calderón (1949), Ochoa Neves (1990) and de Haan (2006), Sotomayor et al. (in preparation). These collections make up CIP's landrace accessions. Nowadays, landrace cultivars are occasionally donated by farming families to CIP genebank. Even the repatriation program has let to build alliances with small farmers communities as *Parque de la Papa* (Potato Park), Grupo Yanapai which have led to projects estimating genetic diversity on farms allowing the identification and fulfilling of genetic gaps in the CIP collection, generation of true seed from small farmers that was deposited in the Svalbard vault, performing crop management trainings and evaluations of growing conditions in elevated lands and given visibility to the program.

The small circle describes the repatriation work that is necessary to prepare the material for redistribution. The genebank prepares the pre-basic material by planting in vitro material in its greenhouses to produce mini tubers. They are then used for planting on potato plots to finally produce the tubers for repatriation. The final multiplication is occurring jointly with the community of San José de Aymara located at about 4,000 m.a.s.l. in the province of Huancavelica in Peru. The high altitude of the community ensures less biotic stressors for the material, and hence, facilitates the growth of healthy material for distribution. CIP genebank staff transports the mini tubers to this community and brings back the harvested potatoes. Because the multiplication process requires both labor and supplies costs, the number of accessions multiplied for repatriations depends on material or resources from genebank routine activities for material characterization or evaluation or side projects that, for example, evaluate specific traits such as late blight resistance. Thus, potatoes for repatriation can come from routine projects – harvest of material planted for characterization or evaluation or as efficient use of resources from side projects as core collection characterization, evaluations of late blight resistance, or evaluation of other traits.

CIP's repatriation team conducts the cultivation together with trained community members. At the end of the multiplication process, the most suitable and promising landrace cultivars are selected. These are then transported back to the genebank where they are post-harvest processed and checked. It is of uttermost importance that the starting *in vitro* material is virus-free to avoid further contamination in the receiving communities. The available material for repatriation marks the starting point of the big circle, the genebank sending the clean material to participating Andean communities. Most repatriation activities are part of the general genebank work and the annual costs are estimated at below 5,000 USD (Ellis and Anglin 2021). (Figure 1)

In 1997, the first repatriation effort by CIP started when a group of farmers participating in a local potato fair contacted the genebank to help them quantify the level of available potato diversity in their communities (Gomez 2020). Within this context, the idea of redistributing healthy landrace germplasm back to the places of origin and establishing community seed banks for *in situ* conservation evolved dynamically in dialogues with CIP staff and Andean farmers (Huaman et al. 2000). In 1999, the term repatriation was used for the first time in an internal CIP report (CIP 1999) documenting the redistribution of potatoes to Peruvian farmers. The repatriations started by redistributing virus-free tuber landraces from specific geographical areas to communal seed banks (CIP 2000). This process aimed at reinforcing *in situ* conservation (Huaman et al. 2000), improving the phytosanitary quality of native potatoes and restoring cultivars lost by farmers (CIP 2000). Endemic potatoes are redistributed back to their places of origin. This means that many repatriated varieties are strongly associated or tied to the cultural or ancestral heritage of the receiving communities. The *ex situ* potato collection in the CIP genebank is held *in trust* under the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and this germplasm is freely distributed under the terms of the ITPGRFA for research, training, and breeding, to *Papa Aririwa* (potato guardians) as well as to farmers who traditionally cultivate the crop. At CIP, repatriation of germplasm to the places of origin furthers the goals of ITPGRFA and directly targets low-income communities in need of healthy and appropriate ancestral germplasm for food security and income diversification.

Between 1997 and 2020, 14,950 landrace samples, including 1,519 unique landrace cultivars, were distributed to 135 communities in the Peruvian Andes (CIP 2021a).[1] These distributions represent over 50% of the active accessions that were originally sourced from Peru (CIP 2021a). Most landrace samples were distributed to the department of Cuzco (7304), followed by Puno (1409), Ancash (1311), and Huancavelica (1205). Figures 3 to 6 as well as Tables 1 and 2 summarize the genebank data on the repatriated accessions and participating communities (p. **Error! Bookmark not defined.** ff.).

The benefits which can be induced by the repatriation to indigenous farmers and their communities are generated through various short-, medium-, and long-term mechanisms.

- Short-term: The reintroduction of healthy potato landraces replaces exhausted seed stocks (disease laden) and hence improves food security, productivity, and poverty alleviation (CIP 2020; Ellis et al. 2020).
- Medium-term: Repatriated potato landraces increase or restore the diversity and variability of potato stocks (CIP 2020; Ellis et al. 2020), thereby increasing the insurance value for farmers (see Smale and Jamora 2020). For centuries, indigenous farmers have cultivated a large number of potato landraces per family as an insurance policy to various stresses on farms (Ellis et al. 2020; Smithson and Lenné 1996). Such a genetically diverse array of landraces which are tolerant or resistant to biotic and abiotic stresses can also mitigate climate change impacts (CIP 2020). Also, the community receives landraces that are deeply rooted in their culture and traditions and thus constitute a cultural benefit.

[11] As of February 2021, the CIP genebank has 7,466 cultivated and wild potato accessions (CIP 2021b). Of these 4,870 are cultivated and 2,596 are wild. The number of active landraces in the CIP collection is 4,467 of these 3,427 are currently available for distribution. Over time the CIP genebank has repatriated 1,519 of all landrace accessions. These numbers also include landraces from other countries of origin.

For Peru, the potato landrace collection currently holds 2,854 active accessions of Peruvian origin, of which 2114 are available for distribution. And over time 1,498 have been repatriated by the here analyzed repatriation program (CIP 2021b). These numbers are dynamic because of the continuous genebank operations.

- Long-term: Benefits are generated through landraces' option and existence values (Bellon 2009; Smale 2006). Repatriation puts potato landraces back in their location of origin, thus re-establishing the open decentralized genetic and social-biological systems in which landraces, environment, and communities constantly evolve (Bellon 2009; Kontoleon, Pascual and Smale 2009).

2.3. Potato production and livelihoods in the Andes

The Andean region is one of the principal centers of crop origin (Vavilov 1951) . Many roots and tubers suitable and not suitable for human consumption originated there. Among these is the potato (*Solanum* spp.). It is the fourth most important food crop behind maize, rice, and wheat and for approximately 10,000 years potatoes have been grown in the Andes (Hawkes 1988; Popenoe et al. 1989). Domesticated tubers of this genus belong to different species having a myriad of shapes, colors, textures, tastes as well as agronomic and nutritional traits. Also, on a global scale, the highest agrobiodiversity levels are present in farm ecosystems and surroundings managed by smallholder farmers or indigenous communities (Jackson et al. 2012). Due to its different altitudinal belts, potato production systems in the Andes have very heterogeneous growing conditions (Arce et al. 2019; Mayer and Fonseca Martel 1979; Scott 2011). Andean farmers commonly have four types of field plantings: single stands of improved cultivars (1), single stands of commercial floury landraces (2), single or mixed stands of bitter landraces for freeze drying (3) and completely mixed stands of floury landraces (4) (de Haan 2009). The third type refers to potatoes that are used for traditional processing such as *chuño* (freeze dried potato). It is a traditional way of preserving specific bitter potato landraces that grow in farmers' highest altitude potato parcels for times of harvest failures (Burgos et al. 2009; de Haan 2006) and the process also maintains micro-nutrients such as iron and enhances calcium concentration (Burgos et al. 2009). The third and fourth type of plantings are commonly called *chaqru*, a Quechua language term, indicating that they consist of a mixture of potato landraces with different shapes, colors, agronomic, nutritional, and traditional traits. This means that they contain various potato species with different ploidy levels (Bellon 1996; Brush 2004; de Haan 2009; Jackson et al. 2012). This concept of planting a wide variety of potato cultivars in the same plot is crucial to understand - Andean potatoes farmers desire to maintain or abandon landraces. *Chaqru* is their risk management strategy to maintain food security in a no input farming systems, as the landraces included in such mixtures have different levels of resistances and tolerances to abiotic and biotic stresses and also each landrace has different culinary and traditional aspects. Andean small holder communities are very dependent on the potato crop and therefore it is of uttermost importance for their food security to have a minimum harvest or enough stocks of processed potatoes (Bellon 1996). The repatriations add, recover, or revitalize accessions of each households' and communities' potato landrace portfolio. The repatriated landraces are redistributed as mixtures and hence also multiplied as such. The choice of landraces for each *chaqru* is influenced by agronomy, culture, demography, time, space and individual characteristics such as gender and age. Arce et al. (2019) found that the landrace diversity amongst Andean smallholder farmers is multifaceted, but unequally diffused across different landscapes (Arce et al. 2019).

Agriculture and potato production are the main livelihood pillars in Andean communities. Therefore, it is deeply rooted in the processes and cooperation within communities. Apart from their individual fields, which are maintained by all members of the farming household, farmers participate in communal activities such as communal crop plantings.

Repatriation provides an ideal setting to analyze the history and evolution of potato gene pools cultivated within the cultural and knowledge systems where they evolved (Negri and Tiranti 2010; van Andel et al. 2016). Previous economic studies about on-farm conservation of landraces apply an economic model to explain the decision to grow landraces (Meng 1997; Van Dusen 2000; Van Dusen, Gauchan and Smale 2007). Another perspective is taken on by studies that investigate the incentives that make farmers grow landraces, e.g. by increasing their market value or providing in-kind benefits for cultivating them (Dyer 2006; Krishna et al. 2013; Narloch, Drucker and Pascual 2011; Negri and Tiranti 2010). Bellon, Gotor and Caracciolo (2015) showed that in the Andes, those *in situ* crop diversity conservation projects were successful that also induced positive livelihood outcomes for the farmers. We model the on-farm survival time of repatriated landrace material and factors that influence it with a duration model. To the best of our knowledge no one has done this so far.

The work by Meng (1997) shows that farmers must choose diversity as a precondition for successful and long-term maintenance of landraces. Bellon et al. (2003) found that landraces must be carefully selected to increase their *in situ* survival.

The time variable in our duration model is the number of years from receipt of a bundle or mixture of repatriated landraces (re-introduction) to the last season in which a farmer plants these landraces. Zimmerer and Haan (2017) asked if repatriation flows of genebank accessions eventually reach the intended farmers, especially those affected by agrobiodiversity loss. Here we provide answers to this question by studying the on-farm survival times of the repatriated potato landraces and analyzed the factors that hinder long-term maintenance with a duration model. Further we analyzed what benefits repatriation brought to the farmers and their communities.

3. Data and Methods

3.1. Data

We employ two main data sources: (1) accession-level genebank distributions data on the repatriated landrace from 19970 to 2020; and (2), household survey data that were collected in 2018 with the purpose of investigating the changes resulting from the repatriations.

CIP genebank data provide information on each repatriated landrace, including accession number, DOI, cultivar name, taxon name, place, and year of repatriation, collecting site, genebank accession status, and reason(s) for the repatriation request. The data allow us to visually analyze the spatial and temporal distribution of the program (see Figures 3 to 6, Tables 1 and 2). A total of 14,950 landrace samples were repatriated from 1997 to 2020. The 135 communities that participated in the program received between 4 and 410 repatriated landrace samples each (Figure 4). Most landraces were repatriated to the department of Cuzco (Table 1).

The survey entitled "Survey on the most significant uses and changes related to repatriated potato landraces received by communities and families from the genebank of the International Potato Center" (original Spanish title: "Encuesta sobre Usos y Cambios más significativos relacionados a la papa nativa recibida por las comunidades y familias como Repatriación desde el Banco de Germoplasma del Centro Internacional de la Papa") was conducted during the second half of 2018 by CIP. For this survey, 301 household heads and community leaders who had participated in the repatriation program were interviewed in 65 communities, covering most of the communities that received repatriations (CIP 2018). These communities are located in 10 of the 26 departments or regions of Peru, which are the largest political and administrative structure in the country. The survey included farmers in 30 of the 196 Peruvian provinces, which are subdivisions of the departments. The survey data are thus considered to be representative of repatriation recipients.

Twenty-six questions with numerous sub-questions were asked to the farmers plus 14 optional questions. The goal of the survey was to create an evidence base of the changes induced by the repatriation program and to document how the repatriated landraces are used by farmers. The survey was conducted with prior informed consent (PIC) of the interviewees.

3.2. Methods

3.2.1. Genebank data analysis

We use the data from the genebank to explore patterns in distribution and to analyze accession-level information on the repatriated landraces. Text variables (e.g., the justifications for receiving reparations) were categorized and clustered in the most named categories. To complement the information from the database, the first author conducted six structured expert interviews with the principal curator for the repatriated accessions, Rene Gomez. These interviews were held from October 2020 to March 2021 and due to the global COVID-19 pandemic they were conducted via Microsoft Teams.

3.2.2. Duration analysis

We analyze the survival time of repatriated potato landraces in the farming households with a duration model. Survival is defined as the number of years that elapsed between the year when a farming household first received repatriated potato landraces and the year when this household does not plant the received landraces anymore. In other words, we consider for how long the repatriated material was planted, from re-distribution to its abandonment, by an individual farming household who participated in the program and was surveyed in 2018. The survival time is a mark of success for the repatriation program because the longer farming households cultivate the repatriated landraces, the longer the project impacts are sustained in the receiving communities and hence additional benefits can be gained.

For our analysis, the duration model consisted of two parts. First, we generated a Kaplan-Meier survival curve to estimate the baseline survival times. This stepwise function shows the probability that the repatriated landraces still survive in a farming household at a certain point in time. The Kaplan-Meier survival curve shows the proportion of surveyed households where the repatriated material survived in the given year. It can also provide information on so called censored items. These are farming households where the landraces still survived when the survey was conducted in 2018, but about whom we have no follow-up data that tells us if they still survive today, after the survey. It is important to note that the surveyed farming households participated in different years in the program. The repatriation program started in 1997 and since then, each year, many farmers received material through agreements between CIP and their communities. This can be seen in Figure 5. Therefore, we have, for example, households in the sample that received material in 1997, but also those who had participated for only one year when being surveyed. As a duration analysis is explicitly designed to analyze programs with censored items, it is possible to analyze the repatriation program with this model. As the survey explicitly asked for the survival time of the material repatriated by CIP and only farmers were interviewed who had participated in the program, our analysis cannot include the survival of repatriated material beyond the survey scope. This means that we cannot deduce information on the survival of originally repatriated material which was potentially exchanged with non-participants within a community or other people beyond the community. As the second step, we conducted a Cox proportional-hazards model (Cox 1972) to estimate the survival time and several predictor variables or covariates. This multivariate analysis shows us which household or community characteristics influence the survival time.

3.2.3. Model variables

Following the adoption literature, we used the following variables in the model (Table 3). In addition to the standard factors that are likely to influence varietal choice and potato diversity managed by Andean farming households, we added a variable that measures food insecurity. This is a key variable of interest because a major objective of the program is to improve the food security level of beneficiaries.

3.3. Benefit and change analysis of the perceived benefits

We analyze the changes and benefits perceived by farmers based on the open-ended questions in the household survey. Of particular importance is understanding the reasons for the abandonment of the repatriated material and for its continued maintenance. The reasons for abandoning the material can show us foregone benefits or why these could not be capitalized. Relevant responses were categorized, clustered, and analyzed descriptively.

4. Results

4.1. Genebank data analysis

4.1.1. Overview of repatriated landrace material

On average each community received about 111 samples and most communities only participated once in the program. The landrace accessions that have been most frequently repatriated are accessions with wide geographical distribution (Table 1). Even though the repatriation material is not selected based on any other criteria than availability and accession origin, the majority of the repatriated potatoes tend to have the following morphological characteristics: oblong; without unusual tuber shapes; slightly deep or deep eyes; cream as the predominant tuber flesh color without a secondary color; purple or violet tuber skin with intermediate to intense intensity; and a wider range of secondary colors.

4.1.2. Reasons for program participation

The genebank repatriation data includes the reasons why communities participated in the program. A recovery of lost or infected material was most mentioned, followed by the abiotic stressors frost, hail, and more rarely precipitation extremes, i.e., drought or excess rainfall. The categories climate change, biotic stressors (pests and diseases), and the wish for healthy seeds were also mentioned. Based on the responses relating to climate change, we categorized some push and pull factors for participating in the program. While most respondents mentioned that they lost some landraces due to increasing and unprecedented climatic changes (pull factor), some others noted that the repatriated material is needed for adaptation (push factor).

4.2. Duration model

4.2.1. Kaplan-Meier curve

The Kaplan-Meier curve (Figure 7) shows the probability that the repatriated landraces survive *in situ*, i.e., that farmers continue maintaining or conserving them in their fields. The solid line shows the probability that a given farming household still conserves the repatriated material at a given point in time after the original repatriation to that household. The dashed line shows the 95%-confidence interval of the estimation. The total number of households included in the estimation is 257. Over the program duration, from 1997 to 2018, 165 households (64%) ceased growing the landraces, while the remainder continued to plant the material at the time when the survey was conducted. The longest survival time of local bundles of repatriated landraces is 20 years, the shortest is one year.

Figure 7 shows that the probability of survival decreases steeply in the first few years after receiving material, indicating that most households abandon the repatriated material during the first four years after receipt. The survival probabilities are 86% in year 1, 67% in year 2 and 55% in year 3 and 44% in year 4. Afterwards, the curve declines at a slower rate and reaches a plateau until year 15. This indicates that for about 10 years, the survival probability stays in a relatively narrow range between 36% (year 5) and 18% (year 15). Afterwards the curve drops again and in year 20 the survival probability is only 3%.

The upper part of Figure 8 also shows a Kaplan-Meier curve. It is stratified by the household's geographical zone. As defined in Table 3, we assigned the households to two zones: center (yellow line) and south (blue). The yellow or blue colored area shows the 95%-confidence limits. The trends exhibited by zones follow the general pattern of the survival curve, but there are differences between the zones. The p-value displayed in the lower left-hand side of the graph shows that the difference in survival behavior between the two zones is statistically significant according to the Log-Rank test. The median *in situ* survival time of the repatriated material is three years for farmers in the center of Peru and five in the south of Peru. The curve also shows that in any year the survival probability of the repatriated material is higher in the zone South.

The middle part of the graph shows the number at risk, i.e., farmers that still maintain repatriated landraces in a given year but could disadopt in the next year. The number at risk is shown in absolute and percentage terms in brackets.

The lower part of the graph shows the data from censored farmers, those who have reported that they still plant repatriated varieties when they were interviewed, but who have not participated over the entire project lifetime. Hence, we cannot ascertain the survival time of their materials.

4.2.2. Cox proportional hazard

The second part of the duration model is the Cox proportional hazard analysis, which quantifies the impact of certain variables (household and regional characteristics) on the survival time of the repatriated material.

The model result table (Table 4) and the forest plot (Figure 9) summarize the results of the Cox proportional model. The effect of each variable is given as the hazard ratio (HR). In the forest plot, the direction and magnitude of the HR is displayed for each variable. An HR > 1 indicates an increased likelihood of abandoning the repatriated material *in situ* and an HR < 1 indicates a decreased likelihood. Here the likelihood is defined as the probability of occurrence of the model event, at which the household stops to plant the repatriated material. To interpret the plot, it is best to first concentrate on the dashed vertical line on the right-hand side of the plot, with an HR value of 1, our reference line. All squares on the right-hand side of the line have HR values higher than 1 and the squares on the left-hand side have values below 1. The squares indicate the estimated value of the hazard ratio, while the "tails" around the square indicate the 95% confidence interval. Each line shows the result for one model variable.

Holding other covariates constant, the likelihood of abandonment increases when the household head is male. The HR value of 1.71 indicates that a male household head increases the likelihood of abandonment, hence the average survival time, by a factor of 1.71 or 71% in comparison to female household heads. This effect is statistically significant and is hence an important factor to predict survival. Farmers under 30 years of age are also significantly more likely to abandon the repatriated materials.

On the contrary, the likelihood of abandonment decreases by a factor of 0.76 or 24% when the household head is over 60 years old. All other factors, including higher levels of education, labor force, wealth, food insecurity and also the geographical zone (South), are related to lower risk of abandonment. Therefore, they are positively connected with longer survival times of repatriated landraces. The effects are statistically significant for education, labor force and the South (zone). For instance, the labor force variable indicates that each additional person who works on the family's potato field decreases the hazard of abandoning the repatriated material by 4%. This is also a key variable, since labor force, combined with education, are indicators of a household's human capital resources.

The overall model is significant based on likelihood-ratio test, Wald test, and score logrank statistics. Also, the test for the proportional hazard assumption confirms that the model is robust.

4.3. Benefit and change analysis

Farmers reported that the greatest benefit from the repatriation program are related to family food consumption or food security (123 respondents), sale (64), sale and consumption (47), conservation of potato landraces (30), processing (21), consumption and conservation (20), and health (14).

Under food security, the majority of farmers note nutritional improvement as the most important benefit induced by the program (81), 19 farmers mentioned economic benefits, and 44 claimed they benefit from both nutritional and economic factors. Some respondents also reported that the program helped them have more potato landraces for traditional processing such as chuño (freeze drying).

Respondents were also asked for key farming changes brought about by the program. 77% said that the program helped them to recover lost landraces. The changes are not clear-cut regarding the effects on farm productivity. 57% stated that yield increases were induced by the program, but also a quarter revealed that these were not realized. 41% of the respondents noted overall increase in production using repatriated landraces, but 38% disagreed. Further, many respondents (44%) observed that they had less output sold to the markets, but 31% confirmed to have more surplus for the market.

The respondents are also divided whether the program generated more income from market sales. About the same number of interviewees responded yes and no. A significant change can be seen in the diversity of subjective flavors and textures. The surveyed farmers reported that they experience an increase in the number of distinct flavors and textures. Unique flavors and textures are defined by for example different levels of sweet and bitter and a watery, starchy, or chewy texture. Also, the farmers perceived a union of traditional and scientific knowledge and the reputation of the farmers growing repatriated landraces increased.

The nutritional benefits and the increased diversity in flavors and textures was also confirmed by the women members of the household and respondents who are mainly responsible for cooking. They reported an average of eight new combinations of flavors and textures brought by the repatriated material. Three quarters of the women said that the program helped them to expand their portfolio of potato landraces. 72% of the interviewed women felt healthier from eating landraces and 81% acknowledged that their family or community benefits from the program.

Table 5 gives an overview of all benefits or changes induced by the repatriation program which were asked through categorical response options in the survey. The most mentioned benefits were the recovery of lost landraces, general benefits for the family and community and a union of traditional and scientific knowledge.

Negative changes and reasons for abandonments

To fully portray the changes induced by the program and better understand the on-farm survival of the repatriated material, it is also necessary to look at the negative changes brought by the repatriation activities and the reasons why farmers have stopped growing the material.

Table 6 shows the reported negative changes and the number of times each was mentioned. The three most mentioned categories are poorer plant vigor (n=53 or 18% of all interviewed farmers), less yield (48), and less production (46).

105 farmers or 65% of the overall sample stated that the main reason why they stopped cultivating the repatriated material was production loss due to abiotic stresses, especially too cold conditions with frost and hail (n=33). The other reasons are biotic stressors (29 farmers), insufficient labor force or knowledge by the farming household (19), no participation in the program or lack of planting material (18), disorganization on the part of the municipality as well as CIP (11). Four farmers also specifically mentioned climate change.

49 farmers said that they had abandoned the material on a communal level and most of them gave the reason as non-survival. Other reasons include disorganization and conflicts within the group or community, including issues regarding the distribution of repatriated material (n=23), insufficient repatriated material (6), low production of the repatriated material (5), time conflicts and insufficient labor force by the farmers (4), biotic and abiotic stressors (each 3).

5. Discussion

5.1. Duration model

The analysis of the survey data shows that the shortest survival time is one year, hence the farmer ceased to use the repatriated material after the first season, while the longest survival time is 20 years. According to the duration model, the survival time decreases steeply in the first five years, which means that many farmers abandon the repatriated material in the first years after they received it. In year four, the survival probability drops below 50%, i.e., more than half of all participating and surveyed farmers do not plant the repatriated material anymore. After this steep decline, the survival probability reaches a plateau until year 14 or 15, where the material survives in about 20% of all households. At the maximum survival time, 20 years, the survival probability is 3%. This does not necessarily mean that another farmer in the same community (and who has not been surveyed) does not continue growing it when another abandons it.

The factors that increase the likelihood of long-term maintenance of the repatriated material on-farm are in line with the large body of literature that has analyzed on-farm (potato) diversity and also the factors that contribute to landrace cultivation. Meng (1997) and Meng, Taylor and Brush (1998) state that farmers must have an intrinsic or underlying preference for landrace diversity if a landrace conservation program is to be successful. This preference is a prerequisite for diversity cultivation and conservation. The cultural and historical ties of Andean smallholder communities to the potato crop are strong (de Haan 2006), as the Andes are the place of origin of the potato crop.

The results from the duration model show that the characteristics of the household head are key to the enhanced survival of the repatriated material. Females and older household heads are more likely to continue growing their repatriated landraces for a longer period of time. These characteristics have been covered by various studies and survey analyses which also conclude that a female household head or women taking care of the potato plots is more likely to have greater diversity in the family's potato portfolio (Gruberg et al. 2013; Lüttringhaus 2016). In Andean small holder communities, women usually conduct the tuber selection after harvest, where they decide which tubers are best used for home consumption, sale, seed potatoes and traditional methods of preservation. It is also considered their responsibility to safeguard the seeds for the next season (de Haan 2006).

Having more experience with potato production and hence older traditional ties to the crop and its production is considered a factor that positively influences farming household's landrace diversity and material maintenance (Cromwell and van Oosterhout 2000; Kruzich and Meng 2006; Perrault-Archambault 2007). On the other hand, older age groups could also be related to reduced potato diversity because its maintenance requires labor force, which can be less available to them due to age, illnesses or other factors, especially in the very heterogenous and high-altitude farming systems in the Andes. Gruberg et al. (2013) found that farmers between 25 and 55 years of age have the greatest variety portfolio. Our analysis does not show that the material of the middle age group has longer survival times, but in the survey regions the rural exodus problem is quite pronounced, especially for the middle age group. Gruberg et al. (2013) describe how migrants used to keep some potato plots in their home villages, which could explain their higher diversity. In Italy, Negri (2003) also finds that the presence of elderly farmers, and not necessarily the active conservation by elderly farmers, can enhance diversity.

Potato production in the Andes is very labor intensive (Arce et al. 2019; de Haan 2009; Zimmerer 1991) and studies on potato diversity of Andean farming households found that an increased number of labor force enhances its potato portfolio. The labor supply of households is determined by the number of its members who participate in the potato production, it can be reduced by off-farm work and migration (Gruberg et al. 2013; Hellin and Higman 2005; Winters, Hintze and Ortiz 2006). In our model, the effect of internal and external labor force was statistically significant, which underscores the different perspectives of landrace maintenance.

The variable wealth had a small effect according to the model results. Literature suggests inconsistent effects of wealth to agrobiodiversity. On one hand, higher potato diversity levels might prevail among poorer farmers as they need it for their sustenance and risk management strategy. On the other hand, less well-off farmers might not have the possibilities to manage great potato diversity due to labor and knowledge disadvantages. Several authors argue that custodian farmers are among the better-offs (Cromwell and van Oosterhout 2000; Perrault-Archambault 2007; Smale and King 2005; Smale and King 2005; Winters, Hintze and Ortiz 2006; Zimmerer 1996). Wealthier farmers profited most from political changes in the Andes (Zimmerer 1996) and are able to maintain high potato diversity levels as they possess more land, can afford to remunerate additional workers, and buy seeds. Again, these are factors that increase the intrinsic motivation of farmers for diversity and hence leading to a higher likelihood of maintaining the material. (Gruberg et al. 2013) find that farmers of the middle to middle-low class cultivate most potatoes varieties. Those have more land than the poorest, but not as much income as well-to-do families. Hence, they cannot afford a great variety of potato substitutes and must cultivate a high level of potato diversity to assure food security. Also Lüttringhaus et al. (2016) found that wealthier households, in this study measured by the number of cows per household, cultivate higher levels of potato diversity, which is a prerequisite for the material survival.

Potato landraces are usually planted as *chaqru* for risk management. Such a behavior prevailed also in other farming systems such as in Italy (Negri 2003). Furthermore, the farming landscape and crop allow to harvest different plots over the year, as to stretch fresh potato harvest over long periods of the year (Clawson 1985; Smithson and Lenné 1996).

The location of the households, measured with the variable zone, shows that the repatriated material survives longer in the south. This is an important center of potato landrace diversity and includes the department of Cuzco. It is also a zone where tourism centers around the world heritage Machu Picchu, the cornerstone of the economy. Also, the *Parque de la Papa* (Potato Park) was established there. It comprises five smallholder farming communities and is the largest *in situ* conservation area of agrobiodiversity in Peru and also on a global scale (Hall 2019). The higher survival times in the South might be also influenced by the longstanding ties between some communities and CIP's principal curator Rene Gomez. The community members attest that their potato production and potato diversity are considered valuable assets not only for food security but also for tourism. The importance of location for *in situ* potato diversity and the underlying preference of landrace diversity are crucial for diversity maintenance as underscored by Meng (1997), was also found as a main determinant in the survey analyses by Arce et al. (2019) and Lüttringhaus et al. (2016). Further, a higher number of plots and farming conditions such as the altitudinal levels and disease risks of plots are found to be related to increased households' landrace diversity (Negri 2003; Winters, Hintze and Ortiz 2006).

5.2. Benefit and change analysis

Overall, the benefit analysis shows that the farmers who participate most also perceive various repatriation-induced benefits. The benefit category that received most mention is the recovery of lost landraces, which is the primary goal of the repatriation efforts conducted by CIP (Ellis et al. 2020; Huaman et al. 2000). Many farmers reported that they gained a combination of traditional and scientific knowledge after the repatriation. This finding indicates that most farmers perceived the cooperation between CIP and their communities as beneficial and that their experiences and knowledge were integrated. The process of repatriation creates a sense of ownership for the program, which can facilitate the long-term benefits of the program and its future upscaling activities. Such an ownership can be also supported by famers' perception of benefits for women, a better reputation of those farmers who participate and a healthier feeling when eating landraces.

Nutritional benefits (relating to food quantity, dry matter content, yield, production etc.) and the necessary pre-conditions for a good harvest (plant health, etc.) were most frequently mentioned by respondents. Also, the production of chuño (freeze-dried potato) supports food security as it provides readily available food when the fresh tubers are depleted, but it requires specific landrace cultivars and steady, reliable environmental conditions for processing. Hence, the repatriation program supports the crucial need for food security in Andean communities.

In other farming systems, traditions and organoleptic reasons lead to farmers' decision to grow landraces (Negri 2003). de Haan (2009) describes that a meal of mixed landrace cultivars (*chaqru*) is "biodiversity transformed into diverse sensory perceptions: color, texture, taste, and odor. During the meal, each family member carefully picks a tuber satisfying long established preferences, curiosity, and appetite for variation. The mix of diverse cooked potato cultivars is an expression of Andean diversity in the kitchen. Having the luxury of choosing from a wide array of cooked cultivars is a welcome diversification within a diet dominated by potatoes." (de Haan 2009, 179).

The benefits and change analysis shows that the two downstream objectives of the CIP repatriation activities – to improve the food security of the receiving households and to increase the diversity of potato landraces – are fulfilled by the program. *In situ* conservation can help decrease the diversity loss of landraces especially when agricultural systems are changing (Brush, Taylor and Bellon 1992). It also underscores the private economic values the landraces perceived by the receiving farmers. Devaux et al. (2020) show that there is evidence of an emerging value of potato landraces and the benefits they induce, partly because of new culinary trends. These values and incentives are crucial to understand the *in situ* maintenance of landraces (Meng, Taylor and Brush 1998; Smale, Bellon and Aguirre Gómez 2001).

The analysis of the negative changes and reasons for abandonment shows that some farmers perceive disadvantages in plant health and food security after the repatriation. However, the survey data do not permit us to conclude whether these changes refer only to repatriated material or the any landrace material present in a community.

The main reasons for the loss of the repatriated material are abiotic and biotic stressors. Climatic and environmental conditions have been changing the growing environment in the Andean region (Arce et al. 2019; Hock et al. 2019) and hence plots or altitudinal belts were specific landrace types grew, before they were lost, might not be suitable anymore. Also, it is possible that the adverse conditions that led to the loss in the first place, persist and hence contributed again to the landrace loss. Future monitoring should integrate these aspects to detect the main driving factors of loss as they can be manifold (socio-economic, biotic, abiotic, etc.).

Many farmers stated that they lack enough farm laborers to maintain the material. The duration model confirms that less work force increases the likelihood of abandoning material. Also, a lack of knowledge was mentioned in combination with the lacking labor force. Here the role of generation gap becomes evident: younger farmers often prefer to seek education and labor opportunities in urban areas. This inhibits an intergenerational exchange to convey the knowledge on potato production and its importance. Other studies have also found that a shift from one generation to the next led to landrace loss (McLean-Rodríguez et al. 2019).

It is important to note that the reasons for loss are highly interconnected and are often location- and landrace-specific (McLean-Rodríguez et al. 2019), ideally calling for a comprehensive local monitoring or mentoring of farmers who act as a connection between the participating farmers and CIP, in cases where advise is needed. Also, intergenerational apprenticeships between the older and younger farmer generation could help to conserve the material.

Another reason for abandonment was related to the organization and management of the program. This underlines that the repatriation program requires a good institutional structure and long-term commitment to multiply the repatriated material in sufficient quantity so that all willing farmers can plant them individually and ensure the future success of repatriation program in Peru. According to Gomez (2021) disorganization was pronounced in two specific communities and the selection process for participating communities was adjusted accordingly.

5.3. Strengths and limitations

Our study is the first comprehensive description and evaluation of CIP's 20-year-old repatriation activities. The analyses are based on a solid set of data: passport data on the repatriated accessions, a household survey on the changes induced by the repatriated material, and interviews and exchanges with involved CIP staff. The work is urgently needed to understand best practices and draw lessons for program management. The repatriation program is part of the routine genebank work and has not been institutionalized at CIP as a project with individual cost-accounting procedures. Therefore, the costs attributed to repatriation can only be estimated.

There are some limitations on the survey data. A few well-established variables for the duration analysis, such as the potato plot or farm size and social and information networks, were not included in the questionnaire. Due to the survey design, we further had a limited number of quantitative and continuous variables per household and used recall data for the duration model, which means that farmers might recall incorrectly for how long they have been planting repatriated material. The household data set is very comprehensive and detailed, covering most beneficiary communities, yet there are gaps regarding the survey set-up, data entry, and comparability across regions. Data cleaning and transformation prior to the analyses required a significant amount of time. Future monitoring is advised and should be done in close collaboration with experts in survey design and socioeconomics if such factors are to be included. A shorter survey with fewer questions is advisable; this would also facilitate enumerator training and hence create more consistent data across enumerators and communities. Ideally, the person or team who will analyze the data later is already involved in the survey set up and monitoring of the data retrieval and data entry. Online survey tools could be helpful here. Again, online tools can give real-time monitoring options to minimize errors at a later period. Another limitation is the exact accessions, a household received from CIP through its community, were not identified during the survey. Therefore, we cannot analyze how survival times differ according to different accessions or their traits. This connection between survival times and diversity should be further explored to detect those accessions and traits that are most valuable to farmers. Nevertheless, it is again important to note, that the risk-minimizing planting strategy *chaqru* is most valuable due its overall trait spectrum of the landraces that constitute it, and to a lesser extent due to the traits of one individual landrace.

6. Conclusion

Our analyses have led to the first comprehensive description of the repatriation activities conducted by the CIP genebank. Further, we identified household and community factors that foster long-term maintenance of the repatriated landraces and the perceived changes for participating farmers and their communities induced by the repatriation.

Through the repatriations, the CIP genebank has distributed a vast diversity of landraces back to their places of origin. Overall, a third of all interviewed participating farmers still conserve the material. The duration analysis showed that most farmers abandon the material in the first years after receiving the material. 44% of the farmers kept the material for four years. But afterwards, from year 5 to 15, survival probability reaches a plateau where it decreases in a relatively narrow range from 36% (year 5) to 18% (year 15). The lowest survival probability (3%) was reached in year 20. Significant factors in the duration analysis and reasons cited by farmers for loss of the repatriated material are diverse and range from a shortage in labor force and knowledge, abiotic and biotic stressors to community disorganization. Most participating farmers confirm that they perceived a multitude of benefits induced by the repatriation even if they stopped to plant the material. The most mentioned are the recovery of lost landraces and nutritional benefits. Therefore, the program fulfills its main objective to return lost landraces by healthy planting material and thereby increasing farmers' food security and intraspecific potato diversity they manage. These results show that the program is very complex and highly interlinked with other factors that influence farmers' livelihood. One factor is climate change altering growing conditions at an unprecedented speed and intensity, including abiotic and biotic stressors. Also, environmental degradation, urbanization, and changes in dietary and lifestyle preference have intensified the changes in farming communities in the Andes.

We provide evidence that a continuation or scaling up of CIP's repatriation activities generates benefits and is a way to improve the livelihoods of many farmers and their communities which depend on potato production for sustenance and traditions. Due to a large number of smallholder farmer communities in Peru and other Andean countries, the upscaling potential of the repatriation activities is large. Up to and including 2020, 135 different communities have participated in the repatriation program, but there are about 6,000 smallholder communities in Peru (Diez Hurtado 2011; Pajuelo Teves 2019). This means that 0.02% of the communities have participated so far and that many more could benefit from the program by receiving clean planting material. To continue the repatriation work, its support and funding must also be secured.

Ultimately, we show that repatriations of potato landraces improve the livelihoods of farming households, their food security, and well-being. Thus, the program is making an impact. These millennia old farming systems, conserve valuable genes and traits, which hold insurance and option values and are important to global food security and climate change adaptation in the Andes and beyond.

There is space for improvement relating to program management. First, there could be efficiency gains in institutionalizing the repatriation program as a separate project under CIP, led by the genebank but capitalizing on the capacity available from other disciplines and units. We show that repatriation is not just about the multiplication of materials from *in vitro* to tubers but is a complex interaction of many stakeholders from CIP and the Andes communities. Hence, a multidisciplinary approach to program implementation and monitoring could greatly enhance the adoption and survival of repatriated landraces. Further best practices could be exchanged between CGIAR centers with repatriation programs with multiple crops being shared back to small holder farmers. Second, a follow-up exchange between the receiving farmers and the repatriation staff after redistributing the landraces in a regular and institutionalized manner would be conducive to increasing the achievements of the repatriation efforts as well as sharing knowledge of agronomic practices. As the duration analysis has shown, a follow-up is crucial in the first four years following a repatriation and could be achieved in cooperation with community elders, an intergenerational apprenticeship, or network farmers.

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8. Figures

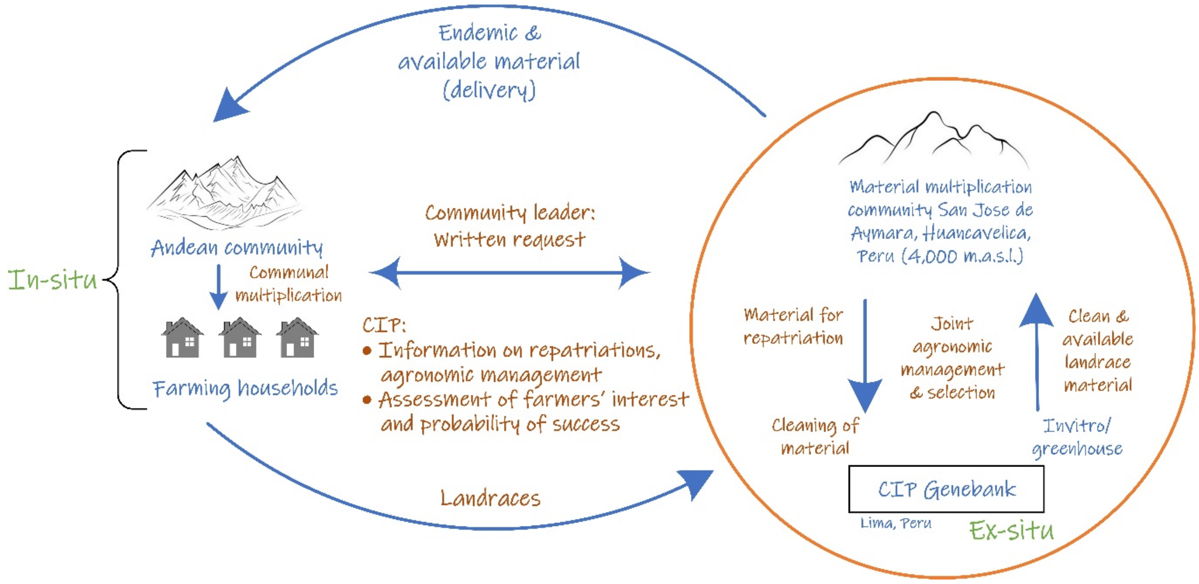

Figure 1. Scheme of the repatriation program. On the left part the repatriation process and on the right in a yellow circle the conservation, cleaning, and multiplication process to generate material for repatriation. Source: Authors.

Figure 2. Repatriation of potato landraces to Ancash, Peru (13/08/2015). The five community representatives hold their list of repatriated landraces, which are packed in the boxes in the foreground. Source: CIP genebank.

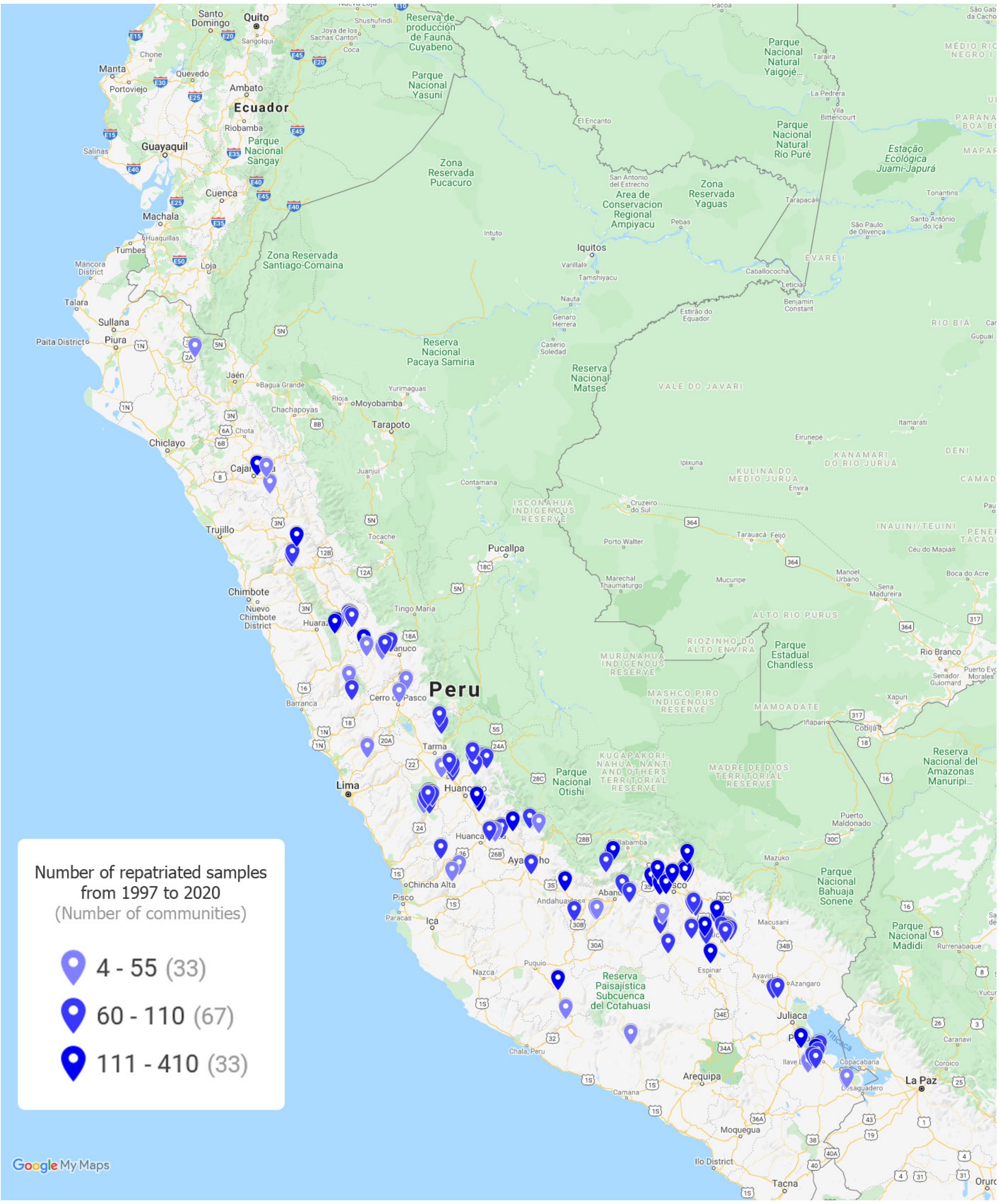

Figure 3. Number of repatriated landrace samples per community. Source: (CIP 2021a)

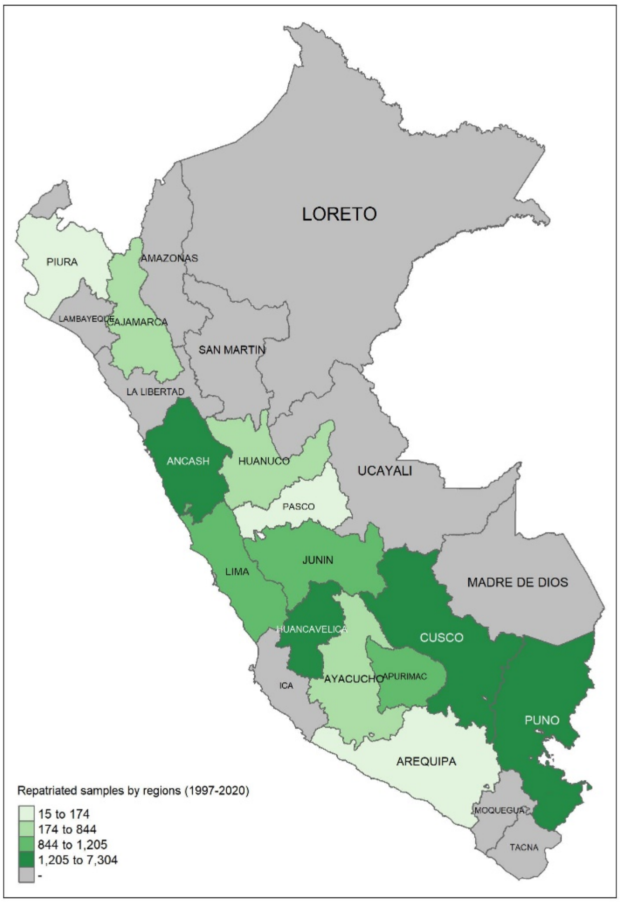

Figure 4. Map indicating the number of repatriated landrace samples per department. Source: (CIP 2021a)

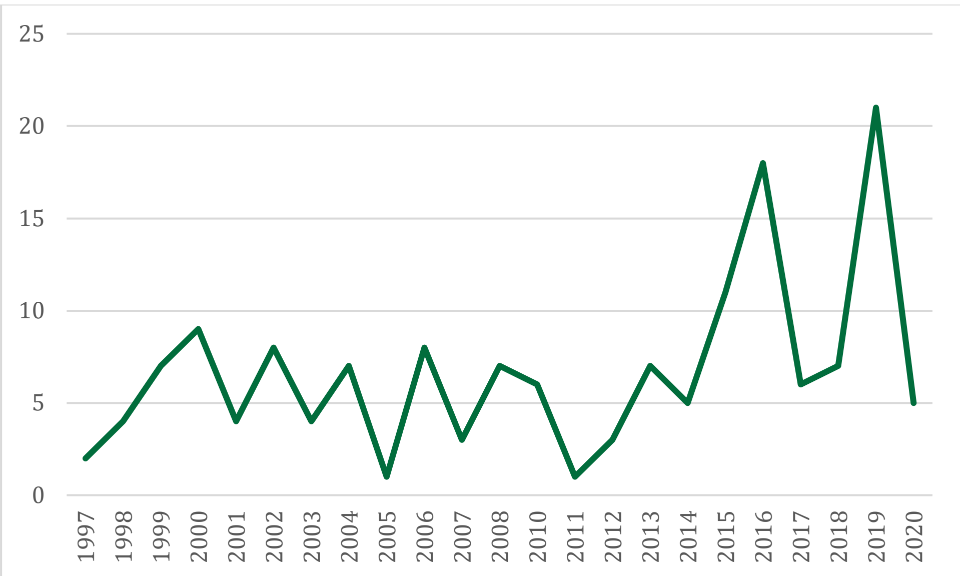

Figure 5. Number of communities receiving repatriations per year. Source: (CIP 2021a)

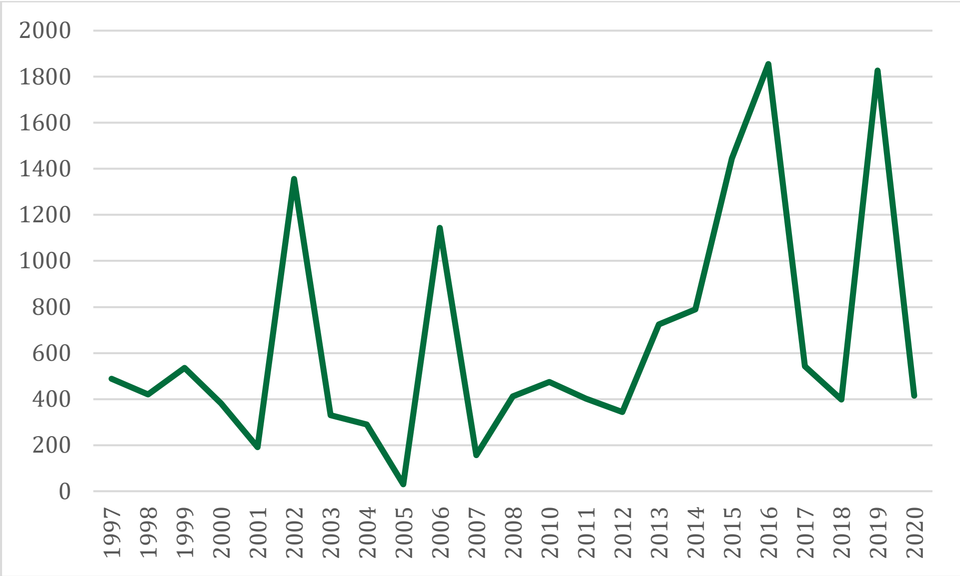

Figure 6. Number of repatriated landraces per year. Source: (CIP 2021a)

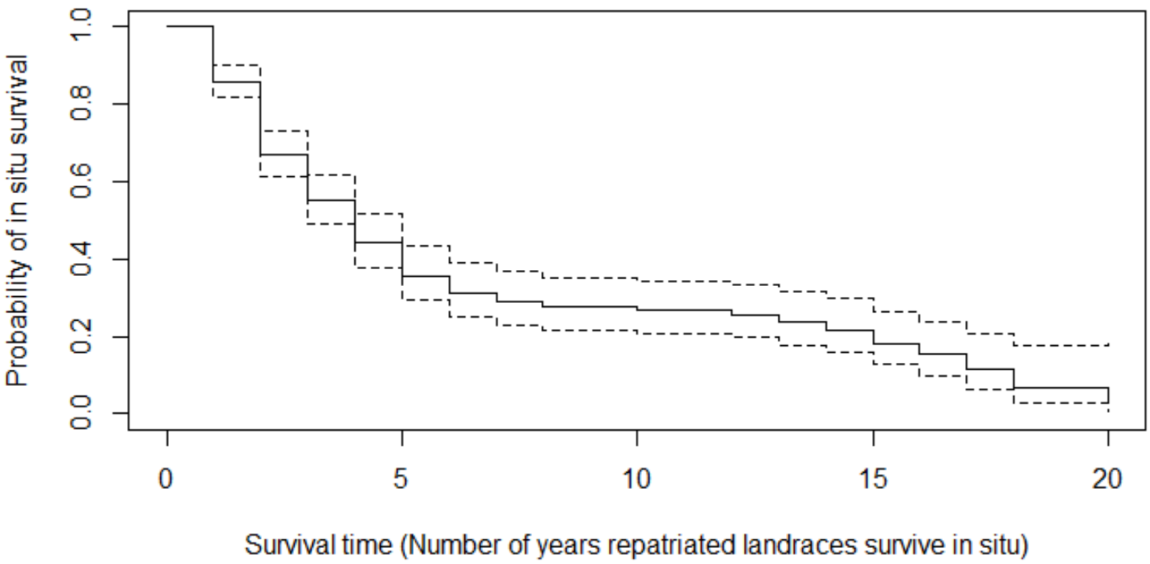

Figure 7. Kaplan-Meier survival curve displaying the survival probability of the repatriated material at each successive year after the repatriations. Source: Authors.

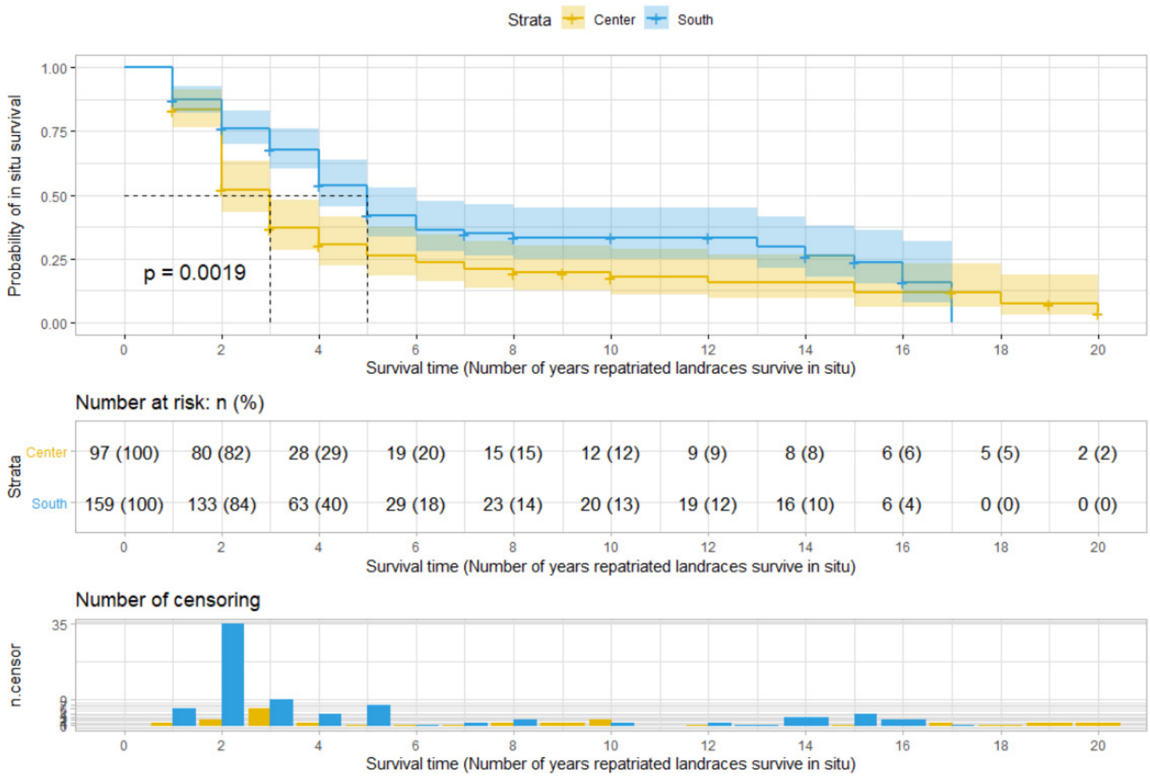

Figure 8. Upper graphic panel: Kaplan-Meier curve stratified by zone; middle graphic panel: number of farming households where the repatriated material still survived at a given year (absolute and in percent), lower graphic panel: Number of censored households, where the repatriated material still survived when being surveyed in 2018, but of whom we do not know the current survival state. Source: Authors.

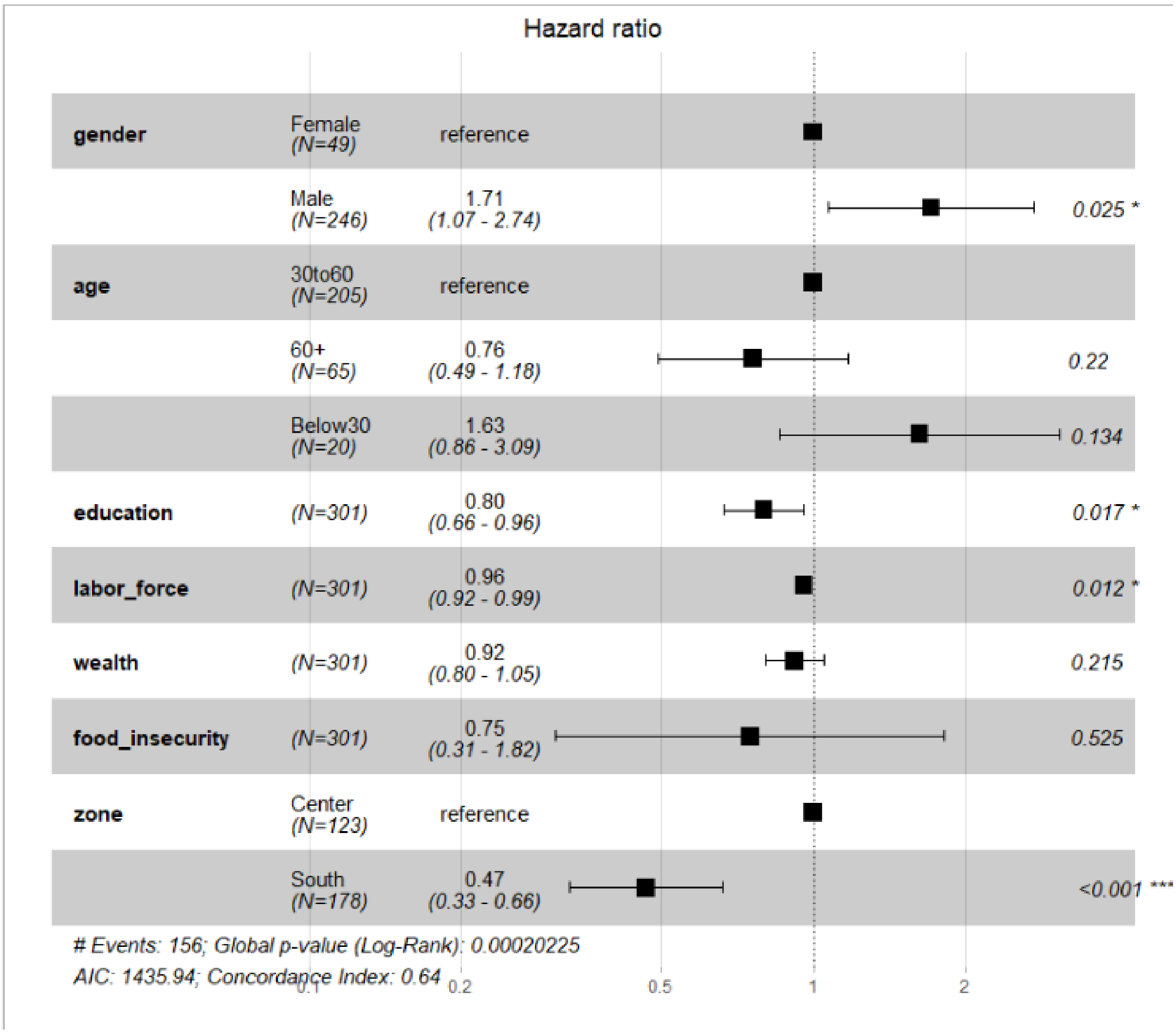

Figure 9. Results of the Cox proportional hazard model displayed in a forest plot. Source: Authors

9. Tables

Table 1. Number of repatriated landrace samples and participating communities per department. Source: (CIP 2021a)

Department	Number of repatriated landraces samples	Number of participating communities
Ancash	1311	12
Apurimac	844	11
Arequipa	54	3
Ayacucho	313	4
Cajamarca	174	3
Cusco	7304	38
Huancavelica	1205	11
Huánuco	377	5
Junín	1035	14
Lima	854	13
Pasco	55	2
Piura	15	1
Puno	1409	18

Table 2. Top 10 most repatriated landrace accessions. Source: (CIP 2021a)

Accession number	Species or subspecies of *Solanum*	Number of repatriated samples
CIP 702013	chaucha	64
CIP 707136	chaucha	62
CIP 700485	*Tuberosum andigena*	51
CIP 701515	*Tuberosum andigena*	49
CIP 703181	*Tuberosum andigena*	47
CIP 703932	*Tuberosum andigena*	45
CIP 702037	*Tuberosum andigena*	45
CIP 702961	*Stenotomum goniocalyx*	44
CIP 700863	*Tuberosum andigena*	43
CIP 700790	*Tuberosum andigena*	42

Table 3. Variable selection for the Cox proportional model. Source: Authors.

Variable	**Description**	**Summary statistics [Mean (std. dev.) or Frequency counts]**
Time variable Time	Survival time, number of years a community receives the repatriated landraces to the last year where farmers plant these varieties (time-to-abandonment)	4.34 (4.44)
Event/Status variable Event	Dummy: 0 = event, i.e., abandonment of repatriated landraces, has not happened yet, 1 = otherwise.	0 (n=96) 1 (n=173) NA (n=33)
Independent variables Gender	Binary gender of person responsible for the plots with repatriated potatoes	Male (n = 246) Female (n = 49) NA (n = 7)
Age	Age group of the person responsible for the plots with repatriated potatoes: Below 30 = Household head is below 30 years of age, 30 to 60 = Household head is between 30 and 60 years, 60+= Household head is older than 60.	Below 30 (n= 20) 30 to 60 (n= 206) 60+ (n = 65) NA (n= 11)
Education	Education of person responsible for the plots with repatriated potatoes (None = 0, Initial = 1, Primary = 2, Secondary = 3, Technical = 4, Tertiary = 5, Other = 6)	0 (n = 14) 2 (n = 175) 3 (n =84) 4 (n = 6) 5 (n = 11) NAs (n = 12)
Labor force	Number of internal (household members) and external people who help with agricultural work	8.00 (5.15)
Wealth	Number of services (drinking water, drainage, electricity, telephone, TV, internet) per household	2.63 (1.33)
Food insecurity	Index of Peruvian food insecurity in the face of recurrent natural disasters. Average per district (index running from 0.00 (= no risk of food insecurity) to 0.85 (=very high risk of food insecurity) (WFP and CENEPRED 2015)	0.36 (0.22)
Zone	Geographical zone in Peru: Center includes the departments Ancash, Huánuco, Pasco, Lima, Junín, Huancavelica, South includes Ayacucho, Apurímac, Cusco, Arequipa, Puno.	Center (n= 123) South (n= 179)

Table 4. Results of the multivariate Cox regression model, (significance codes: *** p-value < 0.001; * p-value < 0.05). Source: Authors

Variable	Hazard ratio
Gender (Male household head, Female is reference group)	1.71 *
Age 60+ (of household head, age group 30-60 is reference)	0.76
Age below 29 (of household head, age group 30-60 is reference)	1.63
Education	0.80 *
Labor force	0.96 *
Wealth	0.92
Food insecurity	0.75
Zone South (Center is reference)	0.47 ***

Table 5. Categorical benefits that have improved due to the repatriation activities, ordered by the number of mentions, total number of mentions 301. Source: CIP (2018) and own calculations

Benefit	Number of mentions
lost landraces recovered	246
general family community benefits	243
union traditional scientific knowledge	228
benefits for women	227
reputation of participating farmers	225
healthier feeling	218
plant health	216
number of tastes	210
plant vigor	204
taste	201
food quantity	198
tuber appearance	198
dry matter content	190
excitement for repatriated material	182
yield	181
production	181
tuber size	179
food security	173
income	114
seed production options	108
commodity options	94

Table 6. Negative changes induced by the repatriation, as perceived by the farmer, and ordered according to the number of mentions, Source: CIP (2018) and own calculations

Benefit	Number of mentions
poorer plant vigor	53
less yield	48
less production	46
less dry matter content	39
less tastes	30
less food quantity	29
poorer tuber appearance	20
poorer plant health	17
less landrace diversity	7
no excitement due to participation	4

10. Author bio and photo

Source: Isabel Hackenberg.

Sophia Lüttringhaus is an interdisciplinary expert in Agricultural Economics and International Relations with international work experience in agricultural research for development and consultancy. Her work focuses on climate change adaptation, agrobiodiversity, genetic resources, plant breeding and food security. As part of her PhD at the Potsdam Institute of Climate Impact Research and the Humboldt University of Berlin she investigates the economics of genetic resources and plant breeding. As a Genebank Impacts Fellow 2020 for the Crop Trust and the International Potato Center (CIP) she analyzes the on-farm survival of potato landraces which were redistributed by the CIP genebank to Andean farmers in Peru. She also investigates the factors that influence this survival time and the induced benefits and changes. Sophia is also a Research Analyst at the scientific consultancy HFFA Research in Berlin, Germany where she leads different projects in the realm of development cooperation and climate change adaptation assessment.