The Historical, Social, and Economic Importance of the Potato Crop

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Abstract

The potato has a fascinating history, from its origin and domestication in the Andean Region, where it was essential for feeding a growing population, for example, the Inca Empire, to its introduction into farming and food systems in Europe and elsewhere in the world. This crop has been the key factor in terms of food security, nutrition, population growth and urbanization in many regions. In recent decades, the potato has become a dominant crop in countries such as China and India, and its cropping area and production have increased more than those of any other food crop in Africa. Besides the social and economic importance of potato, extensively discussed in several published articles and briefly mentioned in this chapter, we discuss two relevant issues that are intimately related to potato genomics and breeding and which make potato a crop that has a lot to offer for the future. Those issues are the potato's contribution to food and nutrition security, and the cultural and genetic importance of biodiversity conservation in the Andes; these issues are strongly related to gender, since women in traditional societies have contributed—and still contribute—to an enormous wealth of knowledge in relation to biodiversity conservation and utilization. The adaptability shown by the potato crop over thousands of years indicates the potential role of the potato as a climate-smart crop, particularly based on its short vegetative period, water utilization efficiency, and productive capacity per unit of input.

1.1 The Unique Saga of the Potato

The history of the potato is, arguably, the most fascinating of all crops. The route it has followed from its origin and domestication in the Andean region, where its cultivation started about

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8000 years ago, and where it became an essential crop for food security in pre-Columbian times (Fiedel 1987; Moseley 1992; Hastorf 1993), to becoming the third most important food crop in the world has been extensively documented in books, reviews and essays (Salaman 1949; Brown 1993; McNeill 1999; Reader 2008). These studies describe very well, both in scientific and anecdotal terms, the amazing saga of the potato on its way from South America to Europe over several centuries and its adaptation to farming and food systems in all the European countries and elsewhere in the world. This globalization process of the potato, which started in the sixteenth century, is still going on today. In addition to its history, the enormous and unparalleled social and economic importance of the potato in different societies in both the New World and the Old World has been narrated and described in great detail in several articles and books (Salaman 1949; De Jong 2016). The potato is credited with the distinction of being the most crucial agricultural factor in the course of human events in the last eight centuries, including its effect on food security, its prowess in nourishment of people on a great scale, aiding explosive population growth in Europe, and urbanization (Nunn and Qian 2011; De Jong 2016). Before that, in its land of origin and domestication, pre-Hispanic societies reached high levels of political organization and cultural and technological development, based on the potato as one of their main staple crops and source of food security and nutrition. Its domestication and continuous process of adaptation to highly diverse agroecosystems in the Andes of South America generated a broad genetic diversity, resulting in a crop that is very well adapted to climatic variability, and able to substantially increase and sustain food production. This remarkable versatility of the crop drove the development and consolidation of highly organized societies, which reached their pinnacle with the Inca Empire. The conquest of this empire by the Spaniards in the sixteenth century gave rise to the subsequent expansion of the potato in the Old World, a process that proved to be a major event in the history of humanity. At the peak of the development of Andean societies, just before the clash with the Western world, it has been estimated that the potato fed and nourished a population of around ten million people in South America (Reader 1990), with no historical trace of a famine in those societies. Potato domestication and cultivation are examples of the skills of Andean societies who developed agricultural knowledge and its associated technology, such as terrace cropping, irrigation management, and post-harvest processing. Also, since wild potatoes contain solanine and tomatine, toxic compounds that protect the plants against herbivores and pathogens and which are not eliminated by cooking, ancient Andean farmers solved the problem by breeding non-poisonous varieties that started the potato revolution, as those new plants were converted into a crop suitable for human consumption (see http://www.smithsonianmag.com/history/how-the-potato-changed-the-world). We should add that one of the first processed potato products known worldwide, the freeze-dried potato, originated in the Andes also thousands of years ago as a storage technique and a way of making bitter potatoes edible. Ortiz (2006) argued that the information, knowledge, and technology associated with potato cultivation, breeding and post-harvest management were disseminated throughout the Andes with the potato itself, transported by migrant populations to the new territories progressively occupied by ancient Andean settlers, and that this process that began with the domestication of the crop still continues to this day.

Although the importance of the potato in the development of pre-Columbian Andean societies is highly relevant, and its impact is greater than that of any other contemporary crop (it could be argued that maize was also extremely important), it is the history of the impact of the potato on a global scale, following its introduction into Europe, that makes a most singular story. In this section, we merely mention some highlights since many excellent reviews have already described this process. The first remarkable effect of the introduction of the potato into Europe was its contribution to the significant increase in the European population during the period from the second half of the eighteenth century to the middle of the nineteenth. This population growth responded to the very significant increase in food production brought about by the expansion of potato cultivation in European countries. It has been estimated that the introduction of the potato resulted, over the years, in the doubling of the food supply in Europe (Mann 2011). The potato is said to have brought a solution to the historical periodic food scarcity in Europe, where food shortages were a recurrent problem (Vandenbroeke 1971). It has also been argued that the potato, by providing plentiful food to increasing populations, was one of the factors that allowed European countries to dominate the world during the colonial centuries (McNeil 1999), facilitated the Industrial Revolution to some extent, and contributed to the recovery after the major European wars in the twentieth century.

However, an infamous and tragic episode of the arrival of the potato into European farming and the dependence it created on a single crop is provided by the history of the potato in Ireland. Several publications describe how the potato became so entrenched in Irish farming and livelihoods that it became the main and almost exclusive staple food for the Irish peasantry, and this was conducive to a very large increase in the population in the country, which soared from three million to eight million in five generations in the period ending in 1840. At that point in time, the potato crop failed in several successive years as a result of a massive outbreak of late blight disease. The tragic consequence was the Irish potato famine, which caused the deaths of more than one million poor farmers from starvation and the emigration of a similar number of people, mostly to the United States and other English-speaking countries, such as Canada and Australia (see Trueman 2016).

In recent decades, the potato has become a dominant crop in emerging countries such as China and India, which are now the largest world producers and consumers of the tuber. China's official policy is to turn the potato into its main source of food security in the near future (Baroke 2015; Frederick and Lei 2015; Qu and Xie 2008). Similar efforts are being carried out in India (Singh and Rana 2013) and elsewhere (Azimuddin et al. 2009; Devaux 2014; Devaux et al. 2014). In addition, the arable potato area has increased more than that of any other food crop in Sub-Saharan Africa in the last three decades. For example, in East Africa, potato production has nearly quadrupled since the 1990s (Gildemacher 2012), and the potential for growth is still significant because consumption per capita is relatively low (Havenkort et al. 2009). Worldwide, potato production has increased at an annual rate of 4.5% over the past 10 years, exceeding the growth in production of any other major food commodity in developing countries, where there is a pressing need to satisfy the growing demand for food and nutrition.

Besides the social and economic importance of the potato, briefly mentioned above, in the following sections we discuss two relevant issues intimately related to potato genomics and breeding. These issues are the potato's contribution to food and nutrition security, and the cultural and genetic importance of potato biodiversity in the Andes, which is intrinsically related to gender aspects. Those attributes of the potato are in addition to its potential role as a climate-smart crop, a condition related to its short vegetative period, its water utilization efficiency, and adaptation to a diversity of agro-ecosystems: all characteristics that make the potato a crop with much to offer for the future.

1.2 Potato's Contribution to Food and Nutrition Security

The potato has traditionally been considered a food security crop, usually implying the sheer volume of a reliable foodstuff, which was critical in the pre-Columbian eras in South America. Even nowadays, the potato is regarded as a crop that provides food for the poor, particularly in developing regions (Lutaladio and Castaldi

2009). A clear example is provided by the increasing reliance of North Korea on the potato as a key crop to solve the chronic food shortages that led to a famine some two decades ago. Following that event, the potato cropping area in the country and correlated per capita consumption increased fourfold, from 11.5 to 49.0 kg per year (FAOSTAT 2013). In rich countries, some misconceptions about the potato's nutritional value are still prevalent, and it is erroneously believed to be a fattening, high carbohydrate foodstuff (Fitzgerald 2014). However, the truth is that the potato is not only a key crop for providing food security to developing regions but also is a highly nutritious food that provides more calories, vitamins, and nutrients per area of cropped land than any other staple crop. Contrary to the above-mentioned erroneous beliefs, potato is a rich source of vitamin C (U.S. Department of Agriculture 2007; Love and Pavek 2008), potassium, and dietary fiber (Nunn and Qian 2011). It is also an excellent source of vitamin B6 and a provider of relatively high amounts of other B complex vitamins, such as thiamin, riboflavin, folate, and niacin, as well as minerals such as magnesium, phosphorus, iron, and zinc, all making the potato ideal for a healthy diet when a few other food components such as dairy and legumes are added to supplement it with calcium, vitamin A and vitamin D (the few nutrients of which the potato is not a good source). Thus, the potato adds a new dimension to food security, widening it to nutrition security in a world in which malnutrition is still prevalent, not only because of the lack of access to food, but also due to the low quality of accessible food from local crops. The potato crop, due to its short duration, is able to produce food during the hunger months (when other crops such as maize are no longer available) in several countries in Sub-Saharan Africa (Demo et al. 2015). The nutritional quality of potato, the wide range of agro-ecosystems where it is able to grow, and its high dry matter and nutrient outputs per unit of land area make this crop the best option for food and nutrition security for large sectors of the human population, both in the developing and the developed regions of the world (DeFauw et al. 2012; Devaux 2014; Devaux et al. 2014; FAO 2008; De Jong 2016); this is particularly applicable to highland agriculture, where not many productive and nutrition options exist. Due to the growing trends of consumption, particularly in developing regions, and the increasing importance of potato as a staple food worldwide, its nutritive value has enormous potential as a vehicle to improve people's health in both the developed and the developing countries (Love and Pavek 2008). It has been shown that the addition of zinc (Zn) through soil and foliar fertilization of potato plants can increase tuber Zn concentrations with some positive effects on crop yield (Kromann et al. 2016; White et al. 2016). High rates of foliar and soil Zn application produced a 2.51-fold and a 1.91-fold tuber Zn increase, respectively. No difference between cultivars was observed. The same experiments showed that tuber iron (Fe) concentrations were not increased with Fe fertilization. However, as the genetic variation for Fe in potato is large, the Fe content in the tuber content can be improved through breeding (Haynes et al. 2012). Current biofortification breeding work undertaken at the International Potato Center (CIP) has increased mineral concentrations by recurrent selection at the diploid level, resulting in new generations of biofortified potatoes with about 27% increased concentrations up to 35 ppm of Fe and 32 ppm of Zn concentrations on a dry weight basis (Amoros et al. 2017). At present, a strategic interploid crossing with top tetraploid parental lines is being carried out, leading to high-yielding, disease-resistant populations of biofortified potatoes. Moreover, recent evidence shows that the bio-availability of Fe from the potato is higher than that found in other crops. More than 50% of the potato Fe is released from the matrix during the in vitro digestion and is therefore available at the intestinal level. In vitro bio-accessibility of Fe from potatoes was shown to be 6.3 to 31.5% higher than that of pearl millet, fava bean, and rice (Andre et al. 2015).

However, increased potato productivity and production, fostered by new breeding and production technologies, have an impact that goes beyond food and nutrition security, positively affecting farming families' livelihoods by increasing income or creating employment (Sullivan 2010; Thiele et al. 2010). It is important to realize that the potato is a crop with a wide range of ecological adaptability, able to grow in different latitudinal and altitudinal conditions where day length, temperatures, and rainfall are highly diverse (Hijmans 2001). In this respect, the ever-increasing pace of the development of genomics is promoting more focused breeding work oriented to producing new varieties that are more efficient in using water and soil nutrients, as well as more tolerant of biotic and abiotic stresses, thereby making the potato an outstanding climate-smart crop. This work is supported by more effective yield analysis based on crop growth modeling linked to proximal and remote sensing of plant reflectance (Quiroz et al. 2017) and also by new phenotyping techniques (Monneveux et al. 2014).

Taking into consideration the need to nearly double global food production by 2050, the potato still has a significant contribution to make to respond to this challenge, and it has already started to do so, because since 2012 more potatoes are being produced in the developing world than in developed countries.

1.3 The Cultural and Genetic Importance of Potato Biodiversity in the Andes

Being a clonal crop with a wide diversity of cultivated species and landraces, in addition to a clearly defined center of origin and domestication, the potato is unique in terms of the historic and modern relevance of in situ conservation of biodiversity. Although there is no full agreement about potato classification, a recently published comprehensive study of the systematics, diversity, genetics, and evolution of wild and cultivated potatoes (Spooner et al. 2014) supports a classification of the cultivated potatoes into four species: (1) *Solanum tuberosum*, with two cultivar groups (the Andigenum Group of upland Andean genotypes containing diploids, triploids, and tetraploids; and the Chilotanum Group of lowland tetraploid Chilean landraces); (2) *Solanum ajanhuiri* (diploid); (3) *Solanum juzepczukii* (triploid); and (4) *Solanum curtilobum* (pentaploid). In addition, the same article mentions that there are some 3000 landraces (indigenous cultivated crops) still grown by indigenous farmers in South America, particularly in the high Andes, who tend to grow many landraces of all ploidy levels together in the same field. For instance, in Central Peru, the planting of large cultivar mixtures in small areas with large agro-ecological variability brought about by differences in altitude accounts for the conservation of at least 406 unique cultivars (de Haan 2009). This cropping system was a strategy developed by pre-Columbian farmers to cope with climate variability and extreme events prevalent in the High Andes. It is still common to find small potato plots in the Peruvian Andes where up to 20 landraces are grown together. Rather than regarding this system as technologically backward, apt to be replaced by a system based on single, modern varieties, it should be conserved based on two main attributes. First, it offers some important lessons as a highly successful adaptive system to cope with climate change and associated high climate variability (particularly extreme events such as drought or frosts). Second, this system is a very successful method of in situ biodiversity conservation. CIP has the largest ex situ (gene bank) potato collection in the world, which included 4787 cultivated and traditional Andean potatoes, up to February 2017. This is a way of securing the conservation of valuable genes for the future, particularly with threats of climate change, the evolution of production systems, and other agro-ecosystem changes. However, in situ conservation has the advantage of exposing the genetic material to the effect of the environment, which is currently important because native potatoes conserved for thousands of years are subject to new challenges and selection pressure that contribute to increased fitness in the face of climate change. Therefore, this system, in addition to the cultural importance of potato as a food security and income-generating crop for the Andean populations, provides an invaluable wealth of genetic resources that need to be conserved for potential use in breeding varieties tolerant of or resistant to biotic and abiotic stresses. As FAO Success Stories on Climate-Smart Agriculture (http://www.fao.org/3/a-i3817e.pdf) point out, potato genetic resources will continue to represent key resources for building the resilience of agro-ecosystems around the world; and traditional Andean cropping systems provide suitable varieties and breeding stocks necessary to adapt production to changing climatic conditions. Thus, their conservation and sustainable use are a prerequisite for coping with climate change. The Global Environmental Fund (GEF)-funded, FAO-led Global Partnership Initiative on conservation and adaptive management of "Globally Important Agricultural Heritage Systems" (GIAHS), in coordination with the Peruvian Ministry of Environment, other local institutions and the participation of local communities, is helping to value these ingenious agricultural technologies to guarantee their conservation, while providing sustainable development conditions for present and future generations of Andean people (http://www.fao.org/giahs/giahsaroundtheworld/designated-sites/latin-america-and-the-caribbean/andean-agriculture/en/), and to date, 3500 smallholder farming families in 18 rural communities are conserving 177 native potato landraces. There is a very important relationship between in situ biodiversity conservation in traditional farming systems and genomic work, as evidenced by the Genomics and Biodiversity: Providing New Opportunities for Smallholder Potato Farmers project, funded by the German Federal Ministry for Economic Cooperation and Development (BMZ). The CIP in Peru and the Max Planck Institute for Plant Breeding Research (MPIZ) in Germany collaborated with several other partners in this project, which built on CIP's attempts to use the biodiversity of potato genetic resources to improve late blight resistance, while providing income to farmers and training national program scientists in using molecular tools that permit further exploitation of conserved germplasm (GILB 2003). The project contributes to genetic conservation, and it documents and systematizes the traditional participatory selection of new varieties in farmers' fields. Another important CIP effort is its contribution to on-farm diversity by giving back, or repatriating, native Peruvian landraces to those farmers whose ancestors had conserved these varieties for millennia. As of 2016, CIP had repatriated over 7685 samples (>1250 unique accessions) to more than 90 different communities, including those in the "Potato Park," which is a ~10,000 ha reservoir of potato genetic resources (see http://cipotato.org/es/research/genebank/parque-de-la-papa/). At present, the park holds more than 1200 varieties of Andean potato cultivated in the highlands, and it is a unique center of biological diversity of this crop, or of any other staple crop. However, lack of funding for this vital activity, which is sometimes erroneously regarded as an anthropological living museum rather than a modern scientific endeavor, is a stumbling block.

The current existence of potato biodiversity still being cultivated in the Andes has motivated public and private organizations to support the establishment of links between small farmers who cultivate a number of potato landraces and the market. CIP's "Papa Andina" Project, implemented between 2001 and 2012, and including a wide range of public and private stakeholders, developed different approaches in order to make potato biodiversity available to the market and position the native potato as a valuable good. As a result, native potato varieties are now recognized as an essential ingredient of Peru's world-class cuisine. You can now find native potatoes in the market and in restaurants, which were not there a decade ago. This integration of potato biodiversity into value chains is contributing to revaluating the importance of conservation and use of native potatoes, and it positions Peru and other Andean countries as producers of potatoes that cannot be found anywhere else in the world (IICA BID 2014; CIP 2014a, b).

In situ potato biodiversity conservation in the Andes is inextricably linked to traditional local culture and is heavily dependent on women's active decision-making and participation, which is based on a highly sophisticated traditional knowledge of plant diversity, breeding, and culinary properties that has been developed since the potato was first domesticated (Brush 2004; de Haan 2009). Although the potato is generally propagated by seed tubers, which produce clones from the parent plant, women in remote Andean communities were able to use true botanical seed to breed new varieties with novel characteristics, which were then propagated by seed tubers. This implies not only the need to conserve biological potato diversity (Pradel 2013) but also the importance of preserving, understanding, and disseminating women's deep knowledge of the value of this diversity and the techniques for maintaining it. One common problem when dealing with in situ biodiversity conservation and the women's role in it is that the approach is based on a cultural anthropological focus, which gives priority to the traditional way of life, particularly the customs, beliefs, and mythology of an ancient people, rather than the actual knowledge developed by that people (Sarapura et al. 2016). One unintended consequence of this point of view, which privileges the ceremonial and customary attributes of traditional societies over the wealth of poorly understood science and technology developed by those societies, is the fact that peasant communities in the Andes, particularly women, are excluded from national development programs (Diez Hurtado 2010). An interesting and rather different approach has been taken in the analysis conducted by Sarapura et al. (2016), which is based on a feminist standpoint that privileges the peasant women's knowledge and perspectives and the gender implications of the traditional management of native potatoes. Based on the realization of the highly relevant relationship between gender, culture, and potato biodiversity conservation, and the potential benefit for genomics work, due consideration to appropriate funding for potato work in the Andean Region is warranted.

1.4 The Future of the Potato as a Crop

As important as the history of the potato and its past and present economic and social importance are, it is absolutely essential to consider the future of the crop and the multiple aspects of its further development as a crop able to contribute to income generation of small farmers and to satisfy the increasing future nutritional needs of people all over the world. Consolidating the future of the potato calls for research work on several complementary research fronts, such as closing the current yield gaps still existing in several developing countries. This research includes improved agronomic management and the breeding of new varieties adapted and resistant to abiotic and biotic stresses in different and new agro-ecosystems, and dealing with the challenges brought about by the conditions imposed by climate change in current production areas. It also involves the further improvement of the nutritional content of the potato, particularly as a source of micronutrients.

Yield gap (Y_g) is the quantitative difference between a baseline yield (usually the average farmers' yield) and either the attainable (usually, experiment-based yield) or the potential yield (Y_p) over a specified spatial and temporal scale (FAO 2015). In developing regions, the potato yield gap is large, as shown for Sub-Saharan Africa (SSA) by a recent participatory yield gap analysis that included data from ten countries from West Africa, Eastern and Central Africa, and Southern Africa (Harahagazwe et al. submitted for publication). This analysis has shown that SSA (excluding South Africa) countries could easily increase by 140% the current annual production of 10.8 million metric tons if high quality seed of improved varieties resistant to and tolerant of abiotic and biotic stresses, along with improved agronomic management practices, were deployed in farmers' fields. However, productivity increases need to go hand in hand with the development of value chains that can bring opportunities to farmers to reduce the income gap.

The furthering of the importance of potato as a staple food for a high proportion of the human population is largely determined by the significant increase in production and productivity in highly populated countries such as China and India. China produces more than 95 million tons of potatoes per year, which makes this country the world's largest potato producer (FAOSTAT 2015). However, domestic consumption is still low and a challenge to be surmounted by a policy to make potato a staple food comparable to rice. Two significant advantages of potato are that it requires 45% less water than rice or wheat and produces more kcal per unit of resources (Monneveux et al. 2013).

Climate change is one of the most important factors affecting agriculture on a global scale and its effects will increase as time, in decades, progresses. Climate change will affect current potato-producing regions by bringing about an increase in average temperature, the concomitant increase in the reproduction rate of vectors of pests and diseases, a variation in water availability caused by altered rainfall, and increased carbon levels in the atmosphere. Taking advantage of the large genetic diversity of potato species and the capacity of the crop to grow in many soil and climate conditions, scientists will be able to adapt/breed and grow potato cultivars more resilient to heat, water shortages, soil salinity, and diseases. This work is currently being conducted by CIP and its partners in different regions. It is complemented by the development of innovative water-saving irrigation techniques such as Partial Root Zone Drying (PRD), as reported by Yactayo et al. (2013).

In an interesting twist of history, it is highly likely that the potato will add another milestone to its saga by being the first crop to be grown on another planet. NASA and CIP are working together in a project conducted in Peru that is exploring the possibility of growing potatoes under Martian conditions (http://potatoes.space/mars/). They are using soil from Las Pampas de La Joya desert in Southern Peru, the world's driest and most nutrient-poor ecosystem, to test the performance of 65 varieties from the CIP's germplasm bank, selected for their capacity to grow under extreme conditions of variations in day/night temperatures, water scarcity, and soil salinity. These varieties are already being planted in a closed environment that replicates the atmospheric conditions of Mars. The potato is a prime candidate to provide food security to human explorers traveling to Mars in a few decades due to the resilience of the crop and its large number of species, varieties, and landraces that provide a huge reservoir of genetic diversity, adapted to the most extreme conditions on Earth, such as high altitude, low oxygen pressure, water scarcity, soil salinity, extreme temperatures, and high UV radiation. In addition, the potato has a high density and high content of proteins, carbohydrates, soluble and insoluble fiber and micronutrients such as vitamin C, Zn and Fe (http://cipotato.org/potato/potatonutrition/).
For CIP, however, this experience is helping to assess the adaptation of the potato to extreme environments that exist on Mars, but which in the future may become more common on Earth, and we need to be prepared for that scenario.

1.5 Conclusion

The potato has contributed to the development of different civilizations for thousands of years and still has a lot to offer to ensure that food and nutrition security for a growing population is achieved in the coming decades. Its genetic diversity has not yet been fully exploited to generate new varieties with sufficient adaptability for changing and diverse conditions, particularly the more frequent extreme conditions generated by climate change, which implies that there is still a wealth of potential enhancement of the potato's role in satisfying human need for secure, nutritious, and delicious food sources. The Andean region is still the repository of genes conserved in landraces that are an integral part of the culture of current farming communities, and there is the challenge of supporting those farmers to conserve the genetic diversity, and the knowledge and culture that have helped the world in the past, and will help it in the future.

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