Potato landraces: Description and dynamics in three areas of Ecuador

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Contents

Dedication

To my parents Manuel and Alicia (+)

To Emilia, Doménica and Itzel

To my fellow potato farmers of Carchi, Chimborazo and Loja.

CHAPTER 1

General Introduction

History of potatoes in Ecuador

In Ecuador agriculture started in the so called “Formative period” (Huerta, 1966; Reyes, 1984). This period lasted from 4400 - 300 B.C. and saw the start of sedentary village life, agriculture and ceramics (Zeidler, 2008). The first archeological record of potatoes in Ecuador was found in Cotocollao (Pichincha province, north of Ecuador) dating 1500 B.C. (Zeidler, 2008). When the Spanish arrived in South America at the end of the 15th century, they discovered what were for them new plant species. Cieza de León was in 1553 one of the first Europeans to mention potato (*papa)*, both in Quito where he first saw the plant being cultivated and in the highlands of Peru. Cieza de León, speaking of the Quito Indians says "…besides maize, there are two other products which form the principal food of these Indians. One is called papa and is a kind of earth nut, which after it has been boiled is as tender as a cooked chestnut, but it has no more skin than a truffle and it grows under the earth in the same way." (cited in Hawkes, 1947).

At the beginning of the 20th century, the Russian scientist N. Vavilov stated that crop variation was correlated to global geographical distributions (Vavilov, 1927). The Andean region was identified as one of the centers of origin and domestication of several crops; including potatoes. The potato was first domesticated in the central area of South America between 10,000 to 6,000 years ago (Brush et al., 1995; CIP, 2010a; Hawkes, 1988; Ames et al., 2008). Ecuador is one of the centers of diversity for wild and cultivated potatoes (Hawkes, 1988; Hawkes, 1990). The Ecuadorian biodiversity of potato includes 23 wild species and three cultivated taxa of tuber-bearing *Solanum* species (*Solanum phureja*, *S. chaucha* and *S. tuberosum* subsp. *andigena*; Spooner et al., 1992; Spooner et al., 2007).

Currently potatoes are mainly produced in the highlands of Ecuador by small farmers. Approximately, 42,000 families are involved in potato production and 66,000 hectares are cultivated (Andrade et al., 2002). Ecuador produced 266,722 MT of potatoes in 2009 (FAO, 2009a). More than 400 landraces of native potatoes are presumed to exist in Ecuador (Cuesta et al., 2005), but a recent inventory is not available.

Potato landraces

The native potatoes growing in the Andes have been described under different names, e.g. Indian potatoes (Hawkes, 1947), native potato varieties (Brush et al., 1981), Andean cultivated potatoes (Quiros et al., 1990); native potato cultivars (Zimmerer, 1991), potato landraces (Brush et al., 1994), or cultivars (De Haan, 2009). In this thesis we will use the term "landrace" when referring to either of these.

Although several definitions of the term landrace have been used since the late 19th century (Zeven, 1998), we adopt the concept of landrace as defined by Camacho et al. (2006): "A landrace is a dynamic population(s) of a cultivated plant that has historical origin, distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems".

Genetic erosion

According to the Food and Agriculture Organization of the United Nations (FAO, 1997), genetic erosion of Plant Genetic Resources for Food and Agriculture (PGRFA) is occurring. Genetic erosion is the loss of genetic diversity including the loss of individual genes or the loss of particular combinations of genes (FAO, 1997). This term is sometimes used in a broader sense, referring to the loss of varieties. The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) defines PGRFA as "any genetic material of plant origin of actual or potential value for food and agriculture" (ITPGRFA, 2009).

In the first State of the World's PGRFA report (FAO, 1997) most of the countries reported the replacement of local varieties or landraces by improved new or exotic varieties as the main cause of genetic erosion, followed by land clearing (deforestation and bush fires) and overexploitation (overgrazing). The second State of the World's PGRFA report (FAO, 2010) presented several contrasting opinions. Some countries mentioned that genetic erosion had continued (Chaudhuri, 2005), but others that diversity was maintained (Jarvis et al., 2008) or that the introduction of new varieties did not reduce but even increased the diversity in farmer fields because farmers maintained both (Cavatassi et al., 2006).

Like many areas in the world, in Ecuador a reduction of genetic diversity grown in farmers' fields seems apparent. Tapia et al. (2004) mentioned genetic erosion for other Andean tubers like oca (*Oxalis tuberosa* Mol.), melloco (*Ullucus tuberosus* Cal.) and mashua (*Tropaeolum tuberosum* R.& P.). These tubers are part of the rotation that includes potatoes in some areas. So far, a possible genetic erosion of the potato diversity has not been assessed in Ecuador. For Peru no genetic erosion was detected based on a comparison of alleles found in the field with alleles found in a core collection of potatoes conserved at CIP (De Haan, 2009).

The number of landraces currently grown by local farmers is not known. In the central provinces: Cotopaxi, Tungurahua, Chimborazo and Bolivar, only 5% of potato landraces reach the main markets (Unda et al., 2005; Monteros et al., 2005a). Two improved varieties (INIAP-Gabriela and Superchola) occupy more than half of the cultivation area (Andrade et al., 2002). Cuesta et al. (2005) mention that local landraces of potato in Ecuador are in danger of extinction due to the introduction and use of new high yielding varieties as well as high pest and disease pressure and lack of market opportunities for landraces (Cuesta et al., 2005).

***Ex situ* conservation**

The FAO began activities concerning PGRFA in 1947 (Brush, 1994). In the early 60's there was a global concern about the loss of genetic resources, and *ex situ* conservation of PGRFA was recommended (Frankel et al., 1974). *Ex situ* conservation is the conservation of components of biological diversity outside their natural habitats (CBD, 1992). This type of conservation continues to represent the most significant and widespread means of conserving PGRFA (FAO, 2010). About 7.4 million accessions are conserved globally in more than 1750 gene banks. Advantages of *ex situ* conservation of seed propagated materials are low maintenance cost, easy accessibility and relatively safe storage (Swanson and Goesch, 2000). However, *ex situ* also has disadvantages, including no further evolution of the plant material, lack of representation of the whole range of diversity in a given crop, potential genetic changes during grow-out procedures, and low representation of minor crops (Altieri and Merrick, 1987).

***In situ* conservation**

In situ conservation, sometimes as called “on-farm conservation” (Jarvis et al., 2000), refers to "the continuous cultivation and management of a diverse set of populations by farmers in the agro ecosystems where a crop has evolved" (Bellon et al., 1997). *In situ* conservation strategies have advantages such as continued crop evolution and the conservation of traditional farming systems that rely on the maintenance of genetic diversity (Altieri and Merrick, 1987; Brush, 1994; Swanson and Goesch, 2000).

The on-farm management and conservation of PGRFA, in particular the maintenance of traditional crop varieties in production systems, has increased in the last decade (FAO, 2010). On-farm conservation related studies on native potatoes have been published for Peru (Brush and Taylor, 1992; Brush et al., 1995; De Haan et al., 2007; De Haan, 2009) and Bolivia (Terrazas et al., 2005; Iriarte et al., 2009). Initial studies on native potatoes in Ecuador have been presented in Monteros et al. (2005b), but this study addressed only a limited number of landraces. To understand the current status of potato conservation additional studies are necessary.

Because *ex situ* and *in situ* conservation strategies have different advantages and disadvantages they should be complementary (Jarvis et al., 2000; Engels and Visser, 2003). The two complementary conservation approaches link the farmer's system and the institutional system involved in the conservation of PGRFA (Almekinders and De Boef, 1999).

Conservation of genetic resources by institutions in Ecuador

The National Institute for Agricultural Research, INIAP (Instituto Nacional Autónomo de Investigaciones Agropecuarias) has been the leading governmental institution in agricultural research for over 50 years in Ecuador. INIAP started the conservation of PGRFA through the National Department of Plant Genetic Resources (INIAP-DENAREF) in the early 80's. However, the first collections started already in the 50's when the cocoa collection was assembled. Currently, INIAP holds the most important gene bank in Ecuador with 17,920 accessions of approximately 200 different plant genera including crops, forestry, grasses, fruits, medicinal plants and ornamentals (Tapia et al., 2009). From these accessions approximately 14,000 are conserved: in cold storage (species with orthodox seeds) and the rest in experimental fields or *in vitro* (species with recalcitrant seeds or sexually propagated crops). Projects on on-farm conservation with local communities are also being developed (INIAP-DENAREF, 2009a). INIAP's Potato Breeding Program (INIAP-PNRT) has been active since the early 60's generating new potato varieties for Ecuador.

The International Potato Center (CIP) maintains the world's largest collection of potato germplasm, including some 1,500 accessions of about 100 wild species collected in eight Latin American countries, and 3,800 traditional Andean cultivated potatoes (CIP, 2010). INIAP (National Program on Root and Tuber Crops, PNRT) and CIP have worked together for many years in releasing new potato varieties such as INIAP-Fripapa and INIAP-Natividad with good acceptance at national level.

Characterization of genetic diversity

The characterization of germplasm involves determining the expression of characters, ranging from morphological features to seed proteins and molecular markers (Engels and Visser, 2003). The importance of the molecular characterization of germplasm is, according to Spooner et al. (2005 a) evident, not only for taxonomy but also for the identification of clones for breeding use or conservation. Characterization of an old Ecuadorian collection was done by using morphological descriptors and isozymes for early and late potato landraces (Alarcón, 1995; Escobar, 1997). However, only few of these accessions were maintained *ex situ* in Ecuador by the beginning of this thesis research.

The use of molecular techniques has helped in the determination of genetic relationships (Sukhotu et al., 2005) and in studying the evolution of cultivated potatoes (Hosaka, 1995; Spooner et al., 2005b). Different DNA fingerprinting techniques such as RAPD, ISSR, AFLP and microsatellites (SSRs) have been used for tetraploid potato germplasm (McGregor et al., 2000; Reid et al., 2009; Reid et al., 2011). RAPDs and nuclear SSRs have been used to analyze the *Solanum tuberosum* L. Phureja Group (Ghislain et al., 2006). Microsatellites have been efficient in genotyping cultivated potatoes (Ashkenazi et al., 2001; Ghislain et al., 2004; Raker and Spooner, 2002). Nuclear and chloroplast DNA have also been applied to determine phylogenetic relationships among wild and cultivated potatoes (Sukhotu et al., 2004). Some of these studies (Sukhotu et al., 2005; Ghislain et al., 2006; Spooner et al., 2007) have included a few accessions of cultivated material from Ecuador. The majority of the Ecuadorian potato landraces still need to be characterized with molecular techniques to describe the genetic diversity present in farmer fields. Compared to other marker systems, SSRs have proven to be very effective because they are co-dominant, reproducible, cost-effective, simple to use and highly polymorphic (McGregor et al., 2000; Milbourne et al., 1997; Jones et al., 1997). SSRs were chosen to study the Ecuadorian diversity of potatoes collected in farmers' fields for this thesis.

Late blight

Late blight (LB) caused the Irish Potato Famine (1845-1847). It is caused by the oomycete *Phytophthora infestans* (Mont.) de Bary and has led to significant economic losses in potato production worldwide. This disease is also the most important limiting factor in potato commercial production in Ecuador and in order to prevent it large amounts of fungicides are used (Crissman et al., 1998).

In South America, small-scale farmers grow different landraces of potatoes in their fields. Germplasm evaluations for resistance to LB in South American tetraploid native potatoes indicated that most germplasm was intermediate to highly susceptible (Van Soest et al., 1984). Diploid Ecuadorian potato landraces of *S. phureja*, also are mostly susceptible, but some of them showed field resistance to LB (Cañizares and Forbes, 1995; Revelo et al., 1997). Regardless the apparent lack of resistance local farmers have maintained landraces under low input conditions and under LB pressure for hundreds of years. Perception of LB resistance by local farmers and studies on their potatoes could help to elucidate how these potatoes have been maintained for several generations.

Quality traits

Potato is the fifth most important crop worldwide in terms of production after rice, wheat, soybean and maize (FAO, 2009b). FAO estimates that just over two-third of the 320 million tons of potatoes produced in 2005 were consumed by people as food (CIP, 2008a). Europe and North America are the regions with the highest consumption per capita 87.7 kg and 60 kg, respectively, while in South America 20.7 kg per capita is consumed (CIP, 2008b). The nutritional composition of potatoes is important considering the high use of this crop in diets of people around the world. Potato is rich in carbohydrate content but it also provides significant quantities of other nutrients such as proteins, minerals and vitamins (Kadam et al., 1991). Potato is also a good source of antioxidants (Brown, 2005). Antioxidants may be of importance in the prevention of cancer and cardio-vascular diseases, immune system decline, brain dysfunction and cataracts (Yang et al., 2001; Ames et al., 1993; Liu, 2004). The vast diversity of Andean potatoes also reflects vast differences in nutrient content (Burlingame et al., 2009b). Examples of these variation include P, K, Ca, Mg, Na, Zn, Fe (Burgos et al., 2007; Andre et al., 2007; Ritter et al., 2008) and antioxidants such as carotenoids, polyphenols, ascorbic acid among others (Campos et al., 2006; Brown et al., 2007; Andre et al., 2007; Burgos et al., 2009a; Burgos et al., 2009b). Data on food composition is useful to describe crop genetic resources and could help to promote the use of lesser-known cultivars with superior quality characteristics (Burlingame et al., 2009a).

Legal instruments in Ecuador regarding genetic resources conservation, access and farmer's rights

Ecuador has ratified the Convention on Biological Diversity (CBD) (Registro Oficial, R.O. 148, 16 March 1993). Currently the CBD include 193 Parties. The National Focal point for the CBD is the Ministry of Environment. The Andean Community of Nations (Colombia, Ecuador, Peru and Bolivia) has adopted Decision 345 (21 October 1993) which refers to a Common Regime for Plant Variety Protection and Decision 391 (2 July 1996) regarding a Common Regime on Access to Genetic Resources (CAN, 2011). The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) was adopted on the 6th January 2004 according to R.O. 245 and currently includes 127 Parties. The objectives of the ITPGRFA are the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising out of their use. ITPGRFA is in harmony with the CBD (ITPGRFA, 2009). INIAP is the National Focal Point for Plant Genetic Resources for Food and Agriculture related matters.

The Ecuadorian Institute for Intellectual Property (IEPI) is the national administrative institution coordinating the Plant Variety Protection (CAN, Decision 345). The Intellectual property Law currently in place was published in R.O. 320 (19 May 1998). Ecuador became member of UPOV, the International Union for the Protection of New Varieties of Plants, on August 8, 1997 and has signed the 1978 Act. IEPI is also the institution responsible for the protection of traditional knowledge of local communities.

Scope of this thesis

This thesis aims to describe the potato genetic diversity present in three selected research areas in Ecuador. To this end we analysed the current situation and the vulnerability of on-farm conservation in Ecuador. We measured the level of genetic diversity among the landraces within and among the areas. We evaluated representative potato landraces with respect to *Phytopthora* resistance and quality traits to assess the possibilities for incorporation of these materials in future breeding programmes or on-farm conservation projects.

In **Chapter 2** we identified three representative areas where a high number of potato landraces was present in the 70's and 80's. We collected the landraces presently grown in farmer fields in those areas. The farmers holding potato landraces were interviewed and we described these potato landrace holders. We also invited farmers to local meetings where we analyzed the vulnerability of on-farm conservation of potato landraces in their areas.

In **Chapter 3** we describe the relationship between landrace names and genetic profiles of the collected landraces by using microsatellites. As these microsatellites were previously applied to a collection of European varieties, we compared the allele diversity present in these two collections. We determined the genetic relationship among the three potato populations studied.

In the **Chapters 4 and 5**, we evaluated selected potato landraces from the research areas with respect to *Phytopthora* resistance and specific quality traits to assess the possibilities for incorporation of the material in future breeding programs or on-farm conservation projects.

A general discussion of the findings of this thesis is presented in **Chapter 6.** We explore the possibilities to complement *ex situ* with *in situ* conservation and to use the potato landrace diversity.

CHAPTER 2

On-farm conservation of potato landraces in Ecuador

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Abstract

Three areas of high potato diversity were identified for Ecuador by using passport data of material collected during the 70's and 80's. During 2006, 2007 and early 2008, collecting missions were conducted to these areas to determine the current diversity of potato landraces. When the earlier collections were compared to the present collection, many new landraces were found. The low number of landraces common to the past and present collections might suggest that the sampling of local landraces was far from exhaustive, both during the 70's and 80's and during the present collection trips. This is further supported by the fact that a diversity fair in Chimborazo resulted in many new landraces.

Mostly elderly people and small-scale farmers are currently maintaining potato landraces. As their farms cannot fully sustain them, these farmers look for income alternatives besides agriculture through migration. The vulnerability of the potato conservation varies among our study areas. For example, in Carchi younger farmers demonstrate a lack of interest in cropping potato landraces. In Loja farming is not seen as the only sustainable source of income and there is a perceived lack of support from the government for the activities necessary to maintain local landraces. In Chimborazo farmers are culturally more attached to their land and see agriculture as a family activity, rendering the potato landrace conservation less vulnerable.

Externally driven on-farm conservation interventions, such as diversity fair or re-introduction of landraces, were highly appreciated by the farmers and could help to conserve the potatoes.

Key words: diversity, Ecuador, farmers, landraces, on-farm conservation, potato

Introduction

In South America a wide diversity in cultivated and wild potatoes species is present. Ecuador is one of the centers of diversity for these species (Hawkes, 1988; Hawkes, 1990). The Ecuadorian biodiversity of potato includes 23 wild species and 3 cultivated taxa (*Solanum tuberosum* subsp. *andigenum* and

Solanum phureja) (Spooner et al., 1992; Spooner et al., 2007). The diversity in cultivated potato is not randomly distributed; spots with a high diversity can be identified. These spots or microcenters are small areas in which the diversity of a crop is concentrated (Harlan, 1951). The International Potato Center (CIP) has identified such microcenters of diversity for native potatoes. For Ecuador, the Chimborazo and Carchi provinces are such microcenters (Ortega-Cartaza et al., 2005; CIP, 2010b). Areas with high diversity are suitable targets for on-farm conservation of plant genetic resources (Bellon, 2004). On-farm conservation related studies on native potatoes have been published for Peru (Brush and Taylor 1992; Brush et al., 1995; De Haan et al., 2007; De Haan, 2009) and Bolivia (Terrazas et al., 2005; Terrazas and Cadima, 2008; Iriarte et al., 2009). Initial studies on native potatoes in Ecuador have been presented in Monteros et al. (2005b), but more studies are necessary.

More than 400 landraces of native potatoes have been reported for Ecuador (Cuesta et al., 2005) but a recent inventory is not available. We use the term landrace as defined by Camacho et al. (2006): "A landrace is a dynamic population(s) of a cultivated plant that has historical origin, distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems". Currently, only 20 landraces are reported to be marketed in the central provinces of Ecuador (Unda et al., 2005). To what extent farmers maintain landraces is unknown. It has been suggested that the introduction and use of modern cultivars and the lack of market opportunities are negatively influencing the conservation of landraces (Cuesta et al., 2005). However, there is no systematic inventory on the forces that favor the conservation of these materials.

In this paper we describe the current situation with respect to the conservation of potato landraces in Ecuador. The current potato diversity at three locations was compared with the diversity at the same places approximately 30 years ago to determine the dynamics in potato diversity. Potato farmers currently growing landraces were interviewed and invited to local meetings to evaluate the vulnerability of the current system.

Materials and methods

Selection of the research areas

To identify the research areas we used three databases with passport data of previous collections in Ecuador from the 70’s and 80’s. We analyzed them by using the program DIVA GIS 4.2 (Hijmans et al., 2004). One database is from the International Potato Center (CIP) containing 459 Ecuadorian accessions, including cultivated and wild species (CIP, 2007), and two others are from The National Institute for Agricultural Research INIAP (Instituto Nacional Autónomo de Investigaciones Agropecuarias). INIAP is the National Focal Point on Plant Genetic Resources for Food and Agriculture for Ecuador. The INIAP databases are from the National Program for Root and Tuber Crops-PNRT (692 accessions of cultivated material) and from the National Department of Plant Genetic Resources-DENAREF (187 accessions of cultivated and wild material). Duplicates, based on name and collection site, were eliminated as well as wild material and accessions of modern cultivars. In total 443 accessions of landraces were included in a new database. We used this database to select three research sites. DIVA GIS 4.2 generated maps with colored cells indicating the number of landraces present (Figure 1) were used as a first selection criterion. Since there were several areas with high numbers of landraces, we also took into account the geographical location (north, center and south). The three research sites that we finally selected are located in the provinces Carchi, Chimborazo, and Loja.

Collection of the landraces in the research areas

The earlier potato collection missions in the 70s and 80s yielded over 400 accessions of Ecuadorian potato landraces. These included 82 accessions from Carchi, 35 from Chimborazo and 41 from Loja. However, over the years accessions were lost and a core collection of only 91 Ecuadorian potato landraces was still maintained *ex situ* when we started with the first collection activities for this study in 2006.

Similarly to the earlier collections we covered the cantons Espejo, Mira, El Angel, Huaca, Montúfar, San Gabriel and Tulcán in Carchi; Chunchi, Colta, Guamote, Guano, Penipe and Riobamba in Chimborazo (the canton Alausí was included in this collection but not in the 70's-80's collection); and Gonzanamá, Loja and Saraguro in Loja. The collections were made following the methodology currently used by INIAP and other gene banks (Castillo and Herman, 1995). The farmers were informed about the purpose of the study and they agreed to provide the materials to the collectors. As there was no information on the individual farmers that were visited in the collection missions in the 70s and 80s, we asked in every microcenter for farmers holding "old potato landraces", assuming this snowball technique would lead us to the current holders of landraces. We did not restrict the search to landraces already reported but tried to find all old landraces available. When we collected a specific landrace we did not collect another with the same name from another farmer in the same canton. Only when the morphological appearance was (slightly) different from the synonym landrace, we collected it. Every collection was a sample of five to ten tubers. After every collection trip, we took the potato samples to INIAP-Santa Catalina Experimental Station in Quito for propagation and evaluation.

As wild potatoes were collected in Ecuador before (Spooner et al., 1992), and there might be interactions between wild and cultivated potatoes, we investigated whether such species were present and if they could be found close to farmer's fields. Berries from any potato-like species close to a farmer field were also collected and vouchered as herbarium sheets for identification at the Herbario Nacional in Quito.

Survey

To collect information about on-farm potato conservation in the research areas, a questionnaire with 40 questions was prepared (see Appendix 1). Fifty (50) farmers were selected in each research area. Initially, all farmers that provided germplasm were interviewed. Then, these farmers were asked to suggest other potato farmers in the area that currently were growing potato landraces or had been growing them in the past. In this way we identified the farmers needed to arrive at the total 50 farmers per research area. At the selected farms, the interviews were made either with men or women based on their availability. This fieldwork was carried out from March to August 2008.

Farmer meetings

Three farmer meetings of one day each were organized in each research area: one in Tenta-Loja (November, 2009), another in San Gabriel-Carchi (December, 2009), and the last one in Pisicaz-Chimborazo (February, 2010). These meetings had three objectives: 1. To return information from the surveys to the local farmers. 2. To clarify some of the issues arisen from the interviews. 3. To return the landraces that were collected in each study area to the farmers. All the farmers involved in the collection and survey were invited.

Data analysis

All the information from the surveys was entered in Excel databases and exported to SPSS 15.0 for analysis (SPSS Inc. 2006). We applied descriptive statistics and conducted bi-variate correlations (Pearson, two tailed).

Results

The research areas

Figure 1 shows the distribution and number of potato landraces collected in Ecuador during the 70’s and 80’s, that resulted from the analysis of the combined database. The three research sites that we selected are located in the provinces Carchi, Chimborazo, and Loja. However, the potato production areas are restricted to some cantons within the provinces. The first research area is the province of Carchi which is located in the North of Ecuador between 0° 27` to 1° 10` N latitude. The second, Chimborazo, is located at the center of Ecuador from 1° 33` to 2° 55’ S latitude and the third, Loja, is located between latitude 3° 18` and 4° 45`S.

These three research areas differ in the ethnic background of the famers managing the potatoes (Carchi mainly a mestizo province, Chimborazo mainly indigenous and Loja a mixture of mestizo and indigenous). Two research sites identified in this study (Carchi and Chimborazo) are identical to the microcenters identified by CIP (Ortega-Cartaza et al., 2005; CIP, 2010b). The province of Loja was identified as the third research site and this province was recognized as a hot spot of biodiversity (Pohle and Gerique, 2008) but its potato diversity was not previously recognized.

Most of the population in Carchi are “mestizos”, persons of mixed Spanish and Indian cultural background. They were never under Inca influence (Frolich et al., 1999; Espinosa, 2006). Carchi has a relatively small number of indigenous people, 2.8% of the total population in the province according to INEC (2006). Carchi is also the first area where intensive monocropping of potatoes became common practice during the last 20-30 years. Nowadays is almost exclusively dedicated to pasture and milk cow grazing (Frolich et al., 1999). Espinosa (2006) points at the lack of organization of and cooperation between farmers in Carchi.

In Chimborazo, most of the farmers are Indians who value their culture (Espinosa, 2006). Chimborazo is considered the capital of the Indians as this group accounts for 38% of the total population in the province (INEC, 2006). From the 17th century on, Chimborazo’s country side was dominated by the hacienda system, the system was based on relations of service tenure “Huasipungo” (Korovkin, 1997). In 1964, the farmers were granted property rights for their small plots of land (Korovkin, 1997). Farmer organization tends to be stronger than in Carchi (Espinosa, 2006).

Loja, in southern Ecuador, has an Indian population of about 3.1%, mostly located in the Saraguro canton (INEC, 2006). Saraguro is one of the areas within the Loja province with the highest level of potatoes crop diversity (Graf 1990 cited by Pohle and Gerique, 2008; Finerman and Sacket, 2003). The Saraguros are highland Indians who speak Quichua. From the nineteenth century they kept cattle to supplement their traditional “system of mixed cultivation”, featuring maize, beans, potatoes and other tubers. It is assumed that they originally came from the Titicaca region in Bolivia and settled as workers and vassals in the Andean highlands by the Incas (Pohle, 2008). Nowadays mestizos and Indians share the region.

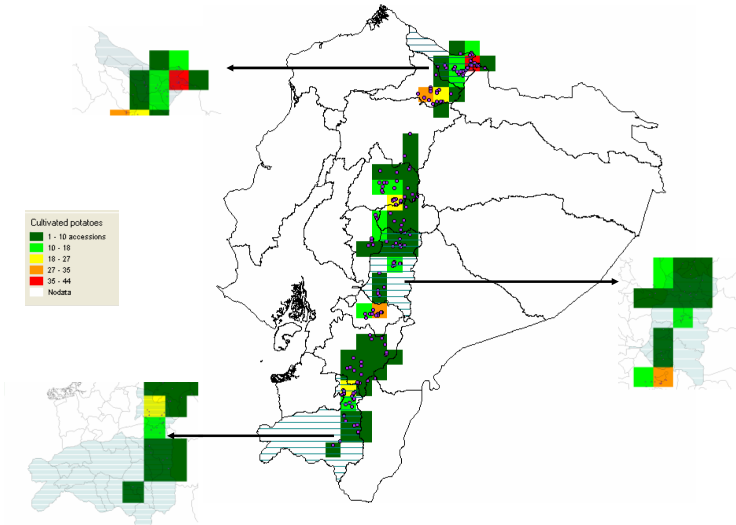

Figure 1. Distribution of cultivated native potatoes in the Andean region of Ecuador using DIVA GIS 4.2 (passport data from collections during the 70's and 80's). The research areas selected for the study are pointed out: the provinces of Carchi (in the North), Chimborazo (Center) and Loja (South).

The collecting missions

Our snowball technique to find the farmers conserving potato landraces was effective. Farmers in each location led to other farmers having specific landraces. In 2007, we conducted two collection trips to Carchi. During the first trip 14 accessions of potato landraces were collected in the Montúfar canton. A second trip later that year added another 38 landraces and 8 accessions of wild potato-like-plants growing close to farmers' fields to the collection. For Chimborazo, INIAP-CIP conducted a collection mission in early 2006 to two cantons of the province: Colta and Guamote. At that time 46 landraces were collected. A complementary collection to other cantons (Guano, Penipe, Riobamba, Alausí and Chunchi) in 2008, resulted in 16 new landraces and two wild potato-like-plants. In Loja, during January 2008 we collected 60 potato landraces and 4 wild potato-like-plants. All together 174 accessions of landraces were collected from 17, 28 and 30 farmers in Carchi, Chimborazo and Loja, respectively. Farmers growing potato landraces are more dispersed and scarce in Carchi and Loja (and consequently more difficult to find); while in Chimborazo most of the farmers (among the indigenous communities) keep old landraces in their fields.

Additionally, a diversity fair was organized in Chimborazo, Colta canton in 2008 (Project INNOVANDES, CIP-INIAP-FAO to celebrate the International Year of the Potato). This fair, which was aimed at creating awareness and bringing potato growers together to exchange their material, resulted in 35 additional landraces based on names and morphological characteristics.

All these potato landraces were integrated into the potato collection at the Ecuadorian genebank at INIAP (Appendix 2). In total our collection provided 209 new accessions of landraces from the research areas. They constitute almost 50% of the newly assembled Ecuadorian potato collection comprising about 450 accessions.

Figure 2 shows the number of landraces collected at each microcenter, based on their names. When we compare the names of the landraces collected during the 70’s and 80’s with those collected in the present study (Figure 2), we observe that in the collections of Carchi only 13 names are similar between the 2 collection periods. For Chimborazo and Loja these figures were 14 and 15 names, respectively.

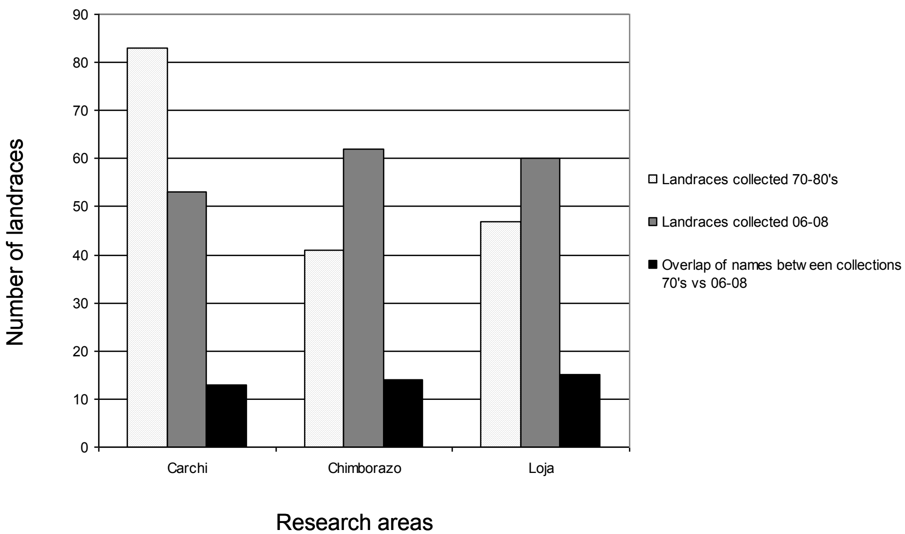

Figure 2. Number of landraces collected in the three research areas. Shown are the number of different landraces, as judged by their name, collected during the 70’s and 80’s (database used for the research areas identification) and those collected during the period 2006-2008 (landraces collected at the diversity fair are not included). The third column is the overlap in names between the two collections.

The characteristics of the interviewed farmers

The characteristics of the interviewed farmers are presented in Table 1. Men and women were interviewed according to their availability, which resulted in fairly equal representation in Chimborazo and Loja. Only the survey in Carchi shows an over-representation of men. However, the category of men includes 6 cases in which husband and wife answered the questions together.

Table 1. Characteristics of the 50 respondents to the questionnaire at each of the three research sites in Ecuador. The respondents currently grow potato landraces or grew them in the past.

Descriptor	Characteristics	Carchi	Chimborazo	Loja
Gender	Men	35	23	23
	women	15	27	27
Age	< 30 years	2	1	5
	30-40 years	7	9	8
	41-50 years	10	16	12
	> 50 years	31	24	25
	Min	25	27	23
	Max	88	70	82
	Mean	58	51	51
	SD	16.1	10.7	15.2
Race	Mestizos	50	10	35
	Indigenous	0	40	15
Farm size (hectares, ha)	≤ 3 ha	19	38	31
	4-10 ha	17	10	4
	≥ 10 ha	6	1	1
	Min	0.2	0.1	0.03
	Max	70	40	50
	Mean	7.3	3.3	3.0
	SD	12.2	5.9	10.7
Education	No education	3	23	4
	Primary school	42	24	38
	Secondary	3	3	4
	College	2	0	4

From Table 1 we can see that most farmers are over the age of 50 and an average age of the respondents of 53. The race distribution (mestizos and indigenous) differs among the regions. Our data in Table 1 also shows that most of the potato diversity is in hands of farmers with landholdings of less than 3 ha: 19 farmers in Carchi, 38 in Chimborazo and 31 in Loja. The level of education of the respondents was generally poor. The statistical test (Pearson, two tailed) showed hardly any significant correlations among the descriptors. The only significant correlation is between age and education. Older people are less educated than younger generations.

Additionally to cropping activities, 46% of the farmers in Carchi, 10% in Chimborazo and 64% in Loja kept livestock (cattle and minor animals), or performed house-keeping activities. Other off-farm income-generating activities were paid labor in agriculture or non-agricultural activities, as mentioned by 20% of the farmers in Carchi, 14% in Chimborazo and 35% in Loja. Figure 3 shows how farmers value their activities based on income generation. In Chimborazo agriculture is the most important activity (86%), whereas in the other regions the other activities play an important role as well. Most of the potato farmers mentioned to have one or more family members who migrated to find a job outside agriculture (53% Carchi, 64% Chimborazo and 52% in Loja).

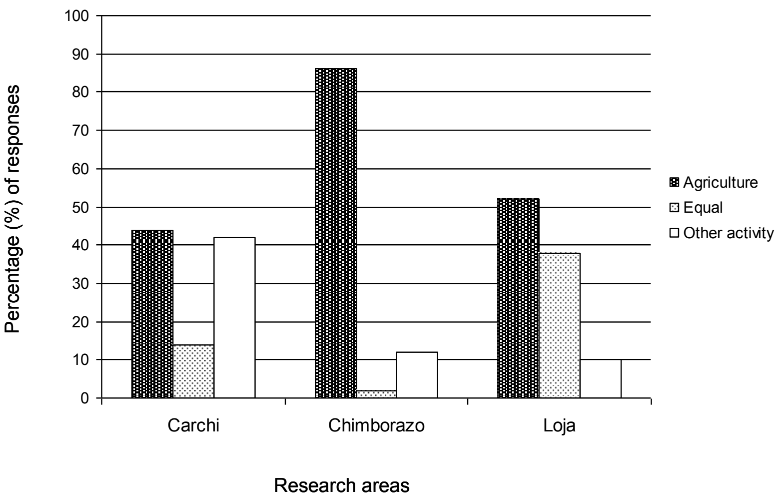

Figure 3. Percentage of farmers' responses regarding which work (agriculture or other) they consider more important for income generation.

Potatoes in the farming system

The farmers rotate potato with other crops. In Carchi an individual farm can produce up to 5 different crops including potatoes, in Chimborazo 8 crops and in Loja 7 crops. In total, besides potato, 16 crops or crop groups were mentioned: wheat (*Triticum vulgare*), barley (*Hordeum vulgare*), grass (various), faba bean (*Vicia faba*), carrot (*Daucus carota*), peas (*Pisum sativum*), maize (*Zea mays*), other vegetables (various), ulluco (*Ullucus tuberosus*), mashua (*Tropaeolum tuberosum*), oca (*Oxalis tuberosa*), chocho (*Lupinus mutabilis*), fruits (various), quinoa (*Chenopodium quinoa*), bean (*Phaseolus vulgaris*) and other minor crops. In Carchi potato farmers include rotations with all crops mentioned above except oca, chocho, fruits, quinoa and beans. In Chimborazo beans are missing from the rotation because this is a crop for lower altitudes. In Loja chocho and quinoa are missing from the potato rotations. The questionnaires addressed only how many major crops were present in the rotation with the potatoes and not all crops present. Medicinal plants or diversity within the other crops were not surveyed.

Most of the farmers at the research areas grow both landraces and commercial cultivars and manage these groups similarly (64% in Carchi, 58% in Chimborazo and 60% in Loja). However, landraces are grown in smaller plots or in home gardens, whereas commercial cultivars are in larger plots (field observation). Some farmers grow early sprouting potatoes (*S. phureja* referred to as "chauchas") along with other potatoes such as *S. tuberosum* subsp*. andigenum* or probably *S. chaucha* in the same fields, but would grow the landraces in separate rows.

After the harvest, the commercial cultivars are sold immediately, and the landraces (that usually are not sold on the market) are stored for consumption (in the kitchen or nearby storage room), distributed among family, exchanged with the neighbors or saved as seeds for the next cycle. Farmers in Carchi mention exchanging seeds in 46% of the cases, 23% in Chimborazo and 60% in Loja. However, farmers usually do not know who else maintains the less common landraces (Carchi 75%, Chimborazo 68% and Loja 53%).

Labor allocation

In the potato farming system in Ecuador, there is a division of labor among the family members. The different activities in the potato growing cycle and the different labor division are summarized in Table 2.

Table 2. Labor division during the potato planting cycle in percentages at three research areas of potato diversity in Ecuador: Land preparation, cropping daily activities and harvest.

Question	Answers	Carchi	Chimborazo	Loja
Who prepares the land?	Farmer (man)	62	22	44
	Farmer (woman)	0	14	14
	Both	9	60	24
	Other	29	4	18
Who does the daily activities?	Farmer (man)	77	30	32
	Farmer (woman)	0	20	26
	Both	6	46	38
	Other	17	4	4
Who harvests the potatoes?	Farmer (man)	32	8	16
	Farmer (woman)	0	0	14
	Both	36	20	52
	Family	0	52	0
	Other	32	20	18

Labor allocation for land preparation is different among research areas. In Carchi it is mainly carried out by the men (62%), in Chimborazo this activity was mainly shared by the men and women (60%) and in Loja 44% of the respondents answered that only men prepare the land, but in 24% of the cases men and women together carry out this activity. The potato cropping activities (daily activities after planting and before harvesting) in Carchi are mainly taken care of by the men (77%). This is different in Chimborazo where 46% answer that the activity is shared by men and women. In Loja, 38% answer that men and women together take care of the daily activities, 32% only men and 26% only women. The harvest is in most cases a family activity done by men and women together, as pointed out by the respondents in Chimborazo.

Reasons to maintain potato landraces

Since most potato landraces are not marketed, farmers grow these potatoes for other reasons. During the meetings farmers mentioned culinary characteristics such as good taste and softness after cooking. In Chimborazo some of the landraces are reported as good for “Cariucho” which is a typical dish among the indigenous farmers, made from faba bean, oca, melloco and potatoes boiled together. Other advantageous characteristics include drought, frost and late blight resistance. Medicinal uses of certain landraces were also mentioned, such as the use of *Puña* to cure headaches and of *Chaucha amarilla* to cure gastritis. These and other attributes have kept their potatoes from disappearing.

Occurrence of wild potato-like species

During the survey, many common names for wild potato-like species were identified. We recorded the following names in the three areas: Carchi: *Charcheres, Coalla, Juarrios, Papa cuarria, Papa de la vieja, Papa del monte*, and *Puerquitas*; Chimborazo: *Aya papa, Cuchi papa, Chahuara, Chavela, Chuco, Lobo, Mata de Tzímbalo, Tzímbalo, Papa chavela bejuca, Papa de monte, Papa del inca, Quita papa, Sacha papa,* and *Urco papa*; Loja: *Ojo de venado, Papa chio, Papa de conejo, Papa chacra, Papa de cerro, Papa del gentil, Papa de monte, Papa de venado, Sacha papa,* and *Tzímbalo*. Only three of these were already recorded by Hawkes (1947): *Aya papa, Papa chio* (as *Zhio*), and *Sacha papa*.

However, based on herbarium identification the only “potato-like species” found close to the cultivated potatoes was *Solanum caripense* Humb. & Bonpl. ex Dunal which, although looking very similar to wild potato species, belongs to the related section *Basarthrum* and not to section *Petota*. This species is a diploid (2n=2x=24), climbing non-tuberizing herb, and sterile when crossed with potato (Nakitandwe et al., 2007). The wild potatoes reported for Ecuador are far away from the potato fields, in the “monte”, a term referring to mountain slopes at the outer limit of the agricultural landscape. This makes crosses between cultivated and wild species not likely to occur.

Discussion

Potato landraces in farmer's fields

Both the collections during the 70's and 80's and our own collections (2006-2008) managed to collect an appreciable number of accessions (158 and 174, respectively). Apparently, farmers have continued to maintain local landraces. When the earlier collections are compared to the results of the present collection trips, it is clear that, based on the recorded names, many new landraces are found. There is only a small overlap in names between materials collected in the two periods (Figure 2). This emergence of new landrace names is remarkable and contrasts with the general trend of landraces disappearing and diversity decreasing. The low number of landraces common to the past and present collections may indicate that the sampling of local landraces was far from exhaustive, both during the 70's and 80's and during the present collection trips. This is further supported by the fact that the diversity fair in Chimborazo resulted in many new landraces. This suggests that potato diversity in Ecuador is larger than presently known.

A change in landraces being grown could be explained by exchange of landraces among farmers and associated changes of names. Exchange of potatoes is very common in the Andes (Brush et al., 1981; Zimmerer, 1991). However, information not necessarily travels with the seed lot, producing name inconsistency (Nuijten and Almekinders, 2008). The movement of potato seed lots may be inter-regional or intra-regional. The fact that some farmers did not know where or who in the community hold rare landraces suggests that the movement has been mainly conducted on individual basis and not in an organized way. Whether more active movement of landraces occurred in the past is an open question.

Because these conclusions are based on the names of the collected landraces, a further study on the allelic variation among the landraces from past collections (gene banks) and the currently collected material, is necessary to give insight in the dynamics of potato landrace usage over time.

Who maintains the diversity?

Our study shows that the majority of the farmers growing native potatoes is relatively old (Table 1). This is similar in all three research areas. This group might be expected to be more knowledgeable about potato landraces than younger farmers. With the current educational system the younger generations get better qualified and eventually migrate to the cities looking for more rewarding jobs and leaving behind agriculture, the potatoes and their ancestors' knowledge. The farmers that conserve potato landraces have small farms (Table 1) and are generally associated with low incomes and even poverty. These small farmers maintain the local landraces for food security and/or cultural heritage but so far there are no market opportunities.

The potato production in Ecuador is an activity shared between men and women. Men carry out the land preparation - which is very labor intensive when done by animal traction or by hand tools - and fungicide application, if any. Women participate in most of the potato cropping activities. Also the harvest is a joint activity of men and women and a whole family activity in Chimborazo. This family involvement in the potato cropping is probably advantageous to the conservation of potatoes. However, migration, especially by men, poses a threat as it leaves the potatoes less attended and hence more vulnerable.

How and why are the farmers maintaining the potato diversity?

In Ecuador the cultivated potatoes are part of broader crop diversity present at farmers' fields and an important element in the crop rotation. Potato landraces coexist with commercial potatoes as is the case in Peru (Brush et al., 1995). The fact that potatoes and other crops co-exist on the farms supports the subsistence of potato landraces indirectly. Income from marketable crops (potatoes or others) subsidizes the maintenance of the non-commercial potato landraces. Also, we can infer that income from activities outside the farm is important for the families currently maintaining potato diversity (Figure 3).

Farmer’s empirically know about the nutritional or medicinal value of their potatoes and because of this they maintain the landraces from generation to generation, as a cultural heritage.

Present status of on-farm conservation and future perspectives

Carchi constitutes the most vulnerable area for the conservation of potatoes landraces. Frolich et al. (1999) already mentioned that ancient landraces are no longer to be found in this area. Farmers holding landraces are scattered in the province and not organized. Mostly elderly people maintain the landraces and the new generation demonstrates a lack of interest in cropping potato landraces. Carchi is a society traditionally based on trading, due to the vicinity of the Colombian border, but potato landraces do not offer market opportunities. As a consequence, in this province the farmer’s income depends equally on agriculture and other activities (Figure 3). Also, cooperation with and training from local institutions is scarce. The activities of INIAP have mainly been focused on developing participatory plant breeding aimed at developing new potato cultivars. There is a clear necessity to focus more on conservation issues and agrobiodiversity.

The potato conservation in Chimborazo looks more sustainable than in the other areas. Even though old people are currently in charge of the potato landraces, farmers see agriculture as the most important source of income. The number of indigenous farmers that keep potato landraces in their fields is higher in this province than in the other areas. Apparently they are culturally more attached to their land and see agriculture as a family activity (Table 2). The high number of farmers attending the diversity fair showed their interest and appreciation for their local potato diversity. The local organization is stronger than in other areas and farmers receive cooperation and training from different organizations. INIAP’s participation in the area has emphasized the promotion of local potato landraces with ongoing projects jointly with CIP and NGO’s.

Farmers at Loja have conserved potatoes through time, but some features could make the conservation vulnerable. Similar to Carchi, farmers holding landraces are scattered in the province and not organized keeping the conservation mainly on individual basis. The farmers get income from agriculture and other activities equally, which shows that farming is not seen as the only sustainable source of income. Additionally, during the meetings, farmers emphasized the lack of training and cooperation and requested more support. On the other hand, a majority of the farmers answered yes to the question ‘Do you exchange seed with the neighbors?’ The presence of an active exchange of landraces shows their interest in keeping the landraces.

Externally driven on-farm conservation activities, such as the diversity fair or re-introduction of landraces, were highly appreciated by the farmers. The diversity fair organized in Chimborazo was effective in raising local awareness on the richness of local crop genetic diversity, as observed in other cases as well (Almekinders, 2001), and to promote landraces exchange among farmers. The fact that new, not yet sampled landraces appeared at this fair indicates that such fairs are an effective means to get insight in the diversity present in a specific area. Diversity fairs should be organized in the other areas to contribute to the on-farm conservation. The creation of communal potato conservation gardens would also help to make landraces better available for the farmers and to raise local awareness. The newly assembled potato collection at INIAP will complement the on-farm conservation activities at the national level.

Finally, the younger generation of farmers should be motivated to maintain local landraces through education in agrobiodiversity (INIAP-DENAREF, 2009a). The creation of market opportunities for the landraces would support both their conservation and use. A project on this is being conducted in the Chimborazo area (Monteros et al., 2005b; Devaux et al., 2009).

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Appendix 1. Questionnaire

1. Farmer name:
2. Age:
3. Race: 1= mestizo, 2=indigenous
4. Education level: 0=none, 1=primary, 2=secondary, 3=university
5. Do you have another job besides agriculture? 0=only agriculture, 1= grow minor animals, 2= cattle, 3=housekeeping, 4=paid labor, 5=other
6. Which one is more important? 1=agriculture, 2=equal, 3= other activities
7. Province: 1= Carchi, 2= Chimborazo= 3 Loja
8. Canton:
9. Parish:
10. Locality:
11. Community:
12. Size of the farm (ha):
13. Observations:
14. Date:
15. How many members of the family are men?
16. How many members of the family are women?
17. How many members of the family are working directly in agriculture?
18. How many members of the family have migrated to look for a job different than agriculture?
19. Who prepares the land? 1= men, 2= women, 3= men + women, 4= hired labor, 5= tractor, 6=. *partidario**, 7= men + hired labor, 8= men + women + hired labor
20. Who takes care of the crop daily? 1= men, 2= women, 3= men + women, 4= hired labor, 5= tractor, 6=. *partidario*, 7= men + hired labor, 8= men + women + hired labor
21. Who applies fungicides? 0= not applied, 1= men, 2= women, 3= men + women, 4= hired labor, 5= tractor, 6=. *partidario*, 7= men + hired labor, 8= men + women + hired labor
22. Who harvests? 1= men, 2= women, 3= men + women, 4= hired labor, 5= tractor, 6=. *partidario*, 7= men + hired labor, 8= men + women + hired labor, 9= all family
23. Who sells? 0= do not sell, self consumption, 1= men, 2= women, 3= men + women, 4= hired labor, 5= tractor, 6=. *partidario*, 7= men + hired labor, 8= men + women + hired labor
24. Invisible work for women:
25. Crops in the farm:
26. Is there any difference among the management of commercial potatoes and native ones? 1= Yes, 2= No
27. Potato diseases:
28. Potato plagues:
29. Grow the landraces mixed or separated? 1= mixed, 2= separated
30. If you lose your landrace, do you try to recover it? 1= Yes, 2= No
31. If you sell these landraces, where do you do it? 1= local market, 2= other
32. Do you exchange seeds with the neighbors? 1= Yes, 2= No
33. Do you know anybody that still has these local potato landraces? 1= Yes, 2= No
34. If you choose one of the lost landraces, which would you choose to get it back?
35. Do you believe if you grow potatoes together, they hybridize? 1= Yes, 2= No
36. Do you collect berries from the field and plant them?
37. Have you seen wild potatoes close to your farm field? 1= Yes, 2= No
38. Do you believe that wild species can hybridize with the cultivated ones? 1= Yes, 2= No
39. Common names of the wild potatoes:
40. Use of potato wild species:

* *partidario*, is a local name referred to a farmer that grows the crop in another farmers' land and they share the profits according to the negotiation process.

Appendix 2. Potatoes collected at the three research areas

Collection #	Landrace name	Collection #	Landrace name	Collection #	Landrace name
Landraces' names found both during the 70-80's and the 2006-08 collecting missions					
	CARCHI		**CHIMBORAZO**		**LOJA**
JS-28	Botella (blanca)	FM FH RA 005	Cacho	MOPG-009	Bodeguera Blanca
JS-33	Carriza	AMA-301	Chaucha blanca	MPG-029	Chaucha amarilla
AXC-008	Chaucha amarilla	MLL-01	Chaucha colorada	MPG-022	Chaucha amarilla alargada
AC-037	Chaucha borrega o Azul		Chaucha roja	MPG-024	Chaucha amarilla redonda
AXC-015	Chaucha botella	AMA-309	Curipamba	MPG-027	Chaucha Blanca
AXC-007	Chaucha negra	AMA-310	Ilusión blanca	MPG-026	Chaucha negra
AXC-001	Chaucha ratona	FM FH RA 002	Norteña negra	MPG-028	Chaucha roja
JS-35	Curipamba	FM FH RA 003	Pera	MPG-041	Escaleña
AC-041	Mambera	FM FH RA 002	Puña negra	MPG-044	Guano de cuchi
AXC-017	Pamba roja. (Tableada roja).	AMA-303	Tabla	MPG-018	Guata morada
AXC-029	Rosada	FM FH RA 004	Tulca	MPG-017	Guata roja. Guata colorada. Papa cuy
AC-034	Sabanera	FM FY RA 004	Uchu rumi	MPG-033	Negra
JS-25	Violeta	FM FY RA IV 001	Uvilla blanca	MPG-038	Papa de chacra
		FM FY RA 003	Uvilla negra	MOPG-012	Perra dormida
				MOPG-007	Suscaleña blanca
Landraces collected during 2006-2008					
	CARCHI		**CHIMBORAZO**		**LOJA**
JS-29	Alpargata	FM RA 002	Alpargate	ARX-2	Alpargate
JS-36	Cardenilla	MLL-02	Alpargate	MG-004	Bodeguera blanca (ojo blanco)
AC-036	Carriza	FM RA FH 002	Cacho blanco	MG-003	Bodeguera blanca (ojo morado)
AXC-014	Chaucha amarilla	FM FY RA 011	Cacho negro	MG-001	Bodeguera negra (Probable Ambateña)
AXC-012	Chaucha blanca	AMA-300	Camotilla	MOPG-015	Bolona
AC-038	Chaucha botella	FM FH RA 006	Cañareja	MPG-032	Bolona
JS-23	Chaucha negra	FM FY RA IV 004	Cayamarco	MPG-019	Bolona amarilla
AXC-028	Chaucha ratona	FM FY RA 010	Chapituna	MPG-031	Bolona negra
JS-3	Coneja blanca	FM FY RA IV 002	Chaucha amarilla	MPG-020	Carriza
AXC-016	Curipamba		Chaucha blanca	MOPG-001	Chaucha amarilla alargada
AXC-023	Curipamba	AMA-302	Chaucha negra "pera"	MOPG-005	Chaucha amarilla redonda/bolonga
AXC-022	Gualcalá	FM FY RA 005	Chihuila blanca	MG-010	Chaucha negra
AXC-027	Guata= Capiro	FM FY RA 006	Chihuila negra	MOPG-013	Chaucha roja
AC-43	Huevo de indio	FM RA FH 001	Chilca	MPG-023	Chaucha roja
AXC-019	Leona	FM RA FH 002	Coneja	MPG-035	Chola antingua
JS-1	Leona blanca 1	FM FY RA 008	Cornos	MG-005	Churona rosada
JS-34	Leona del Carchi	FM FY RA IV 005	Cuchi chupa	MOPG-003	Colorada
JS-26	Leona negra	FM FY RA 009	Cuchi dzili	MPG-042	Colorada antigua 1
AXC-002	Mampuera	FM FH RA 006	Fayre	MPG-043	Colorada antigua 2
JS-24	Manpuera	AMA-307	Gachu papa	MOPG-004	Colorada chaucha
AXC-009	Morasurco	FM FY 003	Guancala	MOPG-016	Cuchicaca "papa de chacra"
AXC-026	Negra conocida como Morasurco	FM FH RA 001	Guantiva	MOPG-006	Unknown
JS-30	Osito	FM FY RA 003	Huarmi papa	MOPG-011	Guacalá blanca
AXC-018	Pamba pintada. (Tableada pintada).	AMA-308	Jobaleña	MOPG-014	Guacalá roja
AXC-020	Parda mejorada	FM FY RA 007	Leona negra	MG-007	Guata amarilla
AC-042	Parda pastusa	FM FY RA 008	Leona roja	MG-012	Guata blanca ojona
AXC-021	Parda suprema	FM FY RA 001	Limeña	MOPG-010	Guata roja
JS-31	Puña	FM FY RA 005	Loro papa	MG-016	María Esperanza
AXC-013	Pura sangre	FM FY 002	Mamey	ARX-1	María Esperanza
AC-040	Rabo de gato	FM FY 001	Mami	MPG-040	Negra ojona
AC-039	Ratona amarilla	FM FY RA IV 003	Manuela	MG-011	Negra ojona
JS-32	Roja plancha	AMA-306	Mishi maqui "uña gato"	MOPG-002	Negra, carrizo o catalina
AXC-030	Roja plancha	FM FY RA 004	Moronga	MPG-021	Papa chacra
JS-27	Rosada	FM FH RA 001	Norte roja	MPG-034	Papa curra (como gusanito)
AXC-003	Sulipamba	FM RA FH 003	Noteña	MG-009	Papa de chacra
AXC-004	Super violeta		Papa yerac	MPG-025	Papa huinga
AXC-011	Uva	FM FY RA 006	Pargate	ARX-3	Quiteña
JS-2	Uva	FM FY RA 001	Pudzu uvilla	MPG-030	Roja
AXC-025	Violeta común	FM FH RA 004	Puña	MG-013	Semibolona 1
		MLL-04	Puña	MG-014	Semibolona 2
		FM FY RA 007	Tsujtsuj	ARX-4	Suscaleña blanca
		AMA-304	Turca	MG-006	Suscaleña colorada
		AMA-305	Turca "tablona"	MOPG-008	Suscaleña negra
		FM RA FH 001	Uvilla	MG-015	Wicupa amarilla
		MAP-001	Uvilla	MPG-037	Wicupa colorada
		FM RA 001	Uvilla amarilla		
		MLL-03	Uvilla original		
		FM FH RA 005	Yana pera		
Landraces collected during the diversity fair (CHIMBORAZO)					
XCFM-11	Caperucita	XCFM-4	Huagrasinga	XCFM-7	Rapuña
XCFM-9	Capulí	AMFY-3	Huancala	AMFY-20	Tabaquera blanca
XCFM-1	Castillo	AMFY-1	Manuela 1	AMFY-19	Tabaquera colorada
XCFM-18	Chaucha manzana	AMFY-2	Manuela 2	XCFM-8	Tanda
AMFY-16	Chaucha ratona	XCFM-17	Marta	AMFY-9	Tsujsuj morado

AMFY-6	Chihuila roja	XCFM-12	Morosel	AMFY-8	Tulca blanca
XCFM-6	Chugsho	AMFY-15	Norteña antigua	XCFM-19	Tulca hembra
AMFY-4	Chuquillinga	AMFY-13	Papa puya	XCFM-3	Unknown
XCFM-2	Cuerno blanco	AMFY-5	Papa tabla	AMFY-12	Ascho Chaqui (pata perro)
AMFY-18	Curiquinga	XCFM-10	Pera amarilla	AMFY-10	Yanatabla
AMFY-17	Frayla	XCFM-5	Puca tabla	AMFY-7	Chaucha crespa
XCFM-13	Freila	AMFY-11	Rapuña		

CHAPTER 3

Ecuadorian potato landraces names and genetic identity

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Abstract

Ecuadorian potato landraces are an important genetic resource, but they have only been poorly described. In order to assess the genetic diversity of these potatoes SSR markers were applied to 152 landraces collected in three areas of high diversity: the provinces Carchi, Chimborazo and Loja. These SSR markers were previously applied in the genotyping of more than 800 European potato varieties. The number of alleles and PIC value of the markers were comparable between the European and our study. However, the overlap in alleles was small. The relationship between local names of landraces and the genetic identity based on SSR data was evaluated. This analysis showed that there were several landraces with different names that had identical molecular profiles. It also showed that landraces with identical names but obvious differences in tuber morphology were almost always genetically different. There was no clear grouping of material collected according to the investigated regions, suggesting extensive movement of seed potatoes all over Ecuador.

Key words: Ecuador, landrace diversity, microsatellites.

Introduction

Potatoes are cultivated throughout the Andes with the greatest diversity located from south Peru to northern Bolivia (Brush et al., 1981; Hawkes, 1988). The potato diversity in the Andes includes different ploidy levels. In Peru for example, farmers grow mixtures of diploid, triploid, tetraploid and pentaploid potatoes in a single field (Jackson et al., 1980; Brush et al., 1995; De Haan, 2009). In Ecuador an important but poorly described resource of potato landraces is present (Monteros-Altamirano et al., 2011a). The Ecuadorian potato diversity also includes multiple ploidy levels (Hawkes, 2004), although the extent to which potatoes with different ploidy levels are grown is still unknown. Three cultivated tuber-bearing *Solanum* species

(*Solanum phureja*, *S. chaucha* and *S. tuberosum* sbsp. *andigena*) are known to be present in Ecuador (Spooner et al., 1992; Spooner et al., 2007).

Another characteristic of the Andean potatoes is that they are accompanied by a rich nomenclature. Hawkes (1947) described the origin and meaning of South American Indian potato names. Most of the Ecuadorian potatoes had Spanish or Quechua names or a combination of both. Understanding variety naming by farmers can be important to understand the genetic diversity present in a crop (Nuijten and Almekinders, 2008). Quiros et al. (1990) and De Haan (2009) studied the consistency between the folk naming system and genetic profiles of potatoes in Peru. Farmer identification and electrophoretic phenotypes were well correlated in a study of Quiros et al. (1990), but De Haan (2009) found only poor correlations using SSRs markers. Both studies reported the possible under-estimation of the genetic variation in farmer fields due to landraces with the same name representing different genetic profiles. The relation between names and genetic profiles has not been studied previously for the cultivated potatoes of Ecuador.

Compared to other marker systems, microsatellites have proven to be very effective because they are co-dominant, reproducible, cost-effective, simple to use and highly polymorphic (McGregor et al., 2000; Milbourne et al., 1997). Studies on the genetic diversity of local varieties of potatoes using SSRs have been conducted in Argentina (Ispizúa et al., 2007), Tenerife (Barandalla et al., 2006), UK (Reid and Kerr, 2007), Canada (Fu et al., 2009) and Russia (Ryzhova et al., 2010). Recently, a set of 9 SSRs has been used to differentiate more than 800 potato varieties from the European Union Common Catalogue (Reid et al., 2009).

Passport data (including local names) of previous collections guided our new collections in three areas of high diversity in Ecuador, the provinces Carchi, Chimborazo and Loja (Monteros-Altamirano et al., 2011a). These areas differ not only in climatic and edaphic conditions but also in ethnicity. Here we determine the relationship between the naming and the genetic identity of the landraces using molecular markers.

Materials and methods

Plant material

A total of 152 Ecuadorian potato landraces was collected in Carchi, located in the north of Ecuador between 0° 27` to 1° 10` N latitude (38 landraces), Chimborazo in the center from 1° 33` to 2° 55’ S latitude (66 landraces) and Loja, in the south between latitude 3° 18` and 4° 45`S (48 landraces) (Table 1).

Table 1. Local name, code and origin of 152 potato landraces collected at the three research areas in Ecuador (Carchi, Chimborazo and Loja). The ploidy level of the landraces is indicated when known. Landraces with identical names are highlighted in gray. The ten Dutch varieties used in the present study are also included.

Name	Code	Prov	2n	Name	Code	Prov	2n	Name	Code	Prov	2n
Alpargata	JS-29	Carchi	4x	Cuerno blanco	XCFM-02	Chimborazo	4x	Pargate	FM FY RA 06	Chimborazo	4x
Ascho chaqui	AMFY-12	Chimborazo	3x	Curipamba (1)	JS-35	Carchi	4x	Pera	FM FH RA 03	Chimborazo	4x
Bodeguera blanca	MOPG-09	Loja	4x	Curipamba (2)	AXC-16	Carchi	4x	Pudzu uvilla	FM FY RA 01	Chimborazo	4x
Bodeguera blanca (ojo morado)	MG-03	Loja	4x	Curiquinga	AMFY-18	Chimborazo	4x	Puña	JS-31	Carchi	4x
Bolona (1)	MOPG-15	Loja	4x	Escaleña	MPG-41	Loja	4x	Puña	FM FH RA 04	Chimborazo	4x
Bolona (2)	MPG-32	Loja	4x	Fayre	FM FH RA 06	Chimborazo		Puña negra	FM FH RA 02	Chimborazo	4x
Bolona amarilla	MPG-19	Loja	4x	Freila	XCFM-13	Chimborazo	4x	Rabo de gato	AC-40	Carchi	2x
Cacho	FM FH RA 05	Chimborazo	4x	Guacalá blanca	MOPG-11	Loja	4x	Rapuña (1)	AMFY-11	Chimborazo	3x
Cacho blanco	FM RA FH 02	Chimborazo	4x	Guacalá roja	MOPG-14	Loja	4x	Rapuña (2)	XCFM-07	Chimborazo	3x
Cacho negro	FM FY RA 11	Chimborazo	4x	Gualcalá	AXC-22	Carchi	4x	Ratona amarilla	AC-39	Carchi	2x
Cañareja	FM FH RA 06	Chimborazo	3x	Guancala	FM FY 03	Chimborazo	4x	Ratona amarilla (selection)	AC-39A	Carchi	2x
Capulí	XCFM-09	Chimborazo		Guano de cuchi	MPG-44	Loja	4x	Roja plancha	AXC-30	Carchi	4x
Carriza (1)	JS-33	Carchi	4x	Guantiva	FM FH RA 01	Chimborazo	4x	Rosada (1)	JS-27	Carchi	3x
Carriza (2)	AC-36	Carchi	4x	Guata amarilla	MG-07	Loja	4x	Rosada (2)	AXC-29	Carchi	4x
Carriza	MPG-20	Loja	4x	Guata blanca ojona	MG-12	Loja	4x	Sabanera	AC-34	Carchi	4x
Castillo	XCFM-01	Chimborazo	2x	Guata morada	MPG-18	Loja	4x	Semibolona (1)	MG-13A	Loja	
Catalina	MOPG-06	Loja	4x	Guata roja	MOPG-10	Loja	4x	Semibolona (2)	MG-14A	Loja	4x
Chaucha amarilla (1)	AXC-08	Carchi	2x	Guata roja (Papa cuy)	MPG-17	Loja	4x	Semibolona (2) (Selection)	MG-14B	Loja	4x
Chaucha amarilla (2)	AXC-14	Carchi	2x	Guata= Capiro	AXC-27	Carchi	4x	Sulipamba	AXC-03	Carchi	4x
Chaucha amarilla	FM FY RA IV 02	Chimborazo	2x	Huancala	AMFY-03	Chimborazo	4x	Super violeta	AXC-04	Carchi	4x
Chaucha amarilla	MPG-29	Loja	2x	Huarmi papa	FM FY RA 03	Chimborazo	4x	Suscaleña blanca	MOPG-07	Loja	4x
Chaucha amarilla alargada (1)	MOPG-01	Loja	2x	Huevo de indio	AC-43	Carchi	4x	Suscaleña negra	MOPG-08	Loja	
Chaucha amarilla alargada (2)	MPG-22	Loja	2x	Leona blanca 1	JS-01	Carchi	4x	Tabaquera blanca	AMFY-20	Chimborazo	2x
Chaucha amarilla redonda	MPG-24	Loja	2x	Leona del carchi	JS-34	Carchi	4x	Tabaquera colorada	AMFY-19	Chimborazo	2x
Chaucha amarilla redonda/bolonga	MOPG-05	Loja	2x	Leona negra	FM FY RA 07	Chimborazo		Tabla	AMA-303	Chimborazo	4x
Chaucha blanca	98p	Chimborazo		Leona roja	FM FY RA 08	Chimborazo	4x	Tanda	XCFM-08	Chimborazo	4x
Chaucha blanca	MPG-27	Loja	2x	Loro papa	FM FY RA 05	Chimborazo	3x	Tsujtsuj	FM FY RA 07	Chimborazo	4x
Chaucha borrega o Azul	AC-37	Carchi	2x	Mambera	AC-41	Carchi	2x	Tulca	FM FH RA 04	Chimborazo	4x
Chaucha botella (1)	AXC-15	Carchi	2x	Mamey	FM FY 02	Chimborazo	4x	Tulca blanca	AMFY-08	Chimborazo	2x
Chaucha botella (2)	AC-38	Carchi	2x	Manuela (1)	FM FY RA	Chimborazo	4x	Tulca hembra	XCFM-19	Chimborazo	4x

					IV 03						
Chaucha negra	JS-23	Carchi	2x	Manuela (2)	AMFY-01	Chimborazo	4x	Uchu rumi	FM FY RA 04	Chimborazo	
Chaucha negra (1)	MPG-26	Loja	2x	Manuela (3)	AMFY-02	Chimborazo	4x	Unknown	XCFM-03	Chimborazo	4x
Chaucha negra (2)	MG-10	Loja	2x	María Esperanza	MG-16A	Loja	4x	Uva (1)	AXC-11	Carchi	4x
Chaucha ratona (1)	AXC-01	Carchi	2x	Maria Esperanza (Selection)	MG-16B	Loja	4x	Uva (2)	JS-02	Carchi	4x
Chaucha ratona (2)	AXC-28	Carchi	2x	Morasurco	AXC-09	Carchi	4x	Uvilla	70 p	Chimborazo	4x
Chaucha ratona	AMFY-16	Chimborazo	2x	Moronga	FM FY RA 04	Chimborazo		Uvilla amarilla	FM RA 01	Chimborazo	4x
Chaucha roja	76p	Chimborazo		Morosel	XCFM-12	Chimborazo	4x	Uvilla blanca	FM FY RA IV 01	Chimborazo	
Chaucha roja (1)	MOPG-13	Loja		Negra	MPG-33	Loja	4x	Violeta común	AXC-25	Carchi	4x
Chaucha roja (2)	MPG-23	Loja	2x	Negra (Morasurco)	AXC-26	Carchi	4x	Wicupa amarilla	MG-15	Loja	2x
Chaucha roja (3)	MPG-28	Loja	4x	Negra (Carriza o Catalina)	MOPG-02	Loja	4x	Wicupa colorada	MPG-37	Loja	2x
Chihuila blanca	FM FY RA 05	Chimborazo	3x	Negra ojona (1)	MPG-40	Loja	4x	Yana pera	FM FH RA 05	Chimborazo	4x
Chihuila negra	FM FY RA 06	Chimborazo		Negra ojona (2)	MG-11	Loja	4x	Yanatabla	AMFY-10	Chimborazo	4x
Chihuila roja	AMFY-06	Chimborazo		Norte roja	FM FH RA 01	Chimborazo					
Chilca	FM RA FH 01	Chimborazo	4x	Norteña antigua	AMFY-15	Chimborazo	4x	**Dutch varieties**			
Chola antingua	MPG-35	Loja	4x	Norteña	FM RA FH 03	Chimborazo	4x	Accord			4x
Chugsho	XCFM-06	Chimborazo	4x	Pamba roja. Tableada roja.	AXC-17	Carchi	4x	Bildstar			4x
Colorada	MOPG-03	Loja	4x	Papa chacra (1)	MPG-21	Loja	2x	Bintje			4x
Colorada antigua (1)	MPG-42	Loja	4x	Papa de chacra (2)	MPG-38	Loja	4x	Eersteling			4x
Colorada antigua (2)	MPG-43	Loja	4x	Papa de chacra (3)	MG-09	Loja	4x	Eigenheimer			4x
Colorada chaucha	MOPG-04	Loja	4x	Papa puya	AMFY-13	Chimborazo		Frieslander			4x
Coneja	FM RA FH 02	Chimborazo	4x	Papa tabla	AMFY-05	Chimborazo	4x	Gloria			4x
Coneja blanca	JS-03	Carchi	4x	Papa yerac	87p	Chimborazo		Mentor			4x
Cornos	FM FY RA 08	Chimborazo	4x	Parda mejorada	AXC-20	Carchi	4x	Mondial			4x
Cuchi chupa	FM FY RA IV 05	Chimborazo	4x	Parda pastusa	AC-42	Carchi	3x	Nicola			4x
Cuchi dzili	FM FY RA 09	Chimborazo		Parda suprema	AXC-21	Carchi	4x				

The altitudinal range of the potato collection varied in Carchi from 2950 to 3400 meters above sea level, in Chimborazo from 2750 to 3950 m, and in Loja from 2250 to 2900 m. Individual farmers provided one or more landraces. Passport data included information about landrace name and origin. Ten well-known and commonly used Dutch varieties were included for comparison. The local potato farmers who provided landraces and other landrace-growers were invited to communal meetings at Carchi, Chimborazo and Loja, as explained by Monteros-Altamirano et al. (2011a). These meetings were intended to discuss the landrace names and geographic origin of the materials, along with other topics not reported in this study.

Ploidy level determination

In vitro plants were prepared, mainly for conservation purposes, by using a routine protocol for tissue culture (INIAP-DENAREF, 2009b). One *in vitro* plant per landrace was used for ploidy level determination by flow cytometry using a Cyflow® Space, Partec, flow cytometer. A protocol as described in Xianpu et al. (2010) was used. Reference varieties were the diploid potato NK2-162 *Yema de huevo* CIP 704218 (CIP, 2010c), the tetraploid Ecuadorian varieties *Fripapa* and *Natividad* (INIAP, 2010) and FMFHRA 005 *Chihuila negra* which is a collected landrace expected and confirmed to be triploid. The histograms for these 3 reference varieties are shown in Figure 1.

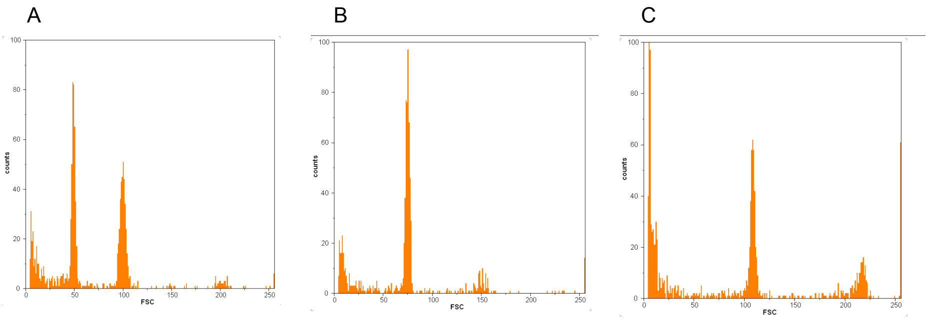

Figure 1. Histograms of the potato references used for ploidy determination of the Ecuadorian landraces. A) NK2-162 *Yema de huevo* (diploid); B) FMFHRA 005 *Chihuila negra* (triploid); and, C) *Fripapa* (tetraploid). [FSC= Forward scatter signal; Count= Nuclei count].

Molecular characterization

DNA extraction

DNA extraction was performed using the protocol described by Colombo et al. (1998) with the modifications introduced by Morillo (2004). In short, genomic DNA was isolated from young leaves or tuber sprouts depending on availability of the material (greenhouse or field). The tissue was suspended in 200 ul of extraction buffer (50mM Tris HCl pH 8.0, 1M NaCl, 20 mM EDTA, 1% PVP and 1% CTAB). Next, 800 ul of extraction buffer and 12 ul of b-mercapthoethanol was added and the suspension was thoroughly mixed, incubated at 60°C for 2 hours and centrifuged at 13000 rpm for 10 min (Eppendorf centrifuge 5415 D). The supernatant was recovered and 750 ul Chloroform: Isoamyl alcohol mixture, (24:1) was added, mixed and centrifuged again at 13000 rpm for 5 min. The supernatant was transferred to a new tube and 750 ul Ethanol 100% was added and incubated at -20°C for 10 min. The suspension was centrifuged at 13000 rpm for 3 min followed by a washing step with 70% Ethanol. The tubes were dried at room temperature overnight. If small drops were still observed in the tubes we used a micro stove at 37°C for 30 minutes. DNA was re-suspended in 200 ul of TE buffer (10 mM Tris HCl, 1 mM EDTA pH 8.0) incubated at 65°C and 2 ul RNase (10 ng/ul) was added per 100 ul of DNA solution). DNA was further purified using the PureLink™ 96 Genomic DNA Kit, Invitrogen®, as recommended by the supplier. The purified DNA was stored at -20°C in TE-buffer.

Microsatellite analysis

Nine nuclear SSRs (Reid et al., 2009) were used to characterize the plant material. The 9 markers were amplified in 3 multiplex PCR reactions each containing 3 markers, as described by Reid et al. (2009), with minor modifications. Instead of 30 cycles described in the protocol we used 40 cycles for multiplex 1 and 2 and 35 cycles for multiplex 3. The PCR products were analyzed using an Applied Biosystems 3130 xl Genetic Analyzer with POP-7™. The peaks present for each microsatellite were visualized using GeneMapper Software v 3.6 (Applied Biosystems) and scored using the rules described by Reid et al. (2009). Six local landraces were eliminated due to missing data.

Data analysis

Alleles were scored as binary data (present or absent, 1 and 0). A distance matrix was calculated using the Nei and Li coefficient (Nei and Li, 1979) and from this an UPGMA tree was obtained using Treecon® (Van de Peer and De Wachter, 1994). The population genetic structure among the 3 research areas (Carchi, Chimborazo and Loja) was compared with an Analysis of Molecular Variance (AMOVA) using Arlequin 3.11 (Excoffier et al., 2005). The polymorphic information content value (PIC) was based on allelic phenotypes

(Becher et al., 2000; Esselink et al., 2003) using the formula PIC = 1-S(p*i*)², where " p*i* " is the frequency of the *i*-th allelic phenotype detected (Nei, 1973).

Results

Naming of landraces

In Ecuador, as in other South American countries, potatoes are referred to as *Papas*, which is the original name for potato in the Quechua language (Hawkes, 1947; De Haan, 2009). Quechua was the original language of the Incas and it spread after the Inca expansion to other regions. The Political Constitution of Ecuador (CRE, 2008) recognizes Kichwa, also known as Quichua, as the official language for indigenous intercultural interactions. Kichwa is considered either an exclusive local variety of Quechua for Ecuador (Haboud, 1998; King, 1999) or a native language with a possible pre-Inca origin (Burgos-Guevara, 1995). Hereafter we refer to Kichwa to indicate native words included in the names of landraces.

Potato names are generally composed of several words, usually nouns and adjectives (Hawkes, 1947). The structure of some landrace names include Kichwa words, e.g. *Kuchi chupa* "pig tail"; *Uchu rumi* "stone to grind chili"; *Ashco chaqui* "dried dog"; *Papa yerac* "white potato" and *Pudzu uvilla* "grey berry" for landraces from Chimborazo. Kichwa names in Loja include e.g. *Guano de kuchi* "pig excrement" and *Papa de chakra* "small field potato". Indigenous farmers from Chimborazo also use mixed Spanish-Kichwa names such as *Yana pera* "black pear", *Yana tabla* "black long and flat tuber" or *Cacho blanco*, or *Cuerno blanco*: "Cacho" and "Cuerno" refer to the shape of the tuber like a bull horn and "blanco" means white. Table 1 lists the collected landraces and includes Spanish (43%), Spanish-Kichwa (26%) and Kichwa (12%) names, 19% of the names were not classified due to uncertainty.

The early sprouting landraces are named mainly by the generic *Chaucha* which stands for "soft or easy". This is consistent across the three research areas. This generic name is followed by tuber related characteristics such as color of the tuber, e.g. *Blanca* “white”, *Amarilla* “yellow”, *Roja* “red” or *Negra* “black”, or animal related names, e.g. *Borrega* “sheep”, *Ratona* “mouse” or tuber shape, e.g. *Botella* “bottle”. In some cases these two naming components are accompanied by a third component that is the tuber shape, e.g. *Chaucha amarilla redonda* (“*redonda”* = round shaped). Exceptions to the naming rule for these early sprouting potatoes are e.g. *Tulca*, *Castillo*, *Wicupa*, *Mambera*, and *Tabaquera*.

Names of potato landraces can also refer to women’s names, such as *Manuela* and *Catalina*. Others allude to their apparent origin, such as *Cañareja* (from Cañar province) or *Norteña* (from the North) and *Leona del Carchi* (Lion shape tuber from Carchi). Others refer to animal related features, e.g. *Coneja* “rabbit ears shape” and *Rabo de Gato* “cat’s tail”. Other names refer to objects, e.g. *Alpargata* “children’s shoes”; or gender, as in *Tulca hembra (*“*hembra* = female”).

From Table 1 we could identify 20 unique names for landraces collected in Carchi, 55 for Chimborazo and 17 in Loja. For the remaining names we collected more than one sample, either from the same area (canton) or from two or even all three research areas. We only collected landraces with identical names from the same canton when they looked different from a morphological point of view. In total there were 24 names of landraces for which we collected more than one sample (Table 1).

Ploidy levels

The ploidy level of 134 landraces was determined and the distribution over the 3 areas analyzed. The Ecuadorian landraces consist of 22 % diploids, 6 % triploids and 72 % tetraploids (Figure 2). No triploids were present in Loja and pentaploid potatoes were not found at all in our research areas. Individual farmers keep landraces with different ploidy level in the same fields, as observed during the collection trips.

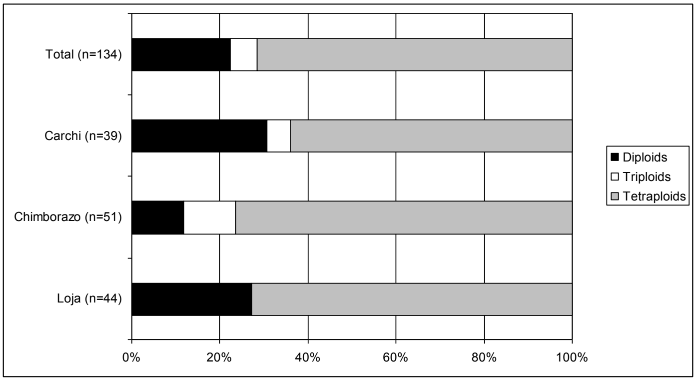

Figure 2. Percentage of landraces with different ploidy levels at the three research sites (Carchi, Chimborazo and Loja).

Molecular characterization

From the nine SSRs used, eight produced clear peaks (Table 2). Marker number nine (STM 0019) produced a considerable number of missing data in this plant material and was not used further. In total, the 8 polymorphic markers produced 72 alleles in the 152 landraces. Table 2 shows the number of alleles and PIC values for each of the markers in the Ecuadorian landraces and in European varieties.

In the Ecuadorian tetraploid landraces 12 alleles were found that are not present in the European varieties while in the European collection 24 alleles were present that are not found in the Ecuadorian landraces.

Table 2. Allele number and PIC values for tetraploid Ecuadorian landraces and European varieties. Allele number for Ecuadorian triploid and diploid landraces also included. Only the landraces with ploidy information were included in the calculations.

STMS Marker	Repeat Linkage group	European Tetraploid varieties (892) [1]			Ecuadorian Tetraploid landraces (96)[2]			Ecuadorian Triploid landraces (8)		Ecuadorian Diploid landraces (30)	
		Number of alleles	Avg. # alleles per phenotype	PIC value	Number of alleles	Avg. # alleles per phenotype	PIC value	Number of alleles	Avg. # alleles per phenotype	Number of alleles	Avg. # alleles per phenotype
2005	XI	6	2.6	0.80	6	2.3	0.85	4	2.4	5	1.4
2028	XII	9	2.7	0.90	6	2.1	0.73	5	2.3	4	1.8
3009	VII	14	2.4	0.80	10	1.7	0.85	3	1.4	7	1.4
3012	IX	7	2.7	0.87	5	2.0	0.87	4	2.9	3	1.5
3023	IV	4	2.2	0.79	5	2.0	0.82	3	2.6	4	1.8
5136	I	11	2.9	0.92	10	3.9	0.93	8	3.0	7	2.7
5148	V	20	3.4	0.98	17	3.2	0.95	10	2.8	9	1.3
SSR1	VIII	14	3.2	0.93	11	2.6	0.93	8	2.6	8	1.6
	Total	85			70						

[1] Number of varieties (Reid et al. 2011).
[2] Number of landraces (this study).

Cluster analysis

The UPGMA tree for the 152 Ecuadorian landraces and 10 Dutch varieties is presented in Figure 3. The tree shows three main branches: 1) a group of two landraces named *Uva*, collected in Carchi; 2) a group consisting of the Dutch varieties; 3) all Ecuadorian landraces.

The Ecuadorian landraces are split in two groups but these are no obvious characteristics, e.g., tuber morphology or origin (collection site) correlated with the split. Several Ecuadorian landraces are very similar, many are even identical in their SSR patterns. The selected Dutch varieties are all different from each other.

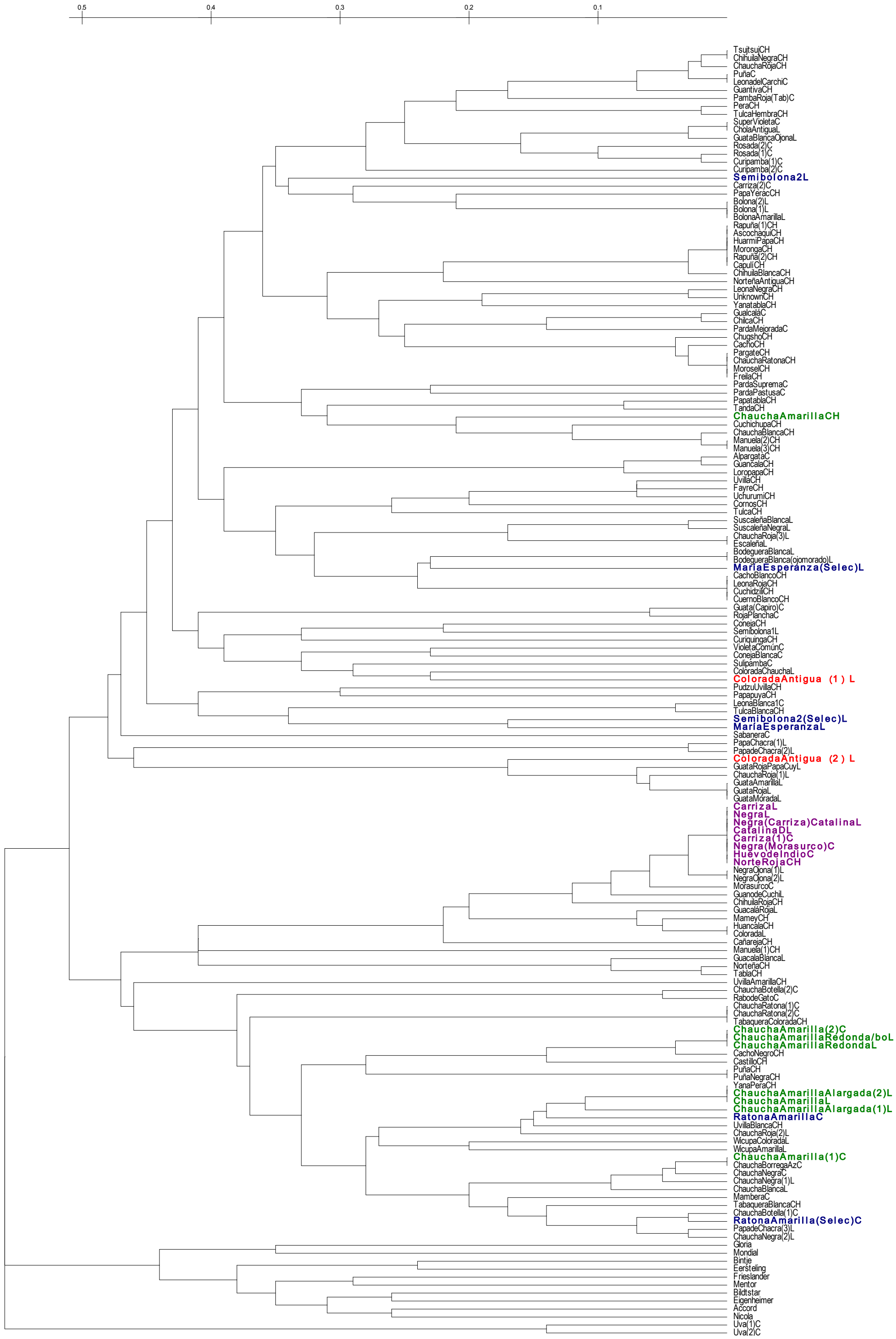
0.5
0.4
0.3
0.2
0.1
TsujtsujCH
ChihuilaNegraCH
ChauchaRojaCH
PuñaC
LeonadelCarchiC
GuantivaCH
PambaRoja(Tab)C
PeraCH
TulcaHembraCH
SuperVioletaC
CholaAntiguaL
GuataBlancaOjonaL
Rosada(2)C
Rosada(1)C
Curipamba(1)C
Curipamba(2)C
Semibolona2L
Carriza(2)C
PapaYeracCH
Bolona(2)L
Bolona(1)L
BolonaAmarillaL
Rapuña(1)CH
AscochaquiCH
HuarmiPapaCH
MorongaCH
Rapuña(2)CH
CapulíCH
ChihuilaBlancaCH
NorteñaAntiguaCH
LeonaNegraCH
UnknownCH
YanatablaCH
GualcaláC
ChilcaCH
PardaMejoradaC
ChugshoCH
CachoCH
PargateCH
ChauchaRatonaCH
MoroselCH
FreilaCH
PardaSupremaC
PardaPastusaC
PapatablaCH
TandaCH
ChauchaAmarillaCH
CuchichupaCH
ChauchaBlancaCH
Manuela(2)CH
Manuela(3)CH
AlpargataC
GuancalaCH
LoropapaCH
UvillaCH
FayreCH
UchurumiCH
CornosCH
TulcaCH
SuscaleñaBlancaL
SuscaleñaNegraL
ChauchaRoja(3)L
EscaleñaL
BodegueraBlancaL
BodegueraBlanca(ojomorado)L
MaríaEsperanza(Selec)L
CachoBlancoCH
LeonaRojaCH
CuchidziliCH
CuernoBlancoCH
Guata(Capiro)C
RojaPlanchaC
ConejaCH
Semibolona1L
CuriquingaCH
VioletaComúnC
ConejaBlancaC
SulipambaC
ColoradaChauchaL
ColoradaAntigua (1) L
PudzuUvillaCH
PapapuyaCH
LeonaBlanca1C
TulcaBlancaCH
Semibolona2(Selec)L
MaríaEsperanzaL
SabaneraC
PapaChacra(1)L
PapadeChacra(2)L
ColoradaAntigua (2) L
GuataRojaPapaCuyL
ChauchaRoja(1)L
GuataAmarillaL
GuataRojaL
GuataMoradaL
CarrizaL
NegraL
Negra(Carriza)CatalinaL
CatalinaDL
Carriza(1)C
Negra(Morasurco)C
HuevodeIndioC
NorteRojaCH
NegraOjona(1)L
NegraOjona(2)L
MorasurcoC
GuanodeCuchiL
ChihuilaRojaCH
GuacaláRojaL
MameyCH
HuancalaCH
ColoradaL
CañarejaCH
Manuela(1)CH
GuacalaBlancaL
NorteñaCH
TablaCH
UvillaAmarillaCH
ChauchaBotella(2)C
RabodeGatoC
ChauchaRatona(1)C
ChauchaRatona(2)C
TabaqueraColoradaCH
ChauchaAmarilla(2)C
ChauchaAmarillaRedonda/boL
ChauchaAmarillaRedondaL
CachoNegroCH
CastilloCH
PuñaCH
PuñaNegraCH
YanaPeraCH
ChauchaAmarillaAlargada(2)L
ChauchaAmarillaL
ChauchaAmarillaAlargada(1)L
RatonaAmarillaC
UvillaBlancaCH
ChauchaRoja(2)L
WicupaColoradaL
WicupaAmarillaL
ChauchaAmarilla(1)C
ChauchaBorregaAzC
ChauchaNegraC
ChauchaNegra(1)L
ChauchaBlancaL
MamberaC
TabaqueraBlancaCH
ChauchaBotella(1)C
RatonaAmarilla(Selec)C
PapadeChacra(3)L
ChauchaNegra(2)L
Gloria
Mondial
Bintje
Eersteling
Frieslander
Mentor
Bildtstar
Eigenheimer
Accord
Nicola
Uva(1)C
Uva(2)C

Figure 3. UPGMA tree showing the relationship among 152 Ecuadorian landraces and ten selected Dutch varieties. Geographical background of the landraces is indicated with C, CH and L at the end of the name, referring to Carchi, Chimborazo and Loja, respectively. The landrace names are color-coded as follows:
green: similar names applied to material with different genetic profiles; red: identical names with different genetic profiles; purple: the cluster of landraces with different names but an identical genetic profile; blue: mixture of two landraces collected under one name with genetically different profiles (we kept the original name of the collection but added "selection" in brackets).

Landraces with similar names do not always cluster together; an example is *Chaucha amarilla* that contains landraces from the 3 study regions (Table 1). *Chaucha amarilla* was subdivided in three groups: 1) four landraces collected as *Chaucha amarilla*; 2) two landraces under the name *Chaucha amarilla alargada*; and 3) two landraces collected as *Chaucha amarilla redonda*. The dendrogram (Figure 3) shows that *Chaucha amarilla* from Carchi and 2 landraces of *Chaucha amarilla redonda* from Loja are genetically identical. Two landraces from Loja, *Chaucha amarilla* and *Chaucha amarilla alargada* are also identical, but different from another *Chaucha amarilla alargada* collected in Loja. Finally two *Chaucha amarilla's,* one from Carchi and the other from Chimborazo, are genetically different from each other, and from the other groups (Figure 3). Even landraces with identical names collected in the same locality do not always cluster together; examples are *Colorada Antigua* from Loja. Of the 24 groups of landraces with identical names (Table 1) 17 are genetically not identical (Figure 3).
Landraces with different names can be genetically identical. An example is the cluster containing the landraces *Carriza*, *Negra* or *Catalina* from Loja; *Carriza, Negra (Morasurco)* and *Huevo de Indio* from Carchi; and *Norte Roja* from Chimborazo. All of these landraces have similar tuber skin: black and white (Appendix 1). The dendrogram (Figure 3) shows that of the 19 genetically identical groups, 17 consist of differently named landraces.
Landraces collected under one name can also be mixtures. Three such cases were identified when the material was grown in the field for multiplication and verified afterwards when the selected material was characterized using the markers. These were *María Esperanza, Semibolona 2* and *Ratona amarilla.* The different representatives of these landraces ended up separated from each other in the dendrogram (Figure 3).

Population differentiation

We conducted Fst analysis at different levels. First, we looked at the distribution of genetic variation among the three ploidy levels. The Fst among diploid, triploid and tetraploid material was 0.157 (P = 0.000). Based on this we decided to carry out an analysis based on geographical origin (landraces grouped according to the area in which they were collected) per ploidy level and not to mix all ploidy levels together. The Fst for diploid materials was 0.081 and significant (P = 0.005). The pairwise Fst values were as follows: Carchi-Chimborazo 0.092 (P = 0.054), Carchi-Loja 0.041 (P = 0.153) and Chimborazo-Loja 0.128 (P = 0. 045). The Fst for the tetraploid potatoes across research areas was 0.034 and highly significant (P = 0.000). The pairwise Fst comparisons were in this case: Carchi-Chimborazo 0.045 (P = 0.009), Carchi-Loja 0.021 (P = 0.045) and Chimborazo-Loja 0.035 (P = 0.000). We did not analyze the triploids as they were only present in low numbers and not in all study areas.

Discussion

Relation between landrace name and genetic profile

The names of the Ecuadorian potato landraces include tuber characteristics, such as color and shape or are related to animals, persons, gender or objects as mentioned in Hawkes (1947) for South America and De Haan (2009) for Peru. The fact that the potato names include Spanish, Spanish-Kichwa and Kichwa names reflects the mixed ethnic groups holding the potato diversity in our study areas. Our potato collection mainly contains Spanish names which is in line with observations by Hawkes (1947). However, in contrast to Hawkes, we found more Spanish-Kichwa names than pure Kichwa (Hawkes refers to Quechua, while we refer to Kichwa, the correct term for Ecuador). The decrease of transmission of Kichwa among generations (King, 1999) resulted in less Kichwa words in potato naming during the last 60 years. We could not determine the etymology of all landrace names studied.

Our results on the relation between landrace name and genetic profile could lead to either under- or overestimation of the genetic diversity present in farmer fields. We found that 17 out of 24 groups with identical names (Table 1) were genetically different (Figure 3), which would suggest underestimation. However, these numbers are biased as we only collected materials under the same name in the same canton when the morphology was different, assuming that the morphological differences in tubers reflect genetic differences. Brush et al. (1981) and De Haan (2009) mention that tuber morphology and genotypic identity are related. Our finding of a mixture of two landraces under one name, as is the case for *Semibolona* 2, *María Esperanza* and *Ratona amarilla*, suggest that even more genetic diversity might be present. To really address the extent of possible underestimation of the diversity resulting from identical names attached to genetically different material a much more extensive study should be carried out. On the other hand, we also found landraces collected under different names that turned out to be genetically identical: 17 out of 19 clusters of genetically identical landraces contain landraces collected under different names (Figure 3). This would indicate that relying on the names only would lead to an overestimation of the diversity. Sampling on the basis of names combined with morphology, as we have done, possibly provides the best results.

Genetic structure based on SSR markers

In our study we used SSR markers that were originally selected as highly informative for the identification of European potato varieties (Reid et al., 2009; Reid et al., 2011). They also proved to be useful for characterizing Ecuadorian landraces (Table 2). In the largest group, containing 96 Ecuadorian tetraploid landraces, the number of alleles per genotype and PIC values were comparable to that in the European collection of 892 varieties. This suggests that there is a large variation among the Ecuadorian landraces and more alleles are expected to be found when more material from other areas will be screened.

The alleles shared among the European and Ecuadorian material may be explained by the fact that European material was derived from Andean and Chilean potatoes (Spooner et al., 2005c; Spooner et al., 2007; Ames and Spooner, 2008) and Andean potatoes are also present in Ecuador. The unique alleles present in the European materials might originate from Chilean potatoes or from crosses with wild relatives. The presence of unique alleles in the Ecuadorian landraces shows that there is unexploited variability in these potatoes, just like previously pointed out by Quiros et al. (1990) for Peruvian potatoes.

The difference in the SSRs between Ecuadorian and European material is also apparent in the dendrogram of Figure 3, where there is a clear separation between the Ecuadorian landraces and the Dutch varieties. Within the cluster of Ecuadorian landraces there are many examples of extremely similar or even identical landraces. This is not true for the Dutch varieties, which are all very different from each other.

The third branch in the dendrogram consists of a group of two landraces named *Uva*, that were collected in Carchi. These *Uva* samples were provided by farmers as landraces but probably are natural hybrids between Andigenum and Chilotanum groups (Ghislain et al., 2009).

Ploidy levels of Ecuadorian potato landraces

Our ploidy level determinations confirm the presence in Ecuador of *Solanum tuberosum* diploid Andigenum Group (Spooner et al., 2007) formerly *S. tuberosum* Phureja Group (Spooner et al., 1992; Huamán and Spooner, 2002); *S. tuberosum* triploid Andigenum Group (Spooner et al., 2007) formerly *S. tuberosum* Chaucha Group (Huamán and Spooner, 2002); and *S. tuberosum* tetraploid Andigenum Group (Spooner et al., 1992; Spooner et al., 2007) formerly *S. tuberosum* Andigenum Group (Huamán and Spooner, 2002). In Ecuador, *Chaucha* refers to early sprouting potatoes and not to the triploid species *S. chaucha* (*S. tuberosum* triploid Andigenum Group). No pentaploid cultivated potatoes were identified among our landraces.

The distribution of landraces over the ploidy classes is similar to what Jackson et al. (1980) and De Haan (2009) found for Peru. Tetraploids are more common than diploids and triploids. With the exception of Loja, where no triploid potatoes are found, all ploidy levels occur at each research site. The absence of triploid potatoes in Loja might be caused by under-sampling.
Our data show that farmers maintain potatoes with different ploidy levels in their fields, which is similar to the reports for Peru in Zimmerer and Douches (1991) and De Haan (2009).

Tetraploid potatoes are preferred at all research sites. In the case of Chimborazo and Loja, environmental conditions demand a seasonal planting. In this case, the tetraploids offer advantages such as the possibility of longer storage for food and late sprouting for the next planting season. In Chimborazo the planting season is from October to July (farmers skip the dry season) and in Loja the planting season is from May to October (farmers avoid the rainy season from November to April to minimize environmental related diseases such as late blight). Regarding the diploids, a larger number of these potatoes is present in Carchi (Figure 2). Here farmers plant potatoes during the whole year (Antle et al., 1994). Diploid potatoes are suitable for this because of their lack of dormancy and thus represent a continuous source for food and "seed". Also, the quality characteristics of the diploid potatoes are appreciated more, as mentioned by the farmers from the three research sites.

Our molecular data helped to distinguish the Ecuadorian landraces of potato. However, apparent grouping inconsistencies are observed with respect to ploidy levels within identical materials (Appendix 1). For example in the cluster containing *Rapuña 1*, *Capulí*, *Huarmi papa*, *Moronga*, *Rapuña 2* and *Ascochaqui* all from Chimborazo, the ploidy level is intermixed with triploids and tetraploids. Another example is the cluster including *Yanapera* (Chimborazo- 4x) and two landraces named *Chaucha amarilla* from Loja (2x). Another case with mixed ploidy level is in a cluster from Chimborazo (*Morosel*, *Freila*, *Pargate* and *Chaucha ratona*) *Chaucha ratona* is diploid and the other tetraploid. Finally, the cluster with *Tsujtsuj* tetraploid and *Chihuila negra* triploid from Chimborazo. What the exact nature of the apparent inconsistencies is unknown and needs further research.

Do the landraces from the 3 research sites constitute genetically different gene pools?

The research areas located in the North, Center and South of Ecuador present different climatic and edaphic conditions. When we compare the three research areas we found significant differences among them for diploid (FST=0.081) as well as tetraploid (FST=0.034) landraces. In this respect our findings are different from similar studies in Peru where no differentiation among regions was found in Cusco (Brush et al., 1995) and Huancavelica (De Haan, 2009). When we make pair wise comparisons between the materials from different regions we see that the Fst for diploid materials is only significant in the Chimborazo-Loja comparison. None of the comparisons is significant at the P = 0.01 level. For the tetraploid landraces the pair wise comparisons between the three areas indicate highly significant Fst values between Carchi-Chimborazo and Chimborazo-Loja.

Our dendrogram does not show any grouping according to region (Figure 3) which means that alleles are shared among the landraces from the three research areas, suggesting exchange of landraces among the areas. Indication of such exchange are the groups of genetically identical landraces, either with the same or different names, that were collected in two or three areas. We discussed the example of the cluster containing the landraces *Carriza* (Carchi, C; Loja, L), *Negra* (L), *Catalina* (L), *Morasurco* (C), *Huevo de indio* (C) and *Norte roja* (Chimborazo, CH). During the communal meetings farmers considered *Carriza* as marketable-landrace. The marketing of these landraces, probably in low quantities, might explain their movement across Ecuador. According to the farmers *Norte Roja* has special frost and late blight resistance, the other members of the group were reported as good for consumption.

Another example supporting the movement of landraces includes: *Parda pastusa*, *Parda mejorada* and *Parda suprema* which were handed in as landraces in Carchi, but these might be Colombian improved varieties. Interestingly, farmers from the three research areas described their landraces mainly as “local”. Apparently farmers over time embrace landraces as their own and maintain them for production under their local conditions.

Carchi, Chimborazo and Loja hold rich potato diversity. We previously discussed the vulnerability of the potato conservation especially in Carchi and Loja (Monteros-Altamirano et al., 2011). Our potato collection aimed at collecting materials for *ex situ* conservation. However, our results suggest that collections are never exhaustive and that under-representation of the genetic variation is difficult to avoid. Therefore complementary *in situ* conservation strategies are necessary to prevent the loss of the unique alleles and genotypes present in Ecuador.

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Annex 1. Nineteen clusters identified as genetically identical by using 8 SSR markers (numbered from 1 to 19). The clusters were arranged according to the names of the landraces within the groups: identical, similar or different names. Two clusters include landraces with identical names and identical molecular profiles. Five clusters include landraces with similar name and identical genetic profile. Twelve clusters include landraces with different names and identical molecular profiles. Landraces were collected at Carchi, Chimborazo and Loja, Ecuador. Clusters containing landraces collected from the same or different research sites are grouped.

IDENTICAL NAMES

Same research site

Landrace name	Research site	Canton	
1.			
a. Manuela (2)	Chimborazo	Guamote	 *a*  *b*
b. Manuela (3)	Chimborazo	Guamote	
2.			
a. Negra ojona (1)	Loja	Gonzanamá	 *a*  *b*
b. Negra ojona (2)	Loja	Gonzanamá	

SIMILAR NAMES

Same research site

Landrace name	Research site	Canton	
3.			
a. Puña	Chimborazo	Colta	 *a*  *b*
b. Puña negra	Chimborazo	Colta	
4.			
a. Bodeguera blanca	Loja	Saraguro	 *a*  *b*
b. Bodeguera Blanca (ojo morado)	Loja	Saraguro	
5.			
a. Bolona (1)	Loja	Saraguro	 *a*  *b*
b. Bolona amarilla	Loja	Saraguro	 *c*
c. Bolona (2)	Loja	Loja	

6. *a.* Guata amarilla *b.* Guata roja *c.* Guata morada	Loja Loja Loja	Saraguro Saraguro Saraguro	 *a*  *b*  *c*

Different research site

Landrace name	Research site	Canton	
7. *a.* Chaucha amarilla (2) *b.* Chaucha amarilla redonda bolonga *c.* Chaucha amarilla redonda	Carchi Loja Loja	Tulcán Saraguro Loja	 *a*  *b* *c.* Photo not available

DIFFERENT NAMES

Same research site

Landrace name	Research site	Canton	
8. *a.* Morosel *b.* Freila *c.* Pargate *d.* Chaucha ratona	Chimborazo Chimborazo Chimborazo Chimborazo	Guamote Quero Guamote Guano	 *a*  *b*  *c*  *d*
9. *a.* Rapuña (1) *b.* Capulí *c.* Huarmi papa *d.* Moronga *e.* Rapuña (2) *f.* Ashco chaqui	Chimborazo Chimborazo Chimborazo Chimborazo Chimborazo Chimborazo	Guamote Guamote Guamote Guamote Guamote Riobamba	 *a*  *b*  *c*  *d*  *e*  *f*

10.			 *a*  *b*
*a.*Tsujtsuj	Chimborazo	Guamote	
*b.*Chihuila negra	Chimborazo	Guamote	
11.			 *a*  *b*  *c*  *d*
*a.*Cacho blanco	Chimborazo	Colta	
b. Leona roja	Chimborazo	Guamote	
c. Cuchi dzili	Chimborazo	Guamote	
d. Cuerno blanco	Chimborazo	Guamote	
12.			 *a*  *b*
*a.*Chaucha roja (3)	Loja	Taquil	
*b.*Escaleña	Loja	Gonzanamá	
13.			 *a*  *b*
*a.*Puña	Carchi	Montúfar	
*b.*Leona del Carchi	Carchi	Montúfar	
14.			 *a*  *b*
*a.*Chaucha amarilla (1)	Carchi	Espejo	
*b.*Chaucha borrega/Azul	Carchi	Huaca	

Different research site

Landrace name	Research site	Canton	
15.			 *a*  *b*  *c*  *d*  *e*  *f*
*a.*Carriza	Loja	Saraguro	
*b.*Negra	Loja	Loja	
*c.*Negra (Carrizo, Catalina)	Loja	Saraguro	
*d.*Catalina	Loja	Saraguro	
*e.*Carriza (1)	Carchi	Montúfar	
*f.*Negra (Morasurco)	Carchi	Tulcán	

*g.*Huevo de indio *h.*Norte roja	Carchi Chimborazo	Bolivar Colta	*g*. Photo not available  *h*
16. *a.*Yana pera *b.*Chaucha amarilla *c.*Chaucha amarilla alargada (2)	 Chimborazo Loja Loja	 Colta Loja Loja	 *a*  *b*  *c*
17. *a.*Chaucha ratona (1) *b.*Chaucha ratona (2) *c.*Tabaquera colorada	 Carchi Carchi Chimborazo	 Tulcán Tulcán Riobamba	 *a*  *b*  *c*
18. *a.*Huancala *b.*Colorada	 Chimborazo Loja	 Guamote Saraguro	 *a*  *b*
19. *a.*Super violeta *b.*Chola antigua	 Carchi Loja	 Tulcán Loja	 *a*  *b*

CHAPTER 4

Ecuadorian potato landraces and late blight resistance

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Abstract

A field experiment was carried out to assess resistance or susceptibility to late blight of 31 Ecuadorian potato landraces collected in Carchi, Chimborazo and Loja. The experiment was conducted in Quito at the Santa Catalina Experimental Station (EESC) of the National Institute for Agricultural Research (INIAP). This location was selected because it is under high *P. infestans* pressure. Additionally, a survey to 150 farmers growing potato landraces in these provinces identified the main diseases affecting their potatoes. Informal conversations with these farmers both during the collections and during farmer meetings provided additional information regarding late blight and their perception of landrace resistance. The landraces under study showed different responses to late blight in the experimental field. Based on the AUDPC scores we distinguish three categories: resistant, intermediate and susceptible. Five landraces (and two commercial varieties grown as controls) showed the best field resistance. Similar to farmers growing commercial varieties also farmers currently cultivating landraces consider late blight as the main disease in their potatoes. It is interesting that farmers have managed to maintain these mostly susceptible landraces for centuries. Probably the broad crop diversity on their farms and the planting of potato landrace mixtures reduces the late blight severity effects within their potato fields. Possible strategies to improve late blight resistance in potato in Ecuador could include the identification of accessions with resistance among local landraces and/or the introduction of new sources of resistance from other origins. Alternatively, one could attempt to introduce novel R-genes in material that already contains some level of quantitative resistance.

Introduction

Late blight, caused by *Phytophthora infestans* (Mont.) de Bary, is one of the most devastating diseases of potato world-wide (Birch and Whisson, 2001). The disease is also a limiting factor in potato production in Ecuador (Crissman et al., 1998). It has been observed that under extreme climatic conditions, the potato crop can be destroyed within a few days after the first symptoms are visible (Oyarzún et al., 2001). All the information on the importance of late blight is based on commercially grown potatoes in Ecuador. However, Ecuadorian farmers also maintain old potato landraces in their fields (Monteros-Altamirano et al., 2011a). These landraces have endured biotic and abiotic stresses for generations and are still maintained under low input conditions.

Resistance to late blight may be based on vertical resistance or horizontal resistance. Vertical resistance is based on major genes which include amongst others the so-called the NBS-LRR type of resistance genes. Such resistance (R)-genes often originate from wild relatives of potato (Jacobs et al., 2010; van der Vossen, 2003; Tan et al., 2008; Pel et al., 2009; Lokossou et al., 2010). Horizontal resistance, also known as quantitative or field resistance, is based on multiple genes that each have a relatively small effect and, in theory, render the host partially resistant to all races of the pathogen (Vanderplank, 1968; Turkensteen, 1993; Colon et al., 1995; Landeo et al., 1995). Some authors consider field resistance more stable than resistance based on R-genes (Turkensteen, 1993; Wulff et al., 2007; Brown and Caligari, 2008). However, also pyramiding of R-genes has been suggested as a strategy for obtaining late blight resistance (Tan et al., 2010).

The Andean cultivated potatoes *S. tuberosum* ssp. *andigenum* and *S. phureja* are reported to have quantitative resistance (Simmonds and Malcomsom, 1967; Turkensteen, 1993; Cañizares and Forbes, 1995; van Soest et al., 1984). Van Soest et al. (1984) evaluated nearly 200 accessions of *S. tuberosum* ssp. *andigenum* and found intermediate to high susceptibility to late blight. Based on this they concluded that these materials have no practical value for breeding. Gabriel et al. (2007) found good quantitative resistance in *S. tuberosum* ssp. *andigenum* accessions when compared to accessions of *S. stenotomum*, *S. juzepczukii* and *S. ajanhuiri* from Bolivia. Also, late blight resistance was found in *S. tuberosum* ssp. *andigenum* seedling populations under long-day conditions after mass-selection (Simmons and Malcoms, 1967). Van Soest et al. (1984) found resistance in one accession of *S. phureja*. In evaluations of Ecuadorian landraces of *S. phureja*, mostly susceptible material was found, but also some accessions with field resistance to late blight were identified (Cañizares and Forbes, 1995; Revelo et al., 1997a). One of the resistant accessions of *S. phureja* (CHS-625) was crossed with a susceptible *S. tuberosum* DH line (PS-3) producing a dihaploid hybrid population that segregated for quantitative resistance (Trognitz et al., 2001). In this population QTLs associated with field resistance to late blight under short-day conditions were identified (Ghislain et al., 2001; Trognitz et al., 2002). Also two PR-1 genes have been isolated and proposed to play a role in horizontal late blight resistance in *S. phureja* (Evers, 2006). In conclusion, Andean potatoes show quite some variation in resistance to late blight, but unfortunately many of them are susceptible. However, field resistance does exist and accessions with this characteristic have been used in breeding programs.

In this study we evaluate selected Ecuadorian landraces from three provinces for late blight resistance under natural conditions. We connect our evaluation with the farmers' perception on their landraces in relation to late blight resistance and their understanding of potato landrace management in the field.

Materials and methods

Plant materials

We studied 31 Ecuadorian potato landraces collected in the provinces of Carchi, Chimborazo and Loja, which are areas of high potato diversity. Three of these landraces are classified as *S. tuberosum* diploid Andigenum Group (Spooner et al., 2007), formerly *S. phureja* (Hawkes, 1990); one landrace as *S. tuberosum* triploid Andigenum Group (Spooner et al., 2007), formerly *S. chaucha* (Hawkes, 1990); and 27 landraces as *S. tuberosum* tetraploid Andigenum Group (Spooner et al., 2007), formerly S. *tuberosum* ssp. *andigenum* (Hawkes, 1990). The ploidy levels of all the materials were confirmed by flow cytometry as described in Monteros-Altamirano et al., (2011b). The 31 landraces were selected from 152 native potatoes, which had been genotyped previously with 8 SSRs in Monteros-Altamirano et al. (2011b). Figure 1 shows the relationship among the materials selected for this study.

Additionally two improved tetraploid commercial varieties were included in the analysis as control: ‘Superchola’ and ‘I-Fripapa’.

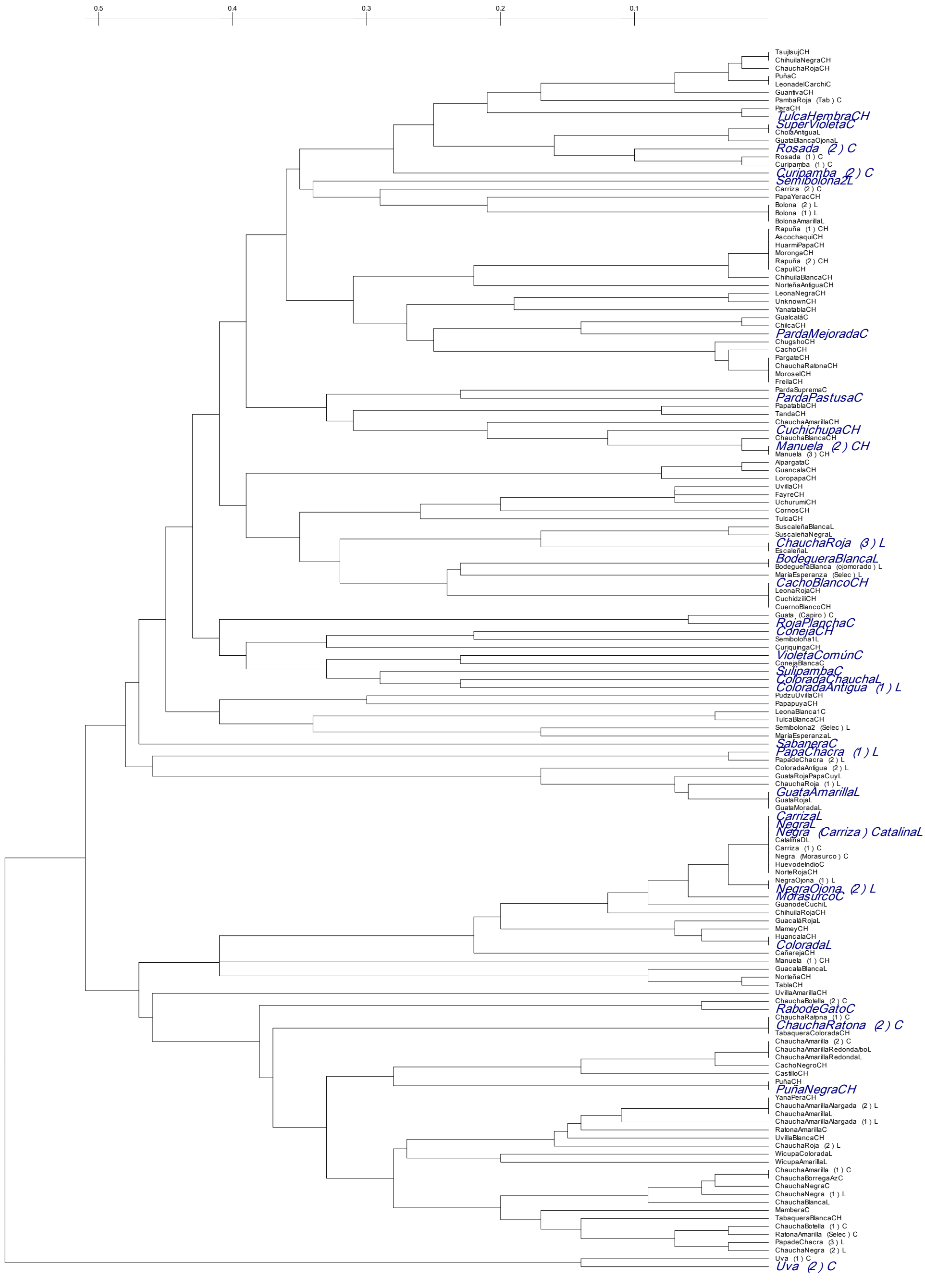

Figure 1. UPGMA tree showing the genetic relationship of the 31 landraces selected for the study (in blue). The tree was constructed using the Nei and Li coefficient (Nei and Li, 1979) based on 8 SSRs (Monteros-Altamirano et al., 2011b).

Farmers from Carchi, which is at the border with Colombia, provided ‘Parda mejorada’ and ‘Parda pastusa’ as landraces. However, there are also Colombian commercial varieties under these names. According to Ñustez (2010) the Colombian ‘Parda pastusa’, was produced by a cross [‘Quincha’ (*S. tuberosum* ssp. *andigenum*) x ‘Tocana colorada’ (*S. tuberosum* ssp. *andigenum*)]. The material of ‘Parda pastusa’ used in our study was triploid and we consider this material as a landrace. We could not get additional information on ‘Parda mejorada’. ‘Uva’ was collected as a landrace but turned out to be genetically distant from all other potato landraces. It apparently is an spontaneous hybrid Andigenum x Chilotanum (Ghislain et al., 2009).

Farmer’s information

150 surveys were conducted with farmers growing potato landraces in the provinces of Carchi, Chimborazo and Loja (Monteros-Altamirano et al., 2011a). The survey included a question regarding the main diseases affecting the potato landraces. Farmers provided common names of the diseases affecting their landraces. This information was compared to Oyarzún et al. (2002) who described potato diseases present in Ecuador. Also, informal conversations with farmers both during the collections and during farmer meetings provided information regarding late blight and their perception of landrace resistance.

Field experiment

A field experiment was carried out to assess resistance or susceptibility of Ecuadorian potato landraces to late blight. The experiment was conducted in Quito at the Santa Catalina Experimental Station (EESC) of the National Institute for Agricultural Research (INIAP) located at 3050 m.a.s.l, Longitude: 78º33’15” and Latitude: 00º22’4” S. The average annual temperature is 13ºC, the annual precipitation: 1432.1 mm, and the relative humidity (annual average) 72.5 % (data from Izobamba Meteorological Station, in EESC). This location was selected because it is under high *P. infestans* pressure. In the past, 36 complex races of *P. infestans* were identified at this location (Tello, 2008).

A complete random block design with four repetitions was used. The landraces were planted in single row plots of ten plants per repetition, with a plant spacing of 0.25 m and a row spacing of 1.0 m. One application of contact fungicide (Mancozeb) was done after 30 days of emergence to protect the plants from complete devastation by late blight. This protocol is common practice at Santa Catalina station due to the high disease pressure. It is also recommended by the International Potato Center (2006).

The plant materials were evaluated under natural infection pressure. The severity of the foliage damage caused by late blight (as a percentage of leaf surface) was assessed every 7 days for 4 weeks. The evaluation started when the first symptoms were observed (62 days after emergence). The late blight assessments were used to calculate the Area Under the Disease Progress Curve (AUDPC) following Shaner and Finney (1977):

$$AUDPC = \sum_{i=1}^{n} [(Y_{i + n1} + Y_i)/2]\,[X_{i+1} - X_i]$$

in which Y_i = late blight severity (per plot) at the i*th* observation, X_i = time (days) at the i*th* observation, and n = total number of observations.

Data analysis

We used SAS (release 9.1, SAS Institute, Inc., Cary, NC) to perform an ANOVA analysis. A LSD Fisher test on the AUDPC data was performed in Infostat® (Di Rienzo et al., 2008) to determine the statistical significance of the differences among the landraces.

Results

Diseases affecting Ecuadorian potato landraces

A total of 145 farmers provided information about the main diseases affecting their potato landraces (47 from Carchi, 49 in Chimborazo and 49 in Loja). Farmers mentioned nine diseases affecting their potatoes. The number of times a respondent mentioned a disease is shown in Figure 2. Late blight, in

Ecuador known as ‘Lancha’, was most frequently mentioned in the three areas. The second important disease in Carchi was ‘Lanosa’ *(Rosellinia* sp.) and in Chimborazo and Loja: ‘Pudrición de la raíz’, which is root wilt (in this case the pathogen is unknown). The farmers from Loja mentioned more local common names of diseases than in the other areas, but the associated pathogens are unknown. These diseases were grouped under the category “Other”.

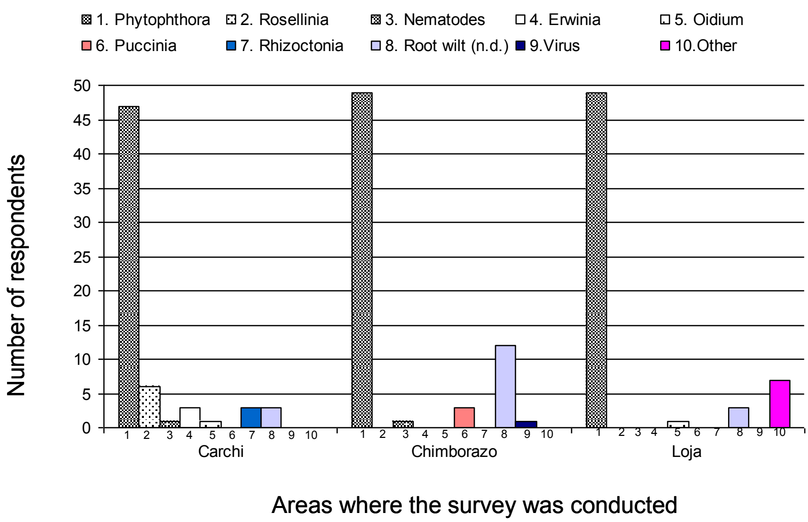

Figure 2. Number of respondents that mentioned a disease affecting potato landraces in three provinces of Ecuador (n=145). All the diseases mentioned by the farmers are included (sometimes more than one per farmer).

Response to late blight of the selected Ecuadorian landraces

The Analysis of Variance for the model AUDPC = Blocks + landraces, was highly significant (F= 4.16; P= 0.0001). The variation among blocks was not significant (F= 0.33; P= 0.8285) and the variation among landraces highly significant (F= 4.52; P= 0.0001).

The LSD test ranked the landraces according to their field response to late blight (Table 1). A total of 5 landraces and 2 varieties were ranked as most resistant. Three of these landraces are from the *S. tuberosum* tetraploid Andigenum Group: ‘Uva’, ‘Guata amarilla’, ‘Coneja’ and ‘Chaucha roja’ and one from the *S. tuberosum* diploid Group: ‘Chaucha ratona’. The landrace *‘*Chaucha roja*’* is an early-sprouting potato but tetraploid while ‘Chaucha ratona’ is a diploid early-sprouting landrace. The landrace ‘Uva’ performed the best.

The most susceptible group included the landraces: ‘Tulca hembra’, ‘Sulipamba’, ‘Colorada antigua’, ‘Roja plancha’, ‘Papa chacra’, ‘Rabo de gato’, ‘Manuela’, ‘Rosada’, ‘Cuchi chupa’, ‘Cacho blanco’ and ‘Sabanera’.

The remaining landraces were ranked as intermediate in late blight resistance. These landraces include: ‘Negra-Carrizo-Catalina’, ‘Super violeta’, ‘Violeta común’, ‘Curipamba’, ‘Colorada chaucha’, ‘Parda pastusa’, ‘Morasurco’, ‘Puña negra’, ‘Negra ojona’, ‘Parda mejorada’, ‘Bodeguera blanca’, ‘Semibolona’, ‘Negra’, ‘Carriza’ and ‘Colorada’.

Discussion

Ecuadorian landraces and late blight performance

The landraces under study showed different responses to late blight in the experimental field. Most of them turned out to be moderately resistant to susceptible (Table 1), which is in line with reports on landraces from other parts of the Andes (Turkensteen, 1993; Van Soest et al., 1984; Birhman and Kang, 1993). Five landraces (one diploid and four tetraploid) showed the best field resistance. The performance of these landraces was similar to the tetraploid variety ‘I-Fripapa’, which is a leading variety in Ecuador and reported as resistant (Oyarzún et al., 2001 a; Perez and Forbes, 2007) or moderately resistant (Cáceres et al., 2008). The variety ‘Superchola’ is believed to be susceptible, but was not significantly different from the most resistant landraces in our field experiment. The landrace ‘Uva’ performed the best and is believed to have *S. tuberosum* ssp *tuberosum* in its pedigree which may have donated its resistance (Turkensteen, 1993).

Late blight perception by farmers

Similar to farmers growing commercial varieties (Ortiz et al., 1999) also farmers currently cultivating landraces consider late blight as the main disease in their potatoes (Figure 2). Other diseases were mentioned but these are less important. Farmers are aware of differences in late blight response among their landraces. They know that certain landraces are more resistant or susceptible than others. For example, 'Sulipamba' is considered susceptible by the farmers, which was confirmed in our field experiment (Table 1). Similarly, 'Uva' was considered resistant by the farmer who provided the landrace.

Table 1. Late blight resistance of the Ecuadorian potato landraces and the two varieties. Common names of the landraces, origin, collection code, AUDPC values, LSD and ploidy levels are shown.

Landrace	Province	Code	Ploidy	AUDPC (average)	LSD*
Uva	Carchi	JS-2	4x	331	A
Chaucha roja	Loja	MPG-028	4x	374	AB
Guata amarilla	Loja	MG-007	4x	427	ABC
Coneja	Chimborazo	FM RA FH 002	4x	434	ABC
Chaucha ratona	Carchi	AXC-028	2x	505	ABC
Fripapa (Var.)			4x	507	ABC
Superchola (Var.)			4x	557	ABCD
Negra, Carriza or Catalina	Loja	MOPG-002	4x	589	BCD
Super violeta	Carchi	AXC-004	4x	597	BCD
Violeta común	Carchi	AXC-025	4x	599	BCD
Curipamba	Carchi	AXC-016	4x	628	BCDE
Colorada chaucha	Loja	MOPG-004	4x	663	BCDE
Parda Pastusa	Carchi	AC-042	3x	692	BCDE
Morasurco	Carchi	AXC-009	4x	696	BCDE
Puña negra	Chimborazo	FM FH RA 002	4x	711	BCDEF
Negra ojona	Loja	MG-011	4x	714	CDEF
Parda mejorada	Carchi	AXC-020	4x	716	CDEF
Bodeguera blanca	Loja	MOPG-009	4x	723	CDEF
Semibolona	Loja	MG-014A	4x	759	CDEF
Negra	Loja	MPG-033	4x	761	CDEF
Colorada	Loja	MOPG-003	4x	768	CDEF
Carriza	Loja	MPG-020	4x	778	CDEF
Tulca hembra	Chimborazo	XCFM-19	4x	781	CDEFG
Sulipamba	Carchi	AXC-003	4x	788	DEFG
Colorada antigua	Loja	MPG-042	4x	842	DEFG
Roja plancha	Carchi	AXC-030	4x	891	DEFG
Papa chacra	Loja	MPG-021	2x	914	DEFG
Rabo de gato	Carchi	AC-040	2x	917	DEFG
Manuela	Chimborazo	AMFY-1	4x	917	EFG
Rosada	Carchi	AXC-029	4x	919	EFG
Cuchi chupa	Chimborazo	FMFYRA IV 005	4x	1013	FG
Cacho blanco	Chimborazo	FM RA FH 002	4x	1069	FG
Sabanera	Carchi	AC-034	4x	1125	G

* Different letters indicate significant difference at α = 0.05.

Changes in the response of landraces to late blight have been noticed by farmers. In Carchi farmers mentioned that ‘Violeta’, ‘Curipamba’ and ‘Morasurco’ were the more resistant landraces in the past. In our field trial these landraces end up in the intermediate group. These changes might be related to the appearance of more virulent races of *P. infestans*. Forbes et al. (1997) reported a shift in *P. infestans* populations. The original clonal lineage US-1 was replaced by EC-1, which has more complex races than the previous one.

Management practices of farmers

It is interesting that farmers have managed to maintain these mostly susceptible landraces for centuries. Apparently, there are other characteristics that promote the continued use of the landraces, despite their lack of late blight resistance. Ortiz et al. (1999) already mentioned that farmers preferred particular cultivars for other reasons than LB resistance. For example in our study the landrace *Sulipamba* was determined as susceptible, but local farmers appreciate its taste.

There are also management practices that decrease the impact of late blight on their potato crop. Farmers growing potato landraces do not only keep potatoes, but a much broader crop diversity on their farms (Monteros-Altamirano et al., 2011a). This crop diversity may provide protection to diseases by inter-cropping and crop rotation (Thurston, 1990; Garret et al., 2001). An example is the susceptible landrace ‘Papa de chacra’, which is grown within corn fields “as weedy potato” with no pesticide application. Another common practice among the farmers is planting potato landraces in mixtures. This can reduce potato late blight severity as observed by Andrivon et al. (2003) and Pilet et al. (2006). We observed different landraces of potatoes and also different ploidy levels intermixed in farmer fields (Monteros-Altamirano et al., 2011b).

Potato landraces were managed organically in the past. The appearance of new commercial cultivars e.g. ‘Superchola’ and ‘I-Fripapa’ has brought new management practices to the commercial potatoes. A large range of fungicides and excessive use of them has been documented in commercial potatoes in Ecuador (Crissman 1994, 1998; Ortiz et al., 1999; Ortiz et al., 2001). Pesticide application on the commercial varieties is now common practice and farmers are also increasing their use of potato landraces. Currently 64% of the farmers in Carchi, 58% in Chimborazo and 60% in Loja are managing landraces similarly to commercial varieties (Monteros-Altamirano et al., 2011a).

Finally, farmers growing landraces are aware of ways to escape late blight; e.g. farmers in Loja skip the heavy rainy season to avoid losses due to late blight attack (Monteros-Altamirano et al., 2011b).

Perspectives for late blight resistance breeding

From this study (Table 1) and previous reports, it is clear that there is variation in the level of resistance to late blight in Ecuadorian landraces (Cañizares and Forbes, 1995; Revelo et al, 1997a). Possible strategies to improve late blight resistance in potato in Ecuador could include the identification of accessions with resistance among local landraces and/or the introduction of new sources of resistance from other origins. A screening of the available potato germplasm could be carried out. However, considering our results on a selection of landraces that represents the available diversity quite well (Figure 1), this might not lead to much improvement as most landraces turned out to be susceptible.

Previous experiences with the release of varieties carrying R-genes in Ecuador showed that the resistance was quickly overcome by the *P. infestans* population (Revelo et al., 1997b; Oyarzun et al., 2001). This probably is due to the high variability of the *P. infestans* populations present in the Ecuadorian highlands (Forbes et al., 1997; Tello, 2008). As an alternative, the pyramiding of novel R-genes obtained from different sources has been proposed to improve late blight resistance and its durability (Tan et al., 2010; Verzaux, 2010). However, we have to keep in mind that several of the R-genes have already been defeated. Therefore, a careful selection has to be made based on the frequency of the different races and composition of the *P. infestans* population. It is encouraging that recent research identified several novel R-genes in wild tuber bearing *Solanum* species that will be useful (Wang et al., 2008; Jacobs et al., 2010; Pel et al., 2009). In addition, it might be a viable strategy to introduce these novel R-genes in material that already contains some level of quantitative resistance, as suggested by Stewart et al. (2003).

CHAPTER 5

Tuber quality characteristics of Ecuadorian potato landraces and farmer preferences

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Abstract

Antioxidants, such as polyphenols and carotenoids, are present in potato and reported to have positive effects on human health. For Ecuadorian landraces there is a lack of data on these compounds. The present study aims 1) to characterize potato landraces from three areas in Ecuador for dry matter, total polyphenol and total carotenoid contents and 2) to determine if farmer preferences for certain landraces are based on characteristics related to nutritional value. We evaluated 23 potato landraces collected from farmer's fields and organized workshops in the areas to collect information on the preferences of local farmers. We found varying levels of dry matter, total polyphenol and total carotenoid contents among Ecuadorian potato landraces, some even comparable to improved varieties. The extent of the use of these potato landraces by farmers and breeders is discussed.

Introduction

In the Ecuadorian highlands, potato is the second most important crop after maize, and it is an important staple food for the population. Approximately 300,000 tons of potatoes are produced annually (FAO, 2011) and the annual consumption is 32 kg/year per capita (OFIAGRO, 2009). The main sources of potatoes for consumers in urban areas are the improved varieties. Only 20 out of the approximately 400 landraces reported for Ecuador actually reach urban markets (Cuesta et al., 2005; Unda et al., 2005). A recent study in areas of local potato production (Carchi, Chimborazo and Loja) showed that landraces are still in the hands of poor and small-scale farmers (Monteros-Altamirano et al., 2011a).

The potato tuber consists for about 80% of water and 20% solids. The exact dry matter content depends on cultivar/landrace and environmental conditions (Navarre et al., 2009), and it varies from 13 to 36% (Kadam et al., 1991). Dry matter content is used as a quality measure for harvested tubers (Kleinkopf et al., 1987), and because of its close relationship to tuber starch content, total solids and mealiness, it is commonly used by the processing industry for assessing acceptability for the consumer (Kleinkopf et al., 1987; Marwaha and Kumar, 1987).

Starch comprises 65-80% of the dry matter (Navarre et al., 2009). The rest of the dry matter consists of proteins, vitamins and minerals such as potassium, phosphorus, and magnesium (Woolfe, 1987; Navarre et al., 2009; Burlingame et al., 2009b). The South American native potatoes show a large variation in nutritional content. Andre et al. (2007a) reported variation among 74 Andean landraces with respect to iron (from 30 to 160 µg g^{-1} of dry weight (DW)), zinc (12.6 to 28.8 µg g^{-1} of DW), calcium (271 to 1093 µg g^{-1} of DW) and total vitamin C (217.7 to 689.5 µg g^{-1} of DW). Variation in ascorbic acid ranged from 22 to 121 mg $100g^{-1}$ on a DW basis (Burgos et al., 2009b).

The positive effect of antioxidants on human health has been reported by several authors (Yang et al., 2001; Arts and Hollman, 2005; Andre et al., 2007a; Andre et al., 2007b; Teow et al., 2007). For this reason there is a continuous search for new compounds with antioxidant activity (Yang et al., 2001; Liu, 2004; Campos et al., 2006) to prevent cancer and cardio- and cerebrovascular diseases. Besides this, many natural antioxidants exhibit a wide range of biological effects, including antibacterial, antiviral, anti-inflammatory, anti-allergic, anti-thrombotic and vasodilatory activity (Cook and Samman, 1996). Potatoes contain significant amounts of antioxidant phytochemicals like carotenoids and polyphenols (Brown, 2005). A recent study in 34 commonly consumed fruits and vegetables showed that the contribution of potato to the daily total phenolic and antioxidant intake was third after orange and apple because of the high daily consumption (Chun et al., 2005).

Characterization of Andean potatoes has shown a total phenolic content between 1.12 and 12.37 g of gallic acid equiv kg^{-1} of DW (Andre et al., 2007b). Environmental conditions significantly affected the total phenolic contents. This was demonstrated for 13 landraces evaluated in Peru, but the genotypic effect was the most determining factor (Andre et al., 2009). Several studies have determined the carotenoid content of raw potato tubers. In improved tetraploid *Solanum tuberosum*, yellow fleshed cultivars are reported to contain 58–175 mg 100 g^{-1} on a fresh weight basis (FW) and white fleshed cultivars, 38– 62 mg 100 g^{-1} FW of total carotenoids (Breithaupt and Bamedi, 2002). In tubers of a hybrid population of the diploid cultivated potatoes the carotenoid content reached up to 1435 mg 100 g^{-1} FW (Lu et al., 2001). Additional data on Andean potato landraces have been presented by Andre et al. (2007b) and Burgos et al. (2009a). Nevertheless information on the extent of variation with respect to antioxidant contents within the native Andean potatoes is still scarce (Bonierbale et al., 2004; Andre et al., 2007b; Brown, 2008) and does not exist for Ecuadorian potatoes.

This study has two objectives. The first objective is to characterize different potato landraces from three areas in Ecuador for potato tuber dry matter, total polyphenol and total carotenoid contents. This analysis will show what the variation in Ecuadorian landraces for these traits is and if it is comparable to the variation observed in widespread Ecuadorian improved varieties. The second objective is to determine if farmer preferences for certain landraces are based on characteristics related to nutritional value. This information may help to understand if nutritional characteristics have influenced the presence of potato landraces in the study areas.

Materials and methods

Evaluation of landraces at Santa Catalina Experimental Station

We studied 23 potato landraces collected from farmer's fields in three provinces of Ecuador: Carchi (9 landraces), Chimborazo (3 Landraces) and Loja (11 landraces). These landraces were selected based on the SSR genotypic information conducted on 152 accessions (Monteros-Altamirano et al., 2011b). We also included three Ecuadorian commercial varieties: INIAP-Estela, INIAP-Natividad and Superchola. A field experiment was carried out in Quito at the Santa Catalina Experimental Station (EESC) of the National Institute for Agricultural Research (INIAP) located at 3050 m.a.s.l, Longitude: 78º33'15" and Latitude: 00º22'4" S. A complete random block design with three repetitions was used. The landraces were planted in single row plots of ten plants per repetition with a plant spacing of 0.25 m and a row spacing of 1.0 m.

Sample preparation

A sample of approximately 2 kg was collected per landrace and per repetition. The tubers were randomly selected from a bulk of 10 plants harvested. These tubers were put in opaque bags, labeled and taken to the Laboratory of Nutrition and Quality in Santa Catalina Experimental Station, Quito, Ecuador. For polyphenol and carotenoids analysis the whole tubers were ground, freeze-dried and stored at -51°C prior to extraction and analysis.

Dry matter determination

The total dry matter content was determined according to Bonierbale et al. (2010). Five tubers were chopped (about 500 g total) into small 1-2 cm cubes. They were mixed thoroughly and two sub-samples of 200 g each were taken. The exact weight of each sub-sample was recorded as fresh weight. Next, each sub-sample was placed in an open container in an oven at 80°C for 72 hours or until constant dry weight was reached. Each subsample was weighted immediately after removal from the oven (recorded as dry weight). The dry matter content for each sub-sample was calculated with the following formula: Dry matter % = (dry weight / fresh weight) x 100.

Total polyphenol content

Total polyphenol content was measured according to Cros et al. (1982) with minor modifications. Polyphenol was extracted with 70% methanol from the freeze dried potato sample, under continuous stirring for 45 minutes, after which the extract was filtered. An aliquot was taken and mixed with distillated water, Folin and Ciocalteu reagent and sodium carbonate at 20% (Singleton et al., 1999). This solution was quantified in the spectrophotometer UV-VIS 2201 (Shimadzu Corp., Kyoto, Japan). The total phenolic content was expressed in g kg^{-1} of gallic acid and reported in Dry Weight (DW). The calibration was done according to Cros et al. (1982).

Total carotenoid content

Carotenoid analysis was carried out according to Kimura et al. (2007). First, 3 g of the freeze dried sample was extracted with acetone (Merck KgaA, Darmstadt, Germany) in an Ultra Turrax Teckmar homogenizer (IKA-Werke, Wilmington, NC, USA) for 3 min at 5000 rpm. The extraction was repeated until the residue was colorless. The extracts were transferred to a 500 ml separatory funnel with petroleum ether (Merck, Darmstadt, Germany) and washed 3 – 4 times with water to remove any acetone residue. The resulting saponified extracts were brought to a volume of 50 ml with petroleum ether. The total carotenoid content was calculated using the absorbance measured in a Shimadzu spectrophotometer UV-VIS 2201 (Shimadzu Corp., Kyoto, Japan) at 450 nm and the extinction coefficient for mixtures of carotenoid (2492). The total carotenoid content is expressed in micrograms of carotenoid per 100 gram in Fresh Weight basis. The calibration was done according to Scott et al. (1996).

Evaluation of landraces in Carchi, Chimborazo and Loja

Besides the evaluation at the Santa Catalina Experimental Station, we also evaluated the potato tuber dry matter content, total polyphenol and total carotenoid from landraces grown in their provinces of origin (place of collection) for two cycles during 2008 and 2009. We planted 9 landraces in Carchi (North of Ecuador), 16 in Chimborazo (Center of Ecuador) and 24 in Loja (South of Ecuador) with one replication per landrace. During the first and second year, local farmers interested in potato landraces provided land-space, except the second year in Carchi where a local agricultural high school was chosen for the evaluation. The selected locations for the 2008 evaluation were: Carchi (La Delicia - San Gabriel canton), Chimborazo (Belén - Colta canton, 3820 m.a.s.l.) and Loja (Gañil - Saraguro canton). The selected locations for the 2009 evaluation were as follow: Carchi (Colegio Agropecuario Martínez Acosta - San Gabriel canton, 2908 m.a.s.l.), Chimborazo (Pisicaz - Riobamba canton, 3300 m.a.s.l.) and Loja (San Pablo de Tenta - Saraguro canton, 2570 m.a.s.l.). Samples were collected and sent to the Laboratory of Nutrition and Quality in Santa Catalina Experimental Station for analysis as described for the Santa Catalina trial.

Farmer preferences

Three farmer meetings of one day each were organized in each research area: one in Tenta-Loja (November, 2009), another in San Gabriel-Carchi (December, 2009), and one in Pisicaz-Chimborazo (February, 2010). During these meetings we recorded information regarding the use of local landraces by using participatory tools (De Boef and Thijssen, 2007) and farmers selected locally collected landraces to take home as seed tubers.

In Loja, we invited farmers from whom we collected potato landraces (Monteros-Altamirano et al., 2011a). We prepared one bag of approximately 4 kg of tubers per landrace (24 in total) and presented them to the farmers in the patio of a local school. A tag with the name of the landrace was put in front of each bag. The farmers could walk around the bags and freely select the landraces they preferred to take home as seed-tubers. They were not restricted in the number of landraces they could take home. We registered how often a landrace was selected by the farmers.

In Carchi, similar to Loja, all the farmers that provided the landraces were invited for a one-day meeting. Later in February 2010, 40 farmers were interviewed. One group of farmers (30) from 12 communities had previously worked together within INIAP's participatory potato breeding program. The second group (10 farmers) was randomly selected from 6 locations. In both cases farmers were from distinct potato production areas in Carchi and had a good knowledge of the potato crop. During the interview we asked farmers to list their preferred "potato varieties" referring either to landraces or improved commercial varieties.

In Chimborazo we invited farmers from six communities. These communities were selected because they were interested in growing potato landraces. During the day of the event 17 native landraces were presented to the farmers for selection. Six bags of 2 kg per accession were displayed in the patio of the communal centre. In total 6 bags per landrace were prepared so every community had the opportunity to select one bag of every landrace if farmers representing the community agreed upon this. A tag with the name of the landrace was put in front of each group of bags. Farmers could register the landraces they wanted and the criteria for selection. Then one farmer per community would put tags on the landraces they selected as a group.

Data analysis

We calculated analyses of variance (one-way ANOVA) for landraces to determine the variation in dry matter content, total polyphenol and total carotenoid grown at EESC. The Shapiro-Wilk test was used to determine normal distribution of the data. The data for total polyphenol and total carotenoid contents were log-transformed and subsequently subjected to analyses of variance. The significance of differences among means was calculated by using a pairwise multiple comparison procedure (Tukey test at $P<0.05$). We performed Pearson correlation between tuber colours (skin and flesh) to total carotenoid and total polyphenol concentrations. Analyses were carried out using SPSS version 16.0 (SPSS Inc. 2007). Estimates of the variance components ANOVA were used to compute broad-sense heritability (*H*) for each trait it was estimated as the ratio of the genotypic (σ_G^2) to total phenotypic variance, $H = \sigma_G^2/ (\sigma_G^2+\sigma^2)$, where, σ_G^2= genotypic variance, σ^2= residual variance (Bos, 1995).

Results

Variation of traits in potato landraces

The Analysis of Variance indicated significant genotypic variation for potato tuber dry matter ($F= 15.532$; $P= 0.0001$), total polyphenol ($F= 7.466$; $P= 0.0001$) and total carotenoid ($F= 9.115$; $P= 0.0001$) contents. Tukey ranking of landraces and commercial varieties are presented in Table 1.

Table 1. Concentrations of Potato Tuber Dry matter (%), Total Polyphenol ($g.kg^{-1}$ DW) and Total Carotenoid ($\mu g.100g^{-1}$ FW) in Ecuadorian landraces.

Common name	Code	Ploidy	Skin color[a] Primary color / Secondary color	Flesh color Primary color / Secondary color	Dry Matter[b]		Total Polyphenol[c]		Total Carotenoid[d]	
Puña	FMFHRA-04	4X	RP / Y	C / A	23.07	a	1.90	cdefgh	40.0	gh
Superchola	Comm. var.	4X	Pi / Y	Y / A	22.77	a	0.94	i	112.3	abc
Roja plancha	AXC-30	4X	R / WC	Yb / A	22.70	a	1.88	cdefghi	49.3	defgh
Chaucha botella	AXC-15	2X	Pi / O	Y / A	22.51	a	2.10	bcdefgh	122.5	a
Negra ojona	MG-11	4X	B / O	C / A	22.20	ab	3.01	abcd	77.0	abcdefg
Rosada	AXC-29	4X	Y / WC	C / A	22.00	ab	1.42	efghi	100.7	abc
Huancala	AMFY-3	4x	R / WC	C / A	22.00	ab	1.42	fghi	52.0	cdefgh
Papa chacra	MPG-21	2x	Y / O	Yb / A	21.83	ab	4.28	a	114.3	ab
Uva	JS-2	4x	RP / Y	W / A	21.50	ab	1.38	hi	62.3	bcdefgh
Colorada antigua	MPG-42	4x	R / WC	Yb / A	21.43	ab	2.28	abcdefgh	85.3	abcdef
Violeta común	AXC-25	4x	Y / WC	W / A	21.30	abc	1.83	cdefghi	77.0	abcdefg
Suscaleña negra	MOPG-8	ND	RP / O	C / A	21.10	abc	2.33	abcdefgh	35.3	h
Chaucha roja	MPG-28	4x	B / O	Yb / A	20.57	abcd	1.56	defghi	54.3	cdefgh
Coneja	FMRAFH-02	4x	Y / O	Yb / A	20.30	abcd	1.96	cdefgh	93.3	abc
Parda pastusa	AC-42	3x	Pi / Y	C / A	20.17	abcd	1.43	efghi	46.3	efgh
Mampuera	AXC-2	ND	P / Y	C / A	20.07	abcde	1.39	ghi	91.0	abcde
INIAP-Estela	Comm. var.	4x	RP / Y	Y / A	19.80	abcde	3.36	abc	92.7	abcd
Morasurco	AXC-9	4x	P / Y	C / P	19.80	abcde	2.99	abcde	70.0	abcdefg
INIAP-Natividad	Comm. var.	4x	Y / Y	Y / A	19.67	abcde	1.70	cdefghi	60.7	abcdefgh
Bolona	MOPG-15	4x	Br / WC	Yb / A	19.20	abcde	2.09	bcdefgh	52.7	cdefgh
Suscaleña blanca	ARX-4	ND	RP / Y	W / A	19.00	abcde	2.94	abcdefg	36.0	h
Carriza	MPG-20	4x	P / Y	Yb / P	18.03	bcde	2.51	abcdefgh	101.0	abc
Esperanza	ARX-1	ND	RP / Y	Yb / A	17.03	cde	2.31	abcdefgh	40.3	gh
Colorada	MOPG-3	4x	RP / Y	Yb / A	16.57	de	2.95	abcdef	68.3	abcdefgh
Negra (Carriza o Cat.)	MOPG-2	4x	P / Y	C / P	16.47	de	1.84	cdefghi	67.0	abcdefgh
Sabanera	AC-34	4x	RP / O	W / A	15.77	e	4.08	ab	47.3	fgh

ode colors (Gomez, 2000). A=Absent, W=White, WC= White-cream, C=Cream, Y=yellow, Yb= Yellow bright, O=Orange, Pi=Pink, Br=brown, R=Red, P=Purple, RP=Red-purple, B=Blackish. [bcd] Mean for 3 repetitions. Tukey test α=0.05

Dry matter content (DMC)

The DMC content among landraces varied from 15% for 'Sabanera' to 23% for 'Puña'. The Tukey test showed a group of landraces with high DM content (from 21-23%) which included the tetraploids 'Rosada', 'Puña', 'Roja plancha', 'Negra ojona', 'Huancala', 'Uva', 'Colorada antigua', 'Violeta común' and 'Suscaleña negra' and the diploids 'Chaucha botella' and 'Papa chacra'. The improved variety 'Superchola' was also in this group. The other improved varieties in our study, Iniap-Estela and Iniap-Natividad, showed a DM content of 19.7 and 19.8% respectively.

The landraces 'Carriza', 'Esperanza`, 'Colorada', 'Negra' and 'Sabanera' had the lowest DM content ranking from 15 to 18%. The estimate of broad-sense heritability for DMC was 0.87.

Total polyphenol content (TPC)

The TPC varied from to 4.28 g kg^{-1} DW for 'Papa chacra' to 0.94 g kg^{-1} DW for the improved variety 'Superchola'. According, to the Tukey test the landraces with highest contents (1.90 to 4.28 g kg^{-1}DW) were: 'Papa chacra', 'Negra ojona', 'Sabanera', 'Morasurco', 'Suscaleña blanca', 'Suscaleña negra', 'Colorada antigua', 'Chaucha botella', 'Colorada', 'Carriza' and 'Puña'. The improved variety 'INIAP-Estela' was also in this group.

The group with the lowest content of TPC (0.94 – 1.43 g kg^{-1}DW) included the landraces 'Parda pastusa', 'Rosada', 'Huancala', 'Mampuera', 'Uva' and the improved variety 'Superchola'. The estimate of broad-sense heritability value for TPC was 0.89.

Total carotenoid content (TCC)

The total carotenoid content showed values from 35.0 µg $100g^{-1}$FW for 'Suscaleña negra' to 122.5 µg $100g^{-1}$ FW for 'Chaucha botella'. The landraces with the highest content of total carotenoid (60.7 -122.5 µg $100g^{-1}$FW) were: 'Chaucha botella', 'Papa chacra', 'Carriza', 'Rosada', 'Coneja blanca', 'Mampuera', 'Colorada antigua', 'Violeta', 'Negra ojona', 'Morasurco', 'Colorada', 'Superchola', INIAP-Estela, 'INIAP-Natividad', 'Negra-carrizo' and

'Uva'. The landraces 'Sabanera', 'Parda pastusa', 'Esperanza', 'Puña', 'Suscaleña blanca' and 'Negra' had a lower TC content varying from 35.3 to 47.3 µg $100g^{-1}$FW. The estimate of broad-sense heritability for TCC was 0.91

Correlation analysis

We found a highly significant correlation (at $P<0.01$) between flesh color and carotenoid ($r = 0.467$) content and a negative significant correlation (at $P<0.05$) between skin color and carotenoid content ($r = -0.330$). All other correlations were not significant.

Farmer preferences

Loja

Twenty one farmers attended the workshop in Loja (18 women and 3 men). In Figure 1 we show the number of farmers that selected a particular landrace.

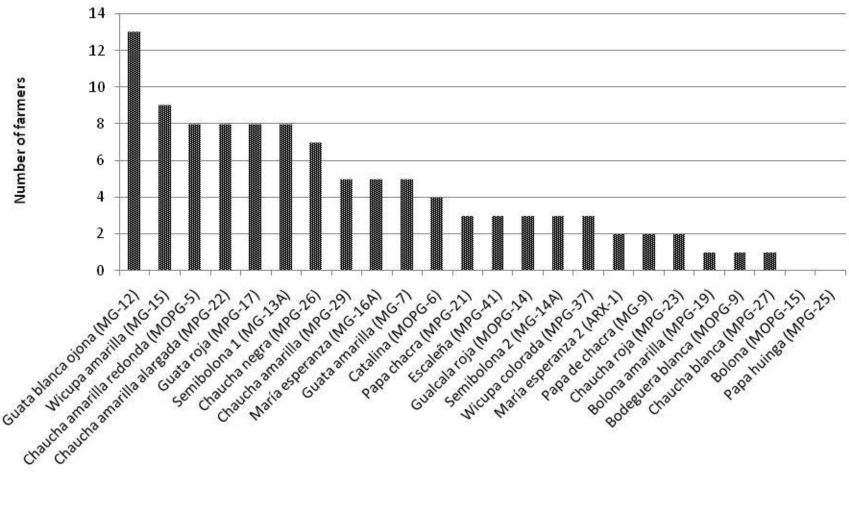

Figure 1. Local landraces preferred by farmers in Loja. The number of farmers who selected landraces is shown on the y axis. Farmers could freely select as many landraces they wanted from the displayed landraces.

Thirteen farmers liked 'Guata blanca ojona' based on morphological characteristics such as tuber shape (round) and skin color (brown with red purple). 'Wicupa amarilla' was selected as good for consumption in soups. These two most preferred landraces 'Guata blanca ojona' and 'Wicupa amarilla' are landraces currently restricted to specific locations within the Loja canton and are not found on the markets.

The rest of the landraces were selected mainly for quality characteristics. For example, 'Chaucha amarilla redonda' and 'Chaucha amarilla alargada' are the most common in the area. According to the farmers these landraces are the most delicious potatoes (consumed in soups or fried). Another landrace ('Semibolona 1') is consumed boiled or in 'chanfaina' (which is a local traditional meal made out of potatoes and pork).

The diploid 'Chaucha negra' is also preferred for its good taste by farmers and even is sold in Saraguro. This landrace can be grown together with other potatoes landraces or within a maize plot. Other potatoes identified growing among maize are the diploid Papa chacra (MPG-21) and the tetraploid Papa de chacra (MG-9). These landraces are traditionally used for self-consumption. Other characteristic make landraces suitable such as 'Guata roja' which can be stored as long as one year for consumption (Emma Mora, farmer, personal communication).

In general we observed farmers taking "new" landraces from the meeting to their farms to diversify their potato crops in the field.

Carchi

In this research area we followed the same methodology to organize the one-day meeting as in Loja, but in this case only 3 farmers attended the event (2 women and 1 man). As a consequence we could not proceed with the selection of landraces. Instead we discussed about the potential lack of interest of growing landraces in the Carchi area. The three farmers took "new" landraces to their home-fields.

The survey conducted several months after this first meeting included 40 farmers. The information about the preference of landraces in Carchi is shown in Figure 2. 'Superchola' which is an improved variety was preferred by the farmers. Among the landraces 'Rosada' was preferred because it has market value in Tulcán (capital of Carchi). Our trial in EESC (Table 1) identified 'Rosada' among the landraces with the highest dry matter content 22% and it was also included in the group with highest total carotenoid content (100.7 µg $100g^{-1}$FW). The polyphenol content is below the average of the group of landraces we studied (1.42g kg^{-1} DW).

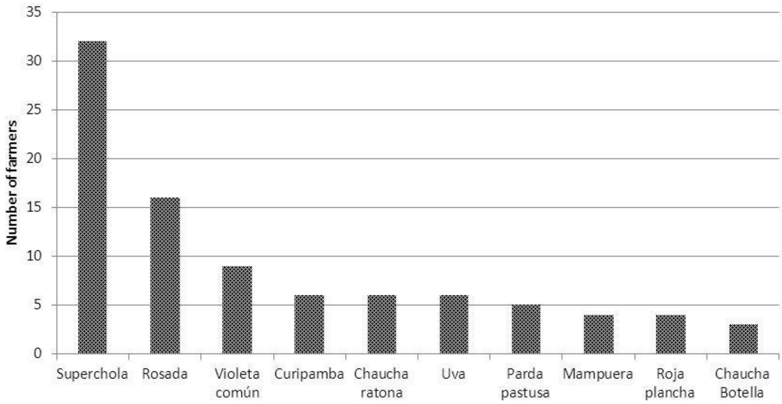

Figure 2. Potato varieties (local landraces or commercial varieties) preferred by farmers in Carchi based on a survey. The number of farmers that selected a variety is show on the y axis.

'Violeta común' was second in preference. In the EESC trial, this landrace was in the first group for DM (21.3%) and also for total carotenoid content (77µg $100g^{-1}$FW). This landrace showed a total polyphenol content of (1.83 g kg^{-1} DW) and was classified in the second group. According to the farmers the 'Uva' landrace has good market opportunities, but the market price is low. A similar 'Uva' landrace in EESC (Table 1) showed a high dry matter (21.5%), low total polyphenol (1.38 g kg^{-1}DW) and intermediate total carotenoid (62.3 µg $100g^{-1}$ FW) content.

Colour descriptors for tubers and dry matter, total polyphenol and total carotenoid contents of the landraces grown in each area of study are shown in Appendix 1.

Chimborazo

Forty farmers representing 6 communities attended the workshop in Pisicaz (36 women 4 men). Figure 3 shows the selection of landraces by the communities. The landraces ‘Cacho’ and ‘Chaucha amarilla’ were preferred by all communities. ‘Cacho’ was selected because of the shape, size, and its good flavour. Similarly as in Loja, farmers from these communities also liked the local ‘Chaucha amarilla’ because of its flavor. This landrace is used for self-consumption but can also be marketed in Riobamba (capital of the province). Representatives of community ‘Calerita Santa Rosa’ mentioned that ‘Cacho’ is new to the area and want to incorporate it in their farming system.

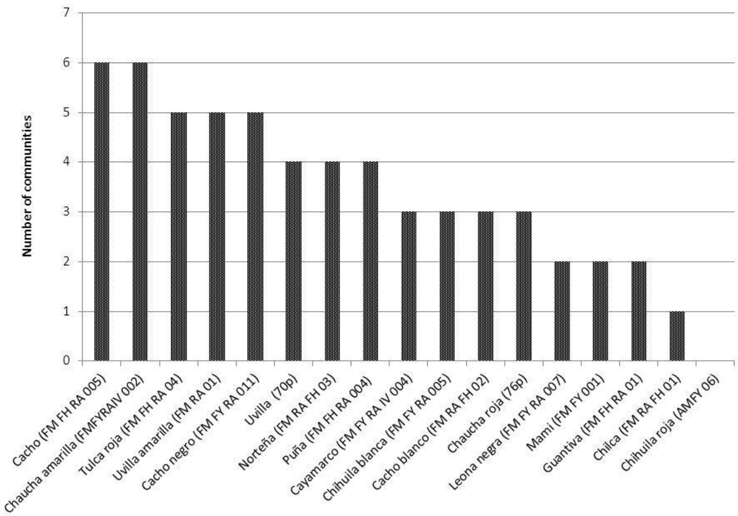

Figure 3. Preference of landraces by farmers representing six communities in Chimborazo. The number of communities that selected the landraces is included in the y axis. Farmers could freely walk through the displayed landraces but the selection was made by consensus of the community members.

The landraces ‘Tulca roja’, ‘Uvilla amarilla’ and ‘Cacho negro’ were selected by 5 communities. ‘Tulca roja’ is used in “Cariucho” (which is a traditional dish containing faba beans, oca, melloco and potatoes), in “locro” (which is a potato soup) and in tortillas. Besides the good flavour, the selection of all farmers was based on shape and color. The landrace ‘Uvilla amarilla’ which is consumed boiled, in soups or fried presents opportunities for marketing according to the farmers and then selected. The community selection was based on flesh color and yield (farmers know it has good production) but also to “recover the seed” because it was lost from their communities. Farmers mentioned that ‘Cacho negro’ is in danger of loss. The community ‘Guantuz’ selected this landrace because farmers wanted to re-introduce it. Farmers appreciated the skin colour (blackish).

‘Uvilla’, ‘Norteña’ and ‘Puña’ were selected by 4 communities. ‘Uvilla’ was selected by the communities because of its flavor, flesh color, shape and yield. Farmers mentioned that these landraces have market opportunities and are consumed boiled or in soups “Locro”. The selection of ‘Norteña’ was based mainly on flavour, shape and skin color. It is possible to find ‘Norteña’ on the markets, but it has largely been replaced by other more commercial varieties. ‘Puña’ was selected because of the color of the skin (red) and good flavour. According to the farmers only few families have ‘Puña’ in small plots.

Discussion

Nutritional quality of Ecuadorian landraces

Dry matter content

The DMC of the evaluated landraces varied from 15.8% to 23.0%. Applying the scale proposed by Cacace et al. (1994) more than 61% of the landraces had a high (>20.0%) dry matter content, 23% had intermediate content (from 18.0 to 19.9%) and 15% had low dry matter content (<17.9%). Most of the variation observed is due to genetic differences between the landraces evaluated. This character is a cultivar characteristic and is influenced by climate, soil and cultural factors as was demonstrated by Stevenson et al. (1964), Love and Pavek (1991), Werner et al. (1998) and Laboski and Kelling (2007) studying diploid and tetraploid potatoes.

The estimate of broad sense heritability was 0.87, which means that most of the variation observed was due genetic differences among landraces. The value is higher than those found by (Ruttencutter et al., 1979), who measure the heritability of breeding clones; they found values up to 0.74 and demonstrate that this character could be accumulated by means of breeding.

For the processing industry the dry matter content is a critical component in the efficient manufacturing of French fries and chips. Dry matter content below 19.5% for French fries and 20% for chips potatoes is not acceptable. Similarly, also very high dry matter contents of more than 25% for French fries manufacturing are not adequate (Kirkman, 2007). Tubers with low DMC require more time and oil for processing have lower chip yields and tend to have darker frying color, whereas tubers with excessively high DMC are susceptible to increased bruising (Mosley and Chase, 1993). Based on the DMC most of the Ecuadorian landraces evaluated were suitable for processing as French fries or chips potatoes. However, in some cases the shape was not ideal, long tubers without deep eyes are preferred (Kirkman, 2007; van Eck, 2007).

The improved cultivars ‘Iniap-Natividad’ and ‘Iniap-Estela’ had a DMC slightly lower than the values reported by Cuesta et al. (2007a, b), they reported values higher than 20% and 22% for these cultivars, respectively. The differences are most likely due to environmental factors, this trait is affected by soil and climate as was demonstrated by Cacace et al. (1994) and Laboski and Kelling (2007) evaluating clones and improved cultivars.

The cultivar ‘Superchola’ is extensively used in Ecuador. It had a DMC similar to that reported by the INIAP and its DMC is significantly higher than the other two improved varieties.

Total polyphenol content

The total polyphenol content (TPC) values were very similar to those found by Lachman et al. (2008) who evaluated some yellow and purple flesh European cultivars and found values between 2.46 and 4.81 g kg^{-1} DW. They were also quite similar to those reported by Andre et al. (2007b) who evaluated the antioxidant capacity of 79 potato accessions of the International Potato Center (CIP) that represent more than 60% of the variability in the potato collection. They found a TPC values from 1.12 to 3.77 g kg^{-1}DW (only two flesh purple accessions had values higher than 5 g kg^{-1} DW).

The improved varieties showed different contents, 'Iniap-Estela' was one of the top three varieties with the highest TPC (3.36 g kg^{-1}DW) compared to 'Superchola' that had the lowest content (0.94 g kg^{-1}DW). 'Iniap-Natividad' had an intermediate performance with a content of 1.70 g kg^{-1}DW. These varieties, in the potato breeding program, were selected for late blight resistance, high yield and tuber quality for cooking and processing but not specifically for TPC (Cuesta et al., 2007a, b). The values measured in the landraces and improved varieties are much lower that than the maximum values (up to 12.37 g kg^{-1} DW) measured by others (Andre et al., 2007b).

The estimated broad sense heritability was 0.89 which means that most of the observed variation was due to genetic differences among the landraces evaluated. Several authors have reported the significant effect of the genetic factor in the variation of the TPC, Hamouz et al. (2006), Lachman et al. (2008) who measured the TPC on European cultivars and Andre et al. (2009), who studied the effect of environment and genotype on polyphenol compounds of thirteen Andean potato cultivars.

Total carotenoid content

The total carotenoid content (TCC) values were in the same order of magnitude as those reported by Breithaupt and Bamedi (2002) who measured a TCC of 58–175 µg $100g^{-1}$ FW in yellow fleshed cultivars and 38–62 µg

100g^{-1} FW in white fleshed cultivars. However, these values are lower than those reported by Brown et al. (2005) studying potato cultivars and selections from the USDA/ARS breeding program at Prosser, Washington, USA. They found a range from 35 to 795 µg 100g^{-1} FW. Nesterenko and Sink (2003), evaluating fifteen potato lines from the Michigan State University breeding program in the USA, reported carotenoid levels ranging from 48 to 879 µg 100g^{-1} FW. More recently Burgos et al. (2009b) found the TCC for some of the *S. phureja* accessions reaching much higher values (1840 µg 100 g^{-1} FW). So the Ecuadorian landraces are in the lower range.

Most of the variation for TCC in this study was due to genetic differences among cultivars as described by Lu et al. (2001), who studied diploid clones or by Nesterenko and Sink (2003) who characterized tetraploid breeding clones. This effect is confirmed by the broad sense heritability of 0.91 which is in close agreement with the value previously reported (*H*= 0.96) in nine clones from the USDA, Agriculture Research Service Beltsville Potato Breeding Program by Haynes et al. (2010).

The improved varieties ‘Superchola’ and ‘Iniap-Estela’ had high TCC and ‘Iniap-Natividad’ had an intermediate TCC, although it was not a selection criteria in the breeding process. However, they were unconsciously selected for high TCC using the yellow tuber flesh color as criteria of selection, because this trait is preferred by the consumers in most of the places in Ecuador (Cuesta et al., In preparation).

Farmers´ preferences for potato landraces

In Chimborazo and Loja farmers selected landraces based mainly on their nutritional characteristics. These nutritional characteristics are understood by the farmers in terms of ‘good flavour’ or usefulness in traditional dishes. This may be related to the participation of mostly women in the workshops. The difference in men and women preferences for potato characteristics has been described in Danial et al., (2007). The uses of these potatoes in specific dishes make the landraces worth growing in their home-gardens.

The few farmers attending the local meeting in Carchi indicated that local farmers currently have little interest in potato landraces. The apparent reason is the current lack of market opportunities for these potatoes. In Carchi, most farmers cultivate improved varieties, which are marketed in the cities of Tulcán and San Gabriel (Yanez and Cuesta, 2006). The surveys showed that the local farmers prefer the commercial improved variety 'Superchola` over the landraces (Figure 2), again pointing at the interest in marketable potatoes for income generation. According to Mazón (2009) and Cuesta et al. (2005) the preference for commercial varieties over local landraces results in loss of landraces. The vulnerability of the *on farm* conservation system in this province has been described by Monteros-Altamirano et al. (2011a). In the other two areas farmers also demonstrated interest in landraces with current or potential market opportunities. One example in Chimborazo is the landrace ´Uvilla´. In Loja the most often selected landrace 'Guata blanca ojona' shows morphological characteristics making it suitable for marketing (round and brown skin color). However, in the South of Ecuador a preference for cream skin potato has been reported (Danial et al., 2007). Also in Loja the selection of landraces such as 'Chaucha amarilla redonda' and 'Chaucha amarilla alargada' demonstrated that the farmers` interest is not only driven by self-consumption but also by market opportunities.

The interest on recovering less frequent landraces also drove the choices in both areas. For example in Loja, landraces considered by farmers to be lost or present in only low frequency, such as 'Papa de chacra' and 'Papa chacra' growing within maize, were selected by some farmers. In the Loja area this kind of potatoes becomes important as staple food for self-consumption to accompany maize and other local crops. The interest of experimenting with new landraces was mentioned in Chimborazo where farmers of one community expressed the interest in growing landraces as "curiosity". Farmers attending the meeting multiplied the selected landraces in a common garden and distributed them to individual farmers later on (Fausto Yumisaca, local technician in Chimborazo, personal communication). Farmers in Chimborazo are used to community based decisions. One example is the widespread use of "mingas" which is a form of un-payed labor devoted to the community objectives including agricultural related activities. According to Parlevliet (2003), local seed production is easier when developed on community basis in countries such as Ecuador.

The values registered for dry matter, total polyphenol and total carotenoid, when growing locally in Carchi, Chimborazo and Loja (Appendix 1) show for example that in Carchi, landraces such as ‘Rosada’, ‘Violeta’ or ‘Uva’ have a similar dry matter and total carotenoid contents as the improved varieties. However, we have shown that farmers´ preferences include empirical valuation of potato-quality rather than specific knowledge on nutritional characteristics of these potatoes. It is necessary to raise awareness on these nutritional qualities with farmers and consumers which could increase consumption and cultivation. The idea of promoting local landraces to urban consumers was proposed by the farmers in Carchi but can be applied in all areas.

Safeguarding landrace diversity

We observed in Chimborazo and Loja that farmers still have an interest in potato landraces. Women are important curators of potatoes on the farm as men migrate to look for additional income generating activities (Tapia and De la Torre, 1998; Monteros-Altamirano et al., 2011a). Their interest is mainly for self-consumption and is driven by flavour or uses in traditional local dishes. It is important to notice that market options for some of the landraces were also a reason for selection and willingness to continue cultivation. This is explained by the fact that farmers currently growing landraces are mainly poor (Monteros-Altamirano et al., 2011a).

Our results also showed that local farmers can be important users of genebank materials as observed by Engels and Visser (2003) and Bonierbale et al., 2004) to support local food security. Re-patriation of locally accepted landraces assures the continuity of cultivation of less frequent landraces.

Use in potato breeding

The main objectives of the potato breeding program of Ecuador is to obtain new improved cultivars with resistance to late blight and good agronomic characteristics like high yield and early maturity. In the last years the concept of tuber quality has been included as criterion for selection, especially for the generation of new varieties for the processing market e.g. chips and French fries (Cuesta, 2005a). One of the main traits that is selected for is dry matter content. This character is polygenic controlled (Freyre et al., 1994; Schäfer-Pregl et al., 1998; Gebhardt, 2005) and can be improved through plant breeding. The variation in DMC observed in the Ecuadorian landraces and improved cultivars may be exploited in the development of new cultivars with high DMC for the processing market.

Currently, the potato breeding program is focussed on increasing the content of two antioxidants present in potato (carotenoids and polyphenols) in order to develop new potato varieties with enhanced health and nutritional benefits. Potato has recently gained recognition for this class of phytonutrient benefits (Brown, 2005; Brown et al., 2005; Brown et al., 2007). The polyphenols consumed through the diet are increasingly considered as effective protective agents against the reactive oxygen species (ROS), which are known to be involved in the pathogenesis of aging and many degenerative diseases (Yang et al., 2001). Carotenoids have numerous health-promoting properties including provitamin A activity (Navarre et al., 2009; Fraser and Bramley, 2004) that may be particularly important for eye health and reduced risk of age-related macular degeneration (Chucair et al., 2007; Tan et al.,2008).

The large variation observed and reported for TPC and TCC could be used to develop new potato varieties with high carotenoids and polyphenols content through plant breeding. As the measurement of TCC is time consuming and expensive, the potato breeding program is aiming to select high carotenoid content genotypes based on tuber flesh colour intensity as an indirect measurement for selection since the TCC and the yellow flesh intensity are correlated traits as shown by Lu et al. (2001) and our present experiment.

The variation observed in the Ecuadorian potato landraces for DMC and antioxidants (TPC, TCC) and the germplasm reported with high contents could be an important source of useful alleles for the generation of new improved varieties with high values for these characteristics. The landraces with the highest contents will be included in the potato breeding scheme as parents to generate superior clones with improved nutrition value and good agronomic characteristics. Depending on the ploidy level of the landrace selected as parents it could be improved at the diploid level, crossing with diploid cultivars or wild species, or at the tetraploid level, crossing with commercial cultivars or superior clones for this purpose.

The identification of improved cultivars or landraces with high TPC, TCC or DMC will help to add value to these potatoes through the development of new products or market opportunities.

Appendix 1. Potato landraces from Carchi, Chimborazo and Loja evaluated in their original location sites. Ploidy levels, codes and name of landraces and values for dry matter (DM %), total polyphenol (g kg^{-1} DW) and total carotenoid (µg $100g^{-1}$ FW) contents are included.

CARCHI															
DRY MATTER (%)							POLYPHENOL (g.kg⁻¹ DW)				CAROTENOID (µg.100g⁻¹ FW)				
2n	Code	Name of landrace	Skin color	Flesh color	y1	y2	Code	Name of landrace	y1	y2	Code	Name of landrace	y1	y2
2x	AC-38	Chaucha botella	Pi/WC	C/P	25.1	25.7	AXC-01	Chaucha ratona	2.58	5.90	AC-38	Chaucha botella	310	100
2x	AXC-01	Chaucha ratona	RP/A	C/V	24.0	22.8	AC-38	Chaucha botella	2.44	3.45	AXC-01	Chaucha ratona	150	60
3x	AC-42	Parda pastusa	Pi/WC	C/A	26.1	24.3	AC-42	Parda pastusa	2.87	3.78	AC-42	Parda pastusa	120	50
4x	AXC-30	Roja plancha	RP/A	C/A	23.7	20.1	AXC-25	Violeta comun	3.64	2.66	AXC-30	Roja plancha	160	60
4x	AXC-25	Violeta comun	Y/RP	C/A	23.5	22.8	AXC-30	Roja plancha	2.21	4.01	AXC-25	Violeta comun	110	70
4x	JS-02	Uva	RP/O	C/A	23.3	21.6	JS-02	Uva	1.76	4.40	JS-02	Uva	190	ND
4x	AXC-29	Rosada	P/WC	W/A	22.0	20.5	AXC-29	Rosada	ND	4.90	AXC-29	Rosada	ND	80
ND	AXC-23	Curipamba	Y/P	C/A	22.9	21.7	AXC-02	Mampuera	3.05	3.17	AXC-23	Curipamba	120	110
ND	AXC-02	Mampuera	P/A	C/A	22.3	19.6	AXC-23	Curipamba	2.82	3.09	AXC-02	Mampuera	50	50

CHIMBORAZO														
DRY MATTER (%)							POLYPHENOL (g.kg⁻¹ DW)				CAROTENOID (µg.100g⁻¹ FW)			
2n	Code	Name of landrace	Skin color	Flesh color	y1	y2	Code	Name of landrace	y1	y2	Code	Name of landrace	y1	y2
2x	FM FY RA IV 02	Chaucha amarilla	Y/A	Yi/A	26.1	22.5	FM FY RA IV 02	Chaucha amarilla	ND	2.77	FM FY RA IV 02	Chaucha amarilla	ND	0.5
4x	FM FH RA 04	Puña	RP/Y	C/P	27.7	17.6	FM RA 01	Uvilla amarilla	4.04	ND	FM FH RA 01	Guantiva	90	60
4x	FM RA FH 02	Cacho blanco	Y/A	Yb/A	26.1	22.4	FM FH RA 05	Cacho	3.14	4.75	FM RA FH 01	Chilca	80	50
4x	FM FH RA 05	Cacho	RP/A	Yb/A	26.0	22	FM FY RA 11	Cacho negro	3.14	3.80	FM FH RA 05	Cacho	80	50
4X	FM RA 01	Uvilla amarilla	O/RP	Y/P	23.8	22.7	70p	Uvilla	2.77	2.98	FM RA FH 003	Norteña	80	ND
4x	FM FH RA 01	Guantiva	R/Y	C/A	23.2	21.3	FM RA FH 003	Norteña	2.55	ND	FM FY RA 11	Cacho negro	60	30

4x	FM RA FH 01	Chilca	RP/A	Yb/P	22.3	21	FM FH RA 04	Puña	1.32	3.05	FM FH RA 04	Puña	70	90
4x	FM RA FH 003	Norteña	RP/Y	C/P	22.3	ND	FM RA FH 01	Chilca	ND	7.17	FM RA FH 02	Cacho blanco	70	70
4X	70p	Uvilla	Br/A	Yi/P	21.2	19.84	FM FH RA 01	Guantiva	ND	3.84	FM RA 01	Uvilla amarilla	50	ND
4x	FM FY RA 11	Cacho negro	B/P	Y/A	21.3	20.3	FM RA FH 02	Cacho blanco	ND	2.63	70p	Uvilla	ND	ND
3x	FM FY RA 05	Chihuila blanca	Y/P	C/A	22.2	26.1	AMFY-06	Chihuila roja	2.16	2.49	AMFY-06	Chihuila roja	50	30
3x	AMFY-06	Chihuila roja	RP/A	C/A	21.4	22.1	FM FY RA 05	Chihuila blanca	ND	ND	FM FY RA 05	Chihuila blanca	ND	ND
ND	76p	Chaucha roja	R/A	Yi/A	27.1	20.5	FMFHRA 04	Tulca roja	3.54	ND	76p	Chaucha roja	120	30
ND	FM FY RA 07	Leona Negra	RP/Y	Y/A	24.2	23.4	FM FY RA 07	Leona Negra	2.21	2.54	FM FY RA IV 04	Cayamarco	90	50
ND	FM FY 01	Mami	R/A	Y/A	24.0	25.7	76p	Chaucha roja	2.16	2.49	FM FY 01	Mami	80	80
ND	FM FY RA IV 004	Cayamarco	O/A	C/A	23.2	27.7	FM FY 01	Mami	0.93	2.13	FMFHRA 04	Tulca roja	60	ND
ND	FMFHRA 04	Tulca roja	R/Y	Yi/A	18.5	19.8	FM FY RA IV 004	Cayamarco	ND	3.59	FM FY RA 07	Leona Negra	40	40

LOJA

	DRY MATTER (%)						POLYPHENOL (g.kg^{-1} DW)				CAROTENOID (µg.100g^{-1} FW)			
2n	**Code**	**Name of landrace**	**Skin color**	**Flesh color**	**y1**	**y2**	**Code**	**Name of landrace**	**y1**	**y2**	**Code**	**Name of landrace**	**y1**	**y2**
2x	MPG-23	Chaucha roja	RP/A	C/P	23.8	21.8	MG-15	Wicupa amarilla	ND	4.40	MOPG-05	Chaucha amarilla redonda	ND	460
2x	MPG-21	Papa chacra	O/RP	C/A	23.6	ND	MPG-23	Chaucha roja	ND	4.26	MG-15	Wicupa amarilla	ND	320
2x	MPG-29	Chaucha amarilla	O/A	Yb/A	22.7	20.9	MPG-21	Papa chacra	4.02	4.12	MPG-37	Wicupa colorada	ND	310
2x	MOPG-05	Chaucha amarilla redonda	O/A	Yi/A	22.0	22	MPG-29	Chaucha amarilla	ND	3.90	MPG-22	Chaucha amarilla alargada	ND	160
2x	MPG-22	Chaucha amarilla alargada	O/RP	C/A	20.9	19.2	MPG-22	Chaucha amarilla alargada	ND	3.65	MPG-21	Papa chacra	100	130
2x	MPG-27	Chaucha blanca	Y/RP	W/A	20.1	ND	MPG-37	Wicupa colorada	ND	3.24	MPG-23	Chaucha roja	ND	120
2x	MPG-26	Chaucha negra	B/RP	W/A	19.6	ND	MOPG-05	Chaucha amarilla redonda	ND	3.04	MPG-29	Chaucha amarilla	70	170
2x	MG-15	Wicupa amarilla	Br/R	C/A	ND	ND	MPG-27	Chaucha blanca	ND	ND	MPG-27	Chaucha blanca	ND	ND
2x	MPG-37	Wicupa colorada	BR/A	Y/A	ND	ND	MPG-26	Chaucha negra	ND	ND	MPG-26	Chaucha negra	ND	ND
4x	MPG-17	Guata roja (papa cuy)	RP/A	Yi/A	27.5	21.5	MPG-17	Guata roja (papa cuy)	6.03	3.08	MPG-17	Guata roja (papa cuy)	240	160
4x	MPG-41	Escaleña	RP/Br	Y/A	27.4	22.4	MOPG-09	Bodeguera blanca	5.17	5.07	MG-16A	María Esperanza	110	130
4x	MOPG-09	Bodeguera blanca	Y/RP	C/A	24.3	23.2	MPG-19	Bolona amarilla	5.15	2.48	MOPG-06	Catalina	100	50

4x	MPG-19	Bolona amarilla	Br/RP	Y/A	24.1	19.1	MG-16A	María Esperanza	3.80	3.85	MPG-19	Bolona amarilla	80	130
4x	MG-16A	María Esperanza	Y/Pi	Yb/A	21.7	ND	MOPG-06	Catalina	3.01	2.11	MPG-41	Escaleña	60	110
4x	MOPG-15	Bolona	Br/Rp	Yb/A	20.6	24	MPG-41	Escaleña	2.62	1.65	MG-07	Guata amarilla	60	100
4x	MOPG-06	Catalina	P/Y	C/P	20.0	24.3	MOPG-15	Bolona	2.44	2.91	MOPG-15	Bolona	50	80
4x	MOPG-14	Gualcala roja	B/A	C/A	17.7	23.1	MOPG-14	Gualcala roja	2.07	3.24	MG-12	Guata blanca ojona	ND	150
4x	MG-07	Guata amarilla	RP/A	YB/A	23.3	ND	MG-09	Papa de chacra	ND	4.68	MOPG-09	Bodeguera blanca	ND	140
4x	MG-09	Papa de chacra	B/A	C/A	ND	ND	MG-07	Guata amarilla	ND	3.66	MOPG-14	Gualcala roja	ND	130
4x	MG-12	Guata blanca ojona	Br/RP	W/A	ND	ND	MG-12	Guata blanca ojona	ND	2.65	MG-09	Papa de chacra	ND	120
4x	MG-14A	Semibolona (2)	Br/R	C/A	ND	ND	MG-14A	Semibolona (2)	ND	2.53	MG-14A	Semibolona (2)	ND	50
ND	MG-13A	Semibolona1	Br/R	W/A	20.1	ND	ARX-1	María esperanza	3.80	3.85	ARX-1	María esperanza	110	130
ND	MPG-25	Papa huinga	O/A	Yi/A	ND	ND	MPG-25	Papa huinga	ND	2.97	MPG-25	Papa huinga	ND	310
ND	ARX-1	María esperanza	RP/Y	Yi/P	ND	ND	MG-13A	Semibolona1	ND	2.43	MG-13A	Semibolona1	ND	50

[a] Color codes (Gomez, 2000). Primary color/Secondary color: A=Absent, W=White, WC= White-cream, C=Cream, Yi=Yellow intense, Y=yellow, Yb= Yellow bright, O=Orange, Pi=Pink, Br=brown, R=Red, P=Purple, RP=Red-purple, V= violet, B=Blackish.

CHAPTER 6
General Discussion

The main objective of this research was to describe the current status of potato landraces conservation in Ecuador. In our work we focused on three areas; Carchi in the North, Chimborazo in the middle and Loja in the South of Ecuador. Part of the material collected was characterized for late blight resistance and quality traits to establish their value for future use. In this work we incorporated farmers' views wherever we could.

I. Trends in potato diversity

Ecuador has been recognized as one of the centers of diversity for cultivated potatoes (Hawkes, 1988; Hawkes, 1990). During our collection trips we collected diploid, triploid and tetraploid landraces. These landraces show a high allelic diversity, which was for the tetraploids comparable to the variation found in the European collection of 892 varieties (Reid et al., 2011). The presence of unique alleles in the Ecuadorian landraces shows that there is unexploited variation, just like previously reported by Quiros et al. (1990) for Peruvian potatoes. More alleles are expected to be found when more material, especially from other areas, will be screened.

Ecuadorian farmers have managed these potato landraces for centuries. Archeological data show the presence of cultivated potatoes in Ecuador as early as 1500 B.C. (Zeidler, 2008). Recent reports mentioned loss of genetic diversity or genetic erosion in farmers' fields (Cañizares and Forbes, 1995; Frolich et al., 1999; Cuesta et al., 2005; De Haan, 2009). During our field study (collections, survey or farmer meetings) the general perception with the farmers was that potato landraces are indeed disappearing. However, we collected more landraces than previously sampled (during the 70s and 80s). In a number of cases a landrace that was presumed to be lost by one farmer was found with another. After our collection in Chimborazo we were able to collect more landraces at a local diversity fair. Our molecular characterization showed that individual landraces can in fact be a mixture of more landraces, suggesting that more extensive sampling could still recover some of the so called lost landraces. The resulting dendrogram (Chapter 3) does not show any clustering according to the region where a group of landraces was collected, suggesting extensive exchange of material between them. Furthermore we found genetically and morphologically identical landraces under different names at different locations (Chapter 3, Appendix 2), also suggesting exchange of seed potatoes.

The lack of evidence of genotypes being lost in the field contrasts with other findings that could potentially decrease the number of landraces in farmer fields:

a) During the collecting missions, farmers growing potato landraces were difficult to find in Carchi and Loja. In fact, landrace-holders were scattered within these areas. Our data show that most of the farmers do not know where to find “seeds” and consequently the seed exchange, that probably was more active in the past (Chapter 3), has decreased.

b) The older generation is in charge of potato landraces. Farmers growing potato landraces are mainly over 50 years-old while the younger generation showed a lack of interest in and knowledge of potato landraces.

c) The low incomes coming from agriculture cause migration from rural areas to the cities. Our data showed that the potato farmers value other activities as much as agriculture for income generation (Figure 3, Chapter 2).

d) Since only few landraces reach the market (Unda et al., 2005) some farmers do not see incentives to grow these potatoes.

Consequently, if these factors influencing the vulnerability of the current on-farm system continue it is very likely that the available number of potato landraces in the field will decrease in the future.

It is also important to mention that the former *ex situ* Ecuadorian collection proved to be vulnerable as well. The lack of financial support for its maintenance caused a decrease in the number of accessions conserved in experimental fields and *in vitro*.

II. Measures towards maintaining potato crop diversity in Ecuador

On-farm and *ex situ* conservation have inherent advantages and disadvantages (Altieri, 1987; Brush, 1991; Cohen, 1991; Dulloo, 2010). Under the local conditions of Ecuador they have both shown to be vulnerable. To maintain potato diversity in Ecuador it is necessary to implement both strategies. The importance of complementarity of both systems has already been highlighted by authors such as Engels and Visser (2003) or Jarvis et al. (2000).

Complementary measures could benefit the conservation of potato diversity. The restitution of landraces partially counteracted the lack of seed availability of some less frequent landraces. The permanence of diversity in the field would support the under-representation of diversity that occurs in gene banks. The diversity fair, as external intervention, raised awareness of the value of native potatoes and the collaboration between local communities and the national gene bank.

We found that most farmers maintain interest in keeping potato landraces. The lack of market opportunities was not an obstacle to the willingness to grow landraces in their home gardens. We observed in the field that farmers maintain potato landraces along with the commercial varieties and other crops. Farmers` motivation was the reincorporation of landraces into their traditional farming system to complement their diets and continue traditional uses in special dishes. These landraces are adapted to local environmental conditions assuring production and food security to local farmers. The challenge is that the new assembled Ecuadorian potato collection, currently conserved at INIAP´s gene bank, responds to the needs of the local communities.

Research and Development projects might support complementary conservation. A project in Peru, the “Pisak Potato Park” is an example of complementary conservation between CIP and a farmer association (ANDES, Association for Nature and Sustainable Development). More than 600 varieties of potatoes are conserved by over 1200 families among six indigenous communities (CIP, 2011a). CIP and the communities have signed a formal *ex situ* - on farm cooperation (CIP, 2004). Another ongoing project is “Innovandes” which is promoting the use of potato landraces by linking farmers to new markets in Ecuador, Peru and Bolivia (Devaoux et al., 2009). This kind of initiatives could be replicated in other areas to encourage farmers in the cultivation of potato landraces. New projects could also support education (formal and linked to agro biodiversity) as our results (Chapter 2) showed low education levels among potato holders.

III. Gene banks and use of potatoes

Thousands of potato landraces and wild relatives are conserved in gene banks (Bamberg et al., 1996; Pavek and Corsini, 2001; CIP, 2011b). However, only a small part of the total variability has been used for potato improvement (Pavek and Corsini, 2001). Current breeding programs using conventional breeding, marked assisted selection or even genetic engineering are likely to continue this trend of limited use. One alternative to promote the use of materials conserved in gene bank is the establishment and use of core collections as proposed by Brown (1989). A core collection for potatoes has been proposed by Huamán et al. (2000); and a representative set of potatoes has been useful for characterization of antioxidant and mineral micronutrients by Andre et al. (2007a). In this thesis, SSRs markers proved to be effective in describing the genetic relationship of 152 Ecuadorian landraces (Chapter 3). This information was used to select genetically different landraces that provided valuable information on late blight resistance and quality characteristics of the whole set of materials. According to FAO (2010), the lack of readily available characterization and evaluation data is a major limitation to the greater use of Plant Genetic Resources for Food and Agriculture (PGRFA) in breeding programmes. Our results suggest that the

Ecuadorian potato breeding programs need external germplasm to solve the lack of LB resistance of potatoes (Chapter 4), but can be self- sustained with the use of adapted local landraces with good nutritional levels (Chapter 5).

Another barrier to the use of gene bank materials has been related to access. The Convention on Biological Diversity (CBD, 1992) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, 2009) provides access but also include provisions for benefit sharing in the event of commercialization. Poor farmers in rich areas of diversity are in need of support coming from the use of their germplasm. How to put international regulations into action is still under discussion in the international agenda (Brush, 2007).

IV. Potato genetic resources and farmers' rights in Ecuador

Some landraces, by definition (See introduction of this thesis), are difficult to satisfy distinctness, uniformity and stability (UPOV, 2002; UPOV, 2004; Bertacchini, 2008). E.g. farmers maintain under one name a mixture of two landraces (Chapter 3) or landraces are subject to common knowledge. Situations that make farmers, that have breed their landraces for centuries, not suitable for granting rights over these landraces; leaving them away from monetary incentives and condemned to live in poverty. Bertacchini (2008) suggests a new *sui generis* system as current regulations do not reflect the system in place in developing countries. In Ecuador, leader representatives from the indigenous communities have prepared a proposal for discussion on the recognition of farmers' rights through a sui generis system (De la Cruz et. al., 2005). The National Intellectual Property Law (IPL) now in place and executed by the Ecuadorian Institute for Property Rights (IEPI) follows Decision 345 and UPOV Dec. 1978 guidelines. Article 278 of IPL recognizes farmer rights about conservation, exchanging seeds and compensation for the use of seeds they have developed. However, all these regulations are far to be applied in practice.

It is known that crop genetic resources are the result of collective actions over many generations of farmers and resulting from shared knowledge, seed exchange, and the accumulation of valuable traits (selection) in crop populations (Brush, 2007). The Convention on Biological Diversity (CBD, 2010) recognizes that respect for traditional knowledge is required and that this traditional knowledge is valued equally with and complementary to scientific knowledge. In this thesis farmers` knowledge collected in passport data, farmer meetings or interviews helped to understand our scientific findings. For example, farmers knowledge about the management of landraces in their traditional farming systems (Chapter 3) may have saved them from getting lost. Our study showed that most of the landraces proved to be susceptible to late blight (LB) (Chapter 4) but interestingly this low LB resistance has not been an obstacle in the use of these landraces by local farmers. Farmers know how to handle LB by simply planting their potatoes in the season not optimal for LB attack or by combining landraces with different levels of resistance in the field (Chapters 3 and 4). Potato landraces have evolved in traditional cropping systems involving intercropping and intermixing of landraces. Intercropping (Thurston, 1990; Garret et al., 2001) and intermixing of potatoes (Andrivon et al., 2003; Pilet et al., 2006; Finckh et al., 2008) have proved effective in controlling this devastating disease in the field. Rietman et al. (2011) observe the benefit of the plant-pathogen management (such as intermixing) as part of the future of resistance breeding. Poor farmers in Ecuador have already such a system in place.

We have also shown that farmers´ preferences include empirical valuation of potato-quality (use in traditional dishes or flavour preferences) rather than specific knowledge on nutritional characteristics of these potatoes (Chapter 5). This traditional knowledge has saved landraces from disappearing.

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Summary

This thesis aims to fill the gap of information on the potato landrace diversity present in farmer fields of Ecuador. Passport data from previous collections (1970's and 1980's) were used to identify Carchi, Chimborazo and Loja as representative areas of potato diversity. The status of on-farm conservation in these three selected areas is covered in Chapter 2. Microsatellites (SSRs) helped us to describe the genetic relationships among the landraces found in these areas (Chapter 3). The characterization of potato landraces with respect to late blight resistance (Chapter 4) and quality traits (Chapter 5) complement the description.

Previous reports suggested loss of potato diversity (genetic erosion) in Ecuadorian farmer fields, but our collection of a total of 174 landraces showed that these areas still hold a substantial amount of potato landrace diversity (Chapter 2). More potato landraces were found in Chimborazo and Loja than previously sampled in the 70's and 80's. A comparison between the two collections, in each of the three areas, indicated only a small overlap in landrace names suggesting that the sampling of local landraces was far from exhaustive, both during the 70's and 80's and during the present collection trips. This is further supported by the fact that the diversity fair, which was organized after our collection trips in Chimborazo, resulted in many new landraces.

Surveys and farmer meetings in the study areas were used to describe the landrace-holders and the characteristics of the farming system they use. Mostly elderly people and small-scale farmers are currently maintaining potato landraces. These farmers look for income alternatives besides agriculture, resulting in migration. The vulnerability of the potato conservation varies among our study areas. In Carchi younger farmers demonstrate a lack of interest in cropping potato landraces. In Loja farming is not seen as the only sustainable source of income and there is a perceived lack of support from the government for the activities necessary to maintain local landraces. In Chimborazo farmers are culturally more attached to their land and see agriculture as a family activity, rendering the potato landrace conservation

less vulnerable. Externally driven on-farm conservation interventions, such as diversity fairs or re-introduction of landraces, were highly appreciated by the farmers and could help to conserve the potatoes.

Diploid, triploid and tetraploid potato landraces are found in farmers fields. The material sampled at the three areas shows a high allelic diversity. At the tetraploid level (the most abundant) this was comparable to the variation present in an European collection of more than 800 varieties. More alleles are expected to be found when more material from other areas will be screened. There was no clear grouping of material collected according to study region, suggesting extensive movement of seed potatoes all over Ecuador.

A comparison of the application of variety names with the genetic relationships among potato landraces can result in either under- or over-estimation of the variability present in farmer fields (Chapter 3). In a number of cases landraces with identical common names proved to be genetically different or individual collection samples were actually a mixture of two landraces, pointing at under-estimation of diversity present. On the other hand, cases that might lead to over-estimation were also evident, e.g. genetically identical material was present under different names.

Our sampling of genetically different landraces for late blight (LB) resistance characterization (Chapter 4) confirmed that there was some variation for this trait among the landraces. Most of the landraces were susceptible to moderately resistant, but also some landraces with field resistance were identified. The observed field resistance was comparable to that in the widespread improved variety Fripapa. Possible strategies to improve late blight resistance in potato in Ecuador could include the identification of accessions with resistance among the local landraces, although only a few accessions may be expected to present field resistance. The introduction of new sources of resistance from other origins is a more viable alternative. One could attempt to introduce novel R-genes in material that already contains some level of quantitative resistance.

We found varying levels of dry matter, total polyphenol and total carotenoid contents among Ecuadorian potato landraces, some were comparable to the improved varieties. Based on the dry matter content most of the Ecuadorian landraces evaluated were suitable for processing as French fries or chips. The total polyphenol content of these potatoes were quite similar to those reported by the International Potato Center (Peru) for a set of accessions representing more than 60% of the variability in their potato collection. The total carotenoid content values of the Ecuadorian potatoes included in our study were similar or lower compared to previous studies on improved or Andean potatoes. The identified outstanding potato materials could be used to develop new potato varieties through plant breeding.

In Chimborazo and Loja farmers select landraces mainly based on their nutritional characteristics. However, in Carchi farmers prefer commercial improved varieties. Farmers´ preferences include empirical valuation of potato-quality rather than specific knowledge on nutritional characteristics of these potatoes.

This thesis provides important knowledge about the potato landraces in Ecuador. Our results can serve as the basis for further description and use of Ecuadorian native potatoes by breeders and local communities.

Samenvatting

Dit proefschrift heeft tot doel informatie te verzamelen over de diversiteit aan aardappel landrassen aanwezig bij boeren in Ecuador. Paspoort gegevens uit eerdere verzamelexpedities in de 70'er en 80'er jaren van de vorige eeuw zijn gebruikt om Carchi, Chimborazo en Loja te identificeren als representatieve gebieden van de aardappel diversiteit. De huidige situatie met betrekking tot 'on farm' conservering wordt beschreven in hoofdstuk 2. Microsatellieten (SSR's) zijn gebruikt om de genetische relaties tussen de landrassen in deze gebieden te beschrijven (hoofdstuk 3). De karakterisering van de aardappel landrassen met betrekking tot resistentie tegen *Phytophthora infestans* (hoofdstuk 4) en kwaliteitskenmerken (hoofdstuk 5) complementeren de beschrijving.

Eerdere onderzoeken suggereerden een verlies aan aardappel diversiteit (genetische erosie) bij de boeren in Ecuador. Echter, tijdens onze verzamelexpeditie waarbij 174 landrassen werden verzameld, bleek dat deze gebieden nog steeds over een aanzienlijke diversiteit beschikken (hoofdstuk 2). In Chimborazo en Loja werden zelfs meer aardappel landrassen gevonden dan tijdens de verzamelexpedities in de jaren '70 en '80. Wanneer we de resultaten van de verzamelexpedities uit die jaren vergelijken met de huidige voor de drie gebieden dan blijkt dat er slechts een beperkte overlap is landras namen. Dit suggereert dat de bemonstering van landrassen verre van uitputtend was, zowel tijdens de jaren '70 en '80 als tijdens de huidige expedities. Dit wordt ondersteund door feit dat de 'diversity fair', die werd georganiseerd na onze verzamelexpeditie in Chimborazo, resulteerde in veel nieuwe landrassen.

Enquêtes en bijeenkomsten met boeren in de studiegebieden zijn gebruikt om de landras-houders en de kenmerken van het landbouwsysteem dat ze gebruiken te beschrijven. Hieruit bleek dat de landrassen voornamelijk in handen waren van oudere boeren, meestal met slechts kleine bedrijven. Deze kleine boeren zoeken naar alternatieve inkomsten bronnen naast de landbouw, hetgeen resulteert in migratie. De kwetsbaarheid m.b.t. het behoud van de aardappel landrassen verschilde per gebied. In Carchi hadden de jonge boeren weinig interesse in het telen van landrassen. In Loja wordt landbouw niet gezien als de enige bron van inkomen en er is een vermeend gebrek aan steun van de regering voor de werkzaamheden nodig om de lokale landrassen te behouden. In Chimborazo zijn de boeren meer cultureel verbonden met hun land en zien de landbouw als een familie-activiteit, waardoor het behoud van aardappel landrassen minder kwetsbaar is. Externe interventies in ‘on farm’ conserveringsactiviteiten zoals de ‘diversity fair’ of herintroductie van landrassen, werden zeer gewaardeerd door de boeren en helpen bij het behoud.

Er zijn diploïde, triploïde en tetraploïde aardappel landrassen gevonden bij de boeren. De gevonden landrassen vertoonden een hoge allelische diversiteit. Op het tetraploïde niveau (de meest voorkomende), was de variatie vergelijkbaar met de variatie die aanwezig is in een collectie van meer dan 800 Europese rassen. Het is de verwachting dat nog meer allelen gevonden zullen worden als er ook landrassen uit andere gebieden van Ecuador worden geëvalueerd. Er was geen duidelijke groepering van de landrassen naar regio van herkomst waar te nemen, hetgeen suggereert dat er op uitgebreide schaal pootgoed wordt versleept over heel Ecuador.

Een vergelijking van de landrasnamen met de genetische verwantschap tussen de landrassen kan resulteren in een onder- of overschatting van de bij de boeren aanwezige variatie (hoofdstuk 3). In een aantal gevallen bleken landrassen met dezelfde naam genetisch verschillend van elkaar. Ook zijn er landrassen verzameld die een mengsel van twee landrassen bleken te zijn. Beide situaties geven aanleiding tot een onderschatting van de aanwezige genetische variatie. Aan de andere kant, waren er ook landrassen met verschillende namen die genetisch identiek bleken te zijn.

Onze steekproef van genetisch verschillende landrassen uit onze verzameling bevestigde dat er verschillen in *Phytophthora* resistentie tussen de landrassen bestaan (hoofdstuk 4). Het merendeel van de landrassen was gevoelig tot matig resistent tegen *Phytophthora*, maar er werden ook een aantal landrassen met veldresistentie geïdentificeerd. De gevonden veldresistentie was vergelijkbaar met die van het veelgebruikte ras Fripapa. Een mogelijke strategie om de *Phytophthora* resistentie in Ecuador te verbeteren is het zoeken naar landrassen met een goede resistentie, hoewel men daar geen hoge verwachtingen van moet hebben. De introductie van nieuwe resistentiebronnen is een meer levensvatbaar alternatief. Men zou kunnen proberen om R-genen te introduceren in materiaal dat al enige mate kwantitatieve resistentie bevat.

We vonden verschillende hoeveelheden droge stof, polyfenolen en carotenoïden in de Ecuadoriaanse aardappel landrassen, sommigen waren vergelijkbaar met de verbeterde rassen die op dit moment gebruikt worden (hoofdstuk 5). Op basis van de droge-stofgehaltes zijn de meeste van de Ecuadoriaanse landrassen geschikt voor de verwerking tot friet of chips. De concentratie polyfenolen van deze landrassen is vergelijkbaar met de concentraties die werden gerapporteerd door het International Potato Center (Peru) in een set van accessies die meer dan 60% van de variabiliteit in hun aardappel collectie vertegenwoordigden. Het totale carotenoïde gehalte van de Ecuadoriaanse landrassen was vergelijkbaar of lager, vergeleken met voorgaande studies waarin verbeterde rassen uit de Andes werden bekeken. De geïdentificeerde landrassen met uitstekende kwaliteitseigenschappen kunnen worden gebruikt in de veredeling.
In Chimborazo en Loja kiezen boeren hun landrassen voornamelijk op basis van nutritionele eigenschappen. In Carchi prefereren de boeren de verbeterde commerciële rassen. De voorkeuren van deze boeren zijn meer gebaseerd op empirische waardering van de specifieke kwaliteit dan op kennis van nutritionele eigenschappen van deze aardappelen.

Dit proefschrift verschaft belangrijke informatie over de aardappel landrassen in Ecuador. Onze resultaten kunnen gebruikt worden voor een verdere beschrijving en gebruik van landrassen door veredelaars en lokale gemeenschappen.

Resumen

El objetivo de ésta tesis fue llenar un vacío de información sobre la diversidad de papas nativas presentes en campo de agricultores del Ecuador. Datos pasaporte de colecciones previas (1970's y 1980's) fueron usadas para identificar a Carchi, Chimborazo y Loja como áreas representativas de ésta diversidad. El estado de la conservación en fincas en las tres áreas ha sido incluida en el Capítulo 2. Microsatélites (SSRs) ayudaron a describir las relaciones genéticas entre las papas nativas halladas en éstas áreas (Capítulo 3). La caracterización de papas nativas con respecto a resistencia a tizón tardío o lancha (Capítulo 4) y caracteres de calidad (Capítulo 5) complementaron esta descripción.

Reportes previos sugerían la pérdida de esta diversidad (erosión genética) en los campos de agricultores de Ecuador, pero nuestra colección de un total de 174 variedades de papas nativas mostraron que éstas áreas todavía mantienen una cantidad substancial de variedades de papas nativas (Capítulo 2). Se encontraron un mayor número de variedades nativas que las muestreadas previamente en los 70s y 80s. Una comparación entre las dos colecciones, en cada una de las tres áreas, indicaron solo una pequeña coincidencia en los nombres comunes, lo que sugiere que el muestreo de variedades nativas no fue exhaustiva ni en los 70´s y 80´s como tampoco en la colección reciente. Esta idea tiene apoyo en el hecho de que la feria de diversidad, que fue organizada después de las colecciones en Chimborazo, resultó en la colecta de variedades de papas nativas adicionales.

Se usaron encuestas y reuniones de agricultores en las áreas de estudio para describir a los cultivadores de éstas variedades y las características del sistema de cultivo que ellos tienen. En su mayoría los agricultores que mantienen estas variedades son de edades altas y de pequeña escala. Estos agricultores buscan nuevas alternativas de ingreso al margen de la agricultura lo que resulta en migración. La vulnerabilidad de la conservación de papas nativas varía entre las áreas de estudio. En Carchi los agricultores jóvenes demostraron poco interés en el cultivo de papas nativas. En Loja la agricultura no es vista como la fuente única de ingreso sostenible y existe una

percepción del escaso apoyo por parte del gobierno en las actividades necesarias para mantener las papas nativas. En Chimborazo los agricultores son culturalmente más ligados a sus tierras y ven a la agricultura como una actividad familiar, lo que pone a la conservación de las papas nativas menos vulnerable. Las intervenciones externas para la conservación en fincas como la feria de diversidad y la re-introducción de variedades nativas, fueron altamente apreciadas por los agricultores y pudieran ayudar a conservar estas variedades.

En los campos de agricultores se hallaron papas nativas diploides, triploides y tetraploides. El material muestreado en las tres áreas mostraron una alta diversidad alélica. Al nivel tetraploide (la más abundante) fue comparable a la variación presente en una colección Europea de más de 800 variedades. Se espera que más alelos sean identificados cuando se incluyan otras áreas de estudio en el Ecuador. No hubo un claro agrupamiento del material colectado de acuerdo a la región estudiada, lo que sugiere que ha existido un movimiento intensivo de semilla de estas papas por las zonas productoras ecuatorianas.

La comparación de nombres de las variedades con la relación genética entre las papas nativas puede resultar tanto en sobre- como en sub-estimación de la variabilidad presente en el campo de agricultores (Capítulo 3). En un número de casos se probó que las variedades nativas con idénticos nombres comunes fueron genéticamente diferentes, o que muestras colectadas como una variedad fueron una mezcla de dos variedades, así apuntando a una sub-estimación de la diversidad presente. Por el otro lado, casos que pueden indicar sobre-estimación fueron también evidentes como por ejemplo están los materiales genéticamente idénticos, que presentaron diferentes nombres.

Nuestro muestreo de papas nativas genéticamente diferentes, para la caracterización de resistencia a tizón tardío (Capítulo 4), confirmó que existe variación para este carácter. La mayoría de las papas fueron susceptibles a moderadamente resistentes, pero también se identificaron algunas variedades nativas con resistencia en campo. Esta resistencia en campo fue comparable con una variedad mejorada Fripapa que es ampliamente distribuida. Estrategias posibles para mejorar la resistencia a tizón tardío de papas en Ecuador podría incluir la identificación de accesiones con resistencia, aunque se espera que solo unas pocas accesiones presenten ésta característica. La introducción de nuevas fuentes de resistencia de otros orígenes es una alternativa más viable. Se podría intentar introducir nuevos genes de resistencia (R) en el material que ya contiene algún nivel de resistencia cuantitativa.

Encontramos diferentes niveles para materia seca, polifenoles totales y carotenoides totales entre las papas nativas ecuatorianas; algunas fueron comparables a variedades mejoradas. Basados en el contenido de materia seca, la mayoría de las papas nativas evaluadas son adecuadas para procesamiento como papas bastón o chips. El contenido total de polifenoles fueron similares a los reportados por el Centro Internacional de la Papa (Perú) para un grupo de accesiones que representaban más del 60% de la variabilidad presente en su colección. El contenido de carotenoides totales para las papas ecuatorianas incluidas en nuestro estudio, fueron similares o menores a estudios previos para papas mejoradas o papas Andinas. Las papas nativas con valores superiores podrían ser usadas para desarrollar nuevas variedades a través del mejoramiento.
En Chimborazo y Loja los agricultores seleccionan papas nativas principalmente basada en sus características nutricionales. Sin embargo, en Carchi los agricultores prefieren las variedades mejoradas. La preferencia de los agricultores incluye la valuación empírica de la calidad de las papas, antes que el conocimiento específico sobre las características nutricionales de sus papas.

Esta tesis aporta con un importante conocimiento sobre las papas nativas en el Ecuador. Nuestros resultados pueden servir como base para descripciones adicionales y para uso de las papas nativas ecuatorianas por mejoradores y comunidades locales.

Curriculum Vitae

Alvaro Ricardo Monteros Altamirano was born in Quito-Ecuador on 12 January 1971. After graduation from high school at Colegio San Gabriel he studied a Bachelor on Agriculture at Universidad Central del Ecuador, where he graduated in 1996. His bachelor thesis dealed with an Andean tuber crop mashua (*Tropaoelum tuberosum*). Since 1994 he joined INIAP The National Autonomous Institute for Agricultural Research (Instituto Nacional Autónomo de Investigaciones Agropecuarias) at the National Department of Plant Genetic Resources (DENAREF) and continued working there until today. During 2001 to 2002 he studied his master degree at Oregon State University where he got his MSc degree working on True Potato Seeds. He has been involved in several areas of the *ex situ* management of local plant genetic resources: germplasm collecting missions of several crops species (*Oxalis* sp., *Ullucus* sp., *Tropaeloum* sp., *Lycopersicon* sp., *Zea* sp., *Pachyrhizus* sp., *Arachis* sp., *Cucurbita* sp., *Solanum* spp. *Rubus* sp., *Ficus* sp. and others); characterization of germplasm; documentation; and has been in charge of the seed bank, currently conserving more than 12 000 accessions from more than 200 crop species. He has also been involved in the National Sharing Mechanism for the application of the Global Plan of Action in Ecuador jointly with FAO. Alvaro has also participated in activities related to *in situ* conservation of root and tuber crops. In 2007 he started his PhD thesis on Ecuadorian potato diversity. Alvaro is married to Emilia since 1999 and has two daughters Doménica and Itzel.

List of publications

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Education Statement of the Graduate School

Experimental Plant Sciences

Issued to:	**Alvaro R. Monteros Altamirano**
Date:	**20 December 2011**
Group:	**Plant Breeding, Wageningen University and Research Centre**

1) Start-up phase	*date*
► **First presentation of your project**	
In situ conservation of Ecuadorian native potatoes: description and dynamics in three microcenters of diversity	Sep 2007
► **Writing or rewriting a project proposal**	
In situ conservation of Ecuadorian native potatoes: description and dynamics in three microcenters of diversity	Sep 2007
► **Writing a review or book chapter**	
► **MSc courses**	
► **Laboratory use of isotopes**	
Subtotal Start-up Phase	*5.5 credits**

2) Scientific Exposure	*date*
► **EPS PhD student days**	
EPS PhD student days, Wageningen	Sep 13, 2007
EPS PhD student days, Leiden	Feb 26, 2009
EPS PhD student days, Utrecht	Jun 01, 2010
► **EPS theme symposia**	
EPS theme 1, Developmental Biology of Plants. Leiden University	Jan 30, 2009
EPS theme 3, Matabolism adaptation, Amsterdam University	Feb 18, 2009
EPS theme 4, Genome Plasticity, Wageningen University	Dec 10, 2010
► **NWO Lunteren days and other National Platforms**	
ALW meeting 'Experimental Plant Sciences', Lunteren	Apr 19-20, 2010
► **Seminars (series), workshops and symposia**	
El derecho de obtentor en el Ecuador. IEPI	Mar 13, 2008
Plant Breeding research day	Jun 17, 2008
Statistical methods for linkage disequilibrium analysis	Jun 19, 2008
Diálogo Nacional del Fondo para el Medio Ambiente Mundial	Sep 10-12, 2008
Seminario internacional sobre observancia del derecho de obtentor. IEPI, UPOV	Nov 24-25, 2008
Plant Breeding research day	Mar 03, 2009
Molecular marker course	Mar 26, 2009
Conservation, production, processing, comercialization and seed quality control of potatoes in Ecuador	May 29, 2009
Taller: Métodos aplicados en evaluaciones y análisis en la mejora genética de la papa	Mar 22-26, 2010
Plant Science Seminar (PSS) . Profs. Holguer Meinke and Paul Struik	Apr 13, 2010
PSS. Profs. Louise Vet and Just Vlak	May 11, 2010
PSS. Prof. Paul Birch	May 20, 2010
PSS. Profs. Bert Visser and Bela Mulder	Jun 08, 2010
Mini Symposium: How to write a world class paper	Oct 26, 2010
ExPectectionS career day	Nov 19, 2010
Plant Breeding research day	Mar 08, 2011
► **Seminar plus**	
► **International symposia and congresses**	
TROPENTAG 2007, Witzenhausen (Germany)	Oct 09-11, 2007
12th Regular Session of the Comission of Genetic Resources for food and agriculture, Rome (Italy)	Oct 19-23, 2009
I Congreso Internacional de investigación y desarrollo de papas nativas, Quito (Ecuador)	Mar 18-20, 2010
Eucarpia, Potato Breeding after completion of the DNA sequence of the potato genome, Wageningen (The Netherlands)	Jun 27-30, 2010
TROPENTAG 2010, Zurich (Schwitzerland)	Sep 14-16, 2010
► **Presentations**	
Poster: I Congreso Internacional de investigación y desarrollo de papas nativas (Quito-Ecuador)	Mar 18-20, 2010
Oral: EPS theme 4, Genome Plasticity	Dec 10, 2010
► **IAB interview**	Jan 21, 2011
► **Excursions**	
Subtotal Scientific Exposure	*16.6 credits**

3) In-Depth Studies	*date*
► **EPS courses or other PhD courses**	
Uso de marcadores moleculares en el mejoramiento genético de plantas. WU-INIAP	Apr 16-May 11, 2007
Competences for integrated agricultural research (CERES-WIAS)	Sep 02-05, 2007
Molecular Phylogenics: reconstruction and interpretation (EPS)	Oct 15-19, 2007
Scenario development: understanding and applying multi-scale and participatory concepts and tool (PE&RC)	Oct 22-26, 2007
Datos multivariados: Análisis clásicos y nuevas tecnologías. CATIE, CR	Jun 22-26, 2009
► **Journal club**	
► **Individual research training**	
Subtotal In-Depth Studies	*11.4 credits**

4) Personal development		*date*
►	**Skill training courses**	
	PhD information literacy, including introduction to Endnote	Sep 11-12, 2007
	Endnote advanced	Oct 04, 2007
	The art of writing	Feb 11-Mar 11, 2009
	Project and time management	Sep 07, 21, Oct 19, 2010
	Scientific writing	Oct 07-Nov 25 2010
	Techniques for writing and presenting scientific papers	15-18 Feb, 2011
►	**Organisation of PhD students day, course or conference**	
	Training program: Conservation manejo y uso de la agrobiodiversidad en Ecuador. WI-INIAP. Taller de estrategias de manejo	Nov 10-20, 2008
	Training program: Taller de lecciones aprendidas (WI-INIAP)	Sep 15-17, 2009
►	**Membership of Board, Committee or PhD council**	
	Subtotal Personal Development	*7.8 credits**
	TOTAL NUMBER OF CREDIT POINTS*	**41,3**
Herewith the Graduate School declares that the PhD candidate has complied with the educational requirements set by the Educational Committee of EPS which comprises of a minimum total of 30 ECTS credits		
** A credit represents a normative study load of 28 hours of study.*		

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