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S E *Biotechnol. Agron. Soc. Environ.* 2009 **13**(3), 441-448

Genetic diversity and germplasm conservation of three minor Andean tuber crop species

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Received 24 November 2008; accepted 9 March 2009.

In traditional Andean agrosystems, three minor tuber crop species are of regional or local importance: oca (*Oxalis tuberosa* Molina), ulluco (*Ullucus tuberosus* Caldas) and mashua (*Tropaeolum tuberosum* Ruiz & Pav.). Genetic diversity within these species is very large and could result from the high ecological and cultural variability that characterizes the Andean area. Nowadays, many anthropic or ecological factors cause the loss of diversity and contribute to genetic erosion. The development of conservation strategies for genetic resources of Andean tubers, *in situ* as well as *ex situ*, includes a better knowledge of diversity in addition to the study of Andean farming strategies linked to this genetic diversity.
Keywords. Andean tubers, oca, ulluco, mashua, genetic diversity, *in situ* conservation, *ex situ* conservation, phytogenetic resources, Bolivia.

Diversité génétique et conservation du germoplasme de trois tubercules andins mineurs. Dans les agrosystèmes traditionnels andins, trois espèces mineures de tubercules cultivés sont d'une importance régionale ou locale : la oca (*Oxalis tuberosa* Molina), l'ulluco (*Ullucus tuberosus* Caldas) et la mashua (*Tropaeolum tuberosum* Ruiz & Pav.). La diversité génétique au sein de ces espèces est très élevée et pourrait résulter de l'importante variabilité écologique et culturelle qui caractérise la région andine. Actuellement, plusieurs facteurs anthropiques ou écologiques entrainent la perte de cette diversité et contribuent au phénomène d'érosion génétique. La mise au point de stratégies de conservation des ressources génétiques des tubercules andins, tant *in situ* que *ex situ*, passe par la connaissance de la diversité ainsi que par l'étude des stratégies paysannes andines à la base de cette diversité.
Mots-clés. Tubercules andins, oca, ulluco, mashua, diversité génétique, conservation *in situ*, conservation *ex situ*, ressources phytogénétiques, Bolivie.

1. INTRODUCTION

Several crops, produced by many small scale farms in rural areas of traditional agriculture, have a largely unknown importance for feeding an increasing proportion of the world's population. Andean region, which extends from South Venezuela to North Argentina and Chile, has been recognized as a main area for minor crop development and germplasm conservation, including tuber species like potato (*Solanum* spp.), grain species like quinoa (*Chenopodium quinoa* Willd.), maize (*Zea mays* L.), tarwi (*Lupinus mutabilis* Sweet) and beans (*Phaseolus* spp.), or fruit species like cherimoya (*Annona cherimola* Mill.). Moreover, Andean region is also a centre of origin for little known, but potentially important crop species: the Andean tubers oca (*Oxalis tuberosa* Molina), ulluco (*Ullucus tuberosus* Caldas) and mashua (*Tropaeolum tuberosum* Ruiz & Pav.). These species have been neglected for a long time in research, extension and breeding programs and scientific interest emerges since barely a decade. Exclusively propagated through tubers, these crops have formed a high number of clonal varieties that can be distinguished by tuber color and shape (Rousi et al., 1986; Grau et al., 2003; Emshwiller, 2006). However an alarming loss of variability is currently observed (Altieri et al., 1987; Tapia et al., 2001), and both *ex situ* and *in situ* conservation methods are developed.

The purpose of this paper is to document genetic diversity of these three neglected Andean tuber species and to present possibilities of *in situ* and *ex situ* conservation. The example of *in situ* conservation of Andean tubers in the microcentre of Candelaria (Bolivia) will be presented as a case study.

2. ANDEAN TUBERS

Oca, ulluco and mashua belong, together with potato, to the group of edible tuber crops indigenous to the Andean mountains, where they are a food staple in rural communities. Because of its worldwide importance, potato is the most widely studied Andean tuber species. Little information was available on other Andean tubers until just a decade ago. Through research and field projects, knowledge has been generated in different topics from conservation, genetic diversity, production systems and alternative uses of these tubers.

Oca, ulluco and mashua are cultivated for their edible tubers in small areas under traditional agricultural systems and marginal conditions, in all Andean countries, mainly in Peru, Ecuador and Bolivia, and at high altitudes (2,800 to 4,100 meters). They share the same Andean ecological niches as cultivated potatoes. According to Arbizu et al. (1997), they are grown under short-day conditions of the Andes (11-12 hours), with rainfalls ranging from about 400 to 700 mm across the growing season (an average of 7 months). Andean tubers are exclusively propagated through tubers and there is no evidence of seed propagation by farmers. Oca, ulluco and mashua have remained strictly Andean crops, because their conservation and use are associated with socio-cultural aspects of the Andean people and their traditional production systems (León, 1964). Nevertheless, they are essential to ensure food diversification and livelihood of numerous Andean populations. The production of tubers is mostly devoted to farmer's family food supply. Small volumes are also sent to the market, but demand is limited and temporary (Tapia Vargas, 1994).

2.1. *Oxalis tuberosa*

The name oca is derived from the Quechua words *okka*, *oqa* or *uqa*. Other names are *oca* in Peru, Ecuador and Bolivia, *cuiba* or *quiba* in Venezuela, *huasisai* or *ibi* in Colombia, *truffette acide* in French, or *papa extranjera* in Mexico (Arbizu et al., 1997; Cadima Fuentes, 2006).

Oxalis tuberosa belongs to the Oxalidaceae family that includes eight genera. The genus *Oxalis* includes more than 800 species. Some of them set small tubers, but only *O. tuberosa* is cultivated for its edible tubers. Literature denies the existence of wild oca or related tuber bearing species, though wild populations of *Oxalis* bearing small tubers have been found in Bolivia (Emshwiller et al., 1998). Cultivated oca is octoploid ($2n = 8x = 64$).

After potato, oca is the second more common tuber species in the Andean region. Its cultivated surface does not exceed 10,000 ha (Tapia Vargas, 1994). Reported yields for oca in Ecuador do not exceed 2 $t \cdot ha^{-1}$, even if in experimental trials it can reach 15-28 $t \cdot ha^{-1}$ (Tapia et al., 2004). In Peru, oca has a mean production of 5 $t \cdot ha^{-1}$ and in Bolivia 3-5 $t \cdot ha^{-1}$ (Tapia Vargas, 1994; Cadima Fuentes, 2006). Oca is consumed water cooked or baked, always after that tubers have been exposed for several days to the sun in order to acquire sugar taste. They can also be consumed dehydrated, as chuño (Cárdenas, 1989).

Oca is an annual herbaceous plant that is erect in the first stages of its development, then prostrate towards maturity. Stems vary in color from yellow-green to grey. The color of the tuber surface is an important discriminant character. In the standard descriptors (IPGRI/CIP, 2001) up to 12 variations of colors are mentioned. The tubers can also show secondary colors distributed either in or around the eyes (*i.e.* the axillary buds), or unevenly distributed as bands. Both the tubers as the stems have a tendency to fasciation. Leaves are trifoliate; leaflets are green in the upper face and purple or green on the underside. Tuber shape is ovoid, claviforme or cylindrical (Popenoe, 1989). The tuber eyes vary from horizontal, slightly curved, short or long, close or away to each other, and superficial or deep. Bracts covering eyes can be wide and short, or almost nonexistent (Cárdenas, 1989; Cadima Fuentes, 2006). Most oca accessions flower regularly under field conditions. Inflorescences are made of 4-5 hermaphrodite flowers. However, spontaneous seed set is rare and is only observed when both several genotypes are grown together and natural pollinators (the solitary bumblebees *Bombus funebris* Smith) are present (Trognitz et al., 2001). The oca species possesses a trimorphic system of genetic incompatibility (Gibbs, 1976), associated with the presence of three floral morphs. Each clonal accession presents one of the three flower morphs: long (long-styled, with mid- and short-level stamens/anthers), mid (mid-styled, with long- and short-level stamens/anthers) and short (short-styled, with long- and mid-level stamens/anthers). Legitimate pollinations occur when stigma gets pollen of the corresponding morph; illegitimate pollinations occur when stigma gets pollen of a different morph. Legitimate pollinations usually produce the highest seed set. This fits well with the observations of Emshwiller (1998), showing that cultivated oca is an outbreeder. Trognitz et al. (2000) studied three factors responsible for the poor seed formation in oca (size and fertility of pollen, and pollen tube growth), in order to analyze the relationship between these characters and stylar incompatibility. The reduced number of seeds produced seems to be linked to the oca's stylar incompatibility that may affect the growth of pollen tube (Trognitz et al., 2000). The fruit is a dehiscent capsule with five locules, and 1-3 or more seeds are produced per locule (Cárdenas, 1989).

2.2. *Ullucus tuberosus*

The name ulluco is derived from the Quechua word *ulluku* (*ullu* means male organ). *Ullucus tuberosus* is also known as *chugua*, *ulluma*, *iliaco* and *chiga* in Colombia; *melloco*, *hubas*, *chuga*, and *ulluco* in Ecuador; *olluco*, *olloco*, *ullush*, *ullucu* or *lisas* in Peru; and *papalisa*, *illoco*, *ulluma* and *lisa* in Bolivia (Arbizu et al., 1997; Cadima Fuentes, 2006).

The genus *Ullucus* of the family Basellaceae is monospecific. *Ullucus tuberosus* comprises two sub-species: *aborigineus* and *tuberosus*. Cultivated ulluco belongs to the sub-species *tuberosus*, and is cultivated for its edible tubers. Within the sub-species *aborigineus* are found the wild forms of ulluco, which form small tubers of 1-1.5 cm diameter, pink, red, brown or sometimes white (Cadima Fuentes, 2006). The basic number of chromosomes of ulluco is x = 12. According to Arbizu (2004), wild ullucos (subsp. *aborigineus*) are all triploid (2n = 3x = 36), while around 96% of the cultivated ullucos (subsp. *tuberosus*) are diploid (2n = 2x = 24), 3% are triploid (2n = 3x = 36) and 1% are tetraploid (2n = 4x = 48). According to Pietilä (1995), who tested the effect of cross-pollination *vs* self-pollination on seed set, ulluco is an outbreeder. To our knowledge, mechanisms that promote allogamy in ulluco remain unknown.

In Ecuador, ulluco is the second tuber crop species after potato. In Peru and Bolivia, ulluco has a smaller importance, and is the third species after potato and oca. In Ecuador, Tapia et al. (2004) reported a mean yield of 3.5 $t{\cdot}ha^{-1}$. In Peru, the mean yield is 4-5 $t{\cdot}ha^{-1}$ (Cadima Fuentes, 2006). In Bolivia, ulluco is cropped on around 3,000 ha, giving a yield of 3-5 $t{\cdot}ha^{-1}$ (Tapia Vargas, 1994); it is mainly cultivated in the Departments of Cochabamba and Chuquisaca, with yields of 3 $t{\cdot}ha^{-1}$ (Cadima Fuentes, 2006).

Ulluco is an erect, compact and mucilaginous annual plant. Stems are succulent, angular and 30-60 cm height. Stem color varies from clear yellow-green to red-grey. Leaves are simple and can present four shapes. Tuber can be round, cylindrical, elongated or twisted. Tuber eyes (axillary buds) are superficial and without bracts (Popenoe, 1989). The tuber color shows a wide variation, with 12 states ranging from white to red (IPGRI/CIP, 2003). Besides this predominant tuber color, it is also common to find a secondary tuber color. Inflorescences are axillary and abundant with numerous small flowers, magenta (red-purple), green-yellow alone or with red-purple (Cárdenas, 1989; Arbizu, 2004). Fruit formation is rare and seems to depend on the genotype (Pietilä et al., 1990). However ulluco has been shown to set seeds, though the number of seeds produced is low. The fruit is dry and indehiscent and contains one seed, morphologically normal (Rousi et al., 1989) and capable of germination (Lempiäinen, 1989). According to Pietilä et al. (1994), morphological abnormalities in the ovules and embryo sacs are responsible for the low seed number. These authors suggested that vegetative way of propagation favoured the accumulation of a genetic load: somatic mutations (especially those affecting sexual reproduction) may have appeared and be maintained during hundreds generations of vegetative reproduction, explaining why ulluco could have partly lost its capacity for female sexual reproduction.

2.3. *Tropaeolum tuberosum*

The name mashua is derived from the Quechua names *maswa* or *mashwa*. Many names are given for mashua: *mashwa*, *mashua* in Peru and Ecuador; *isaño*, *añu* in Bolivia; and *cubio* in Colombia (Arbizu et al., 1997; Cadima Fuentes, 2006).

Tropaeolum is the largest genus of the Tropaeolaceae family that includes 86 species distributed in all South America (Grau et al., 2003). These authors recognize two sub-species: the cultivated *T. tuberosum* ssp. *tuberosum* and the wild *T. tuberosum* ssp. *silvestre*. The latter does not set tubers. Both wild and cultivated forms extend from Venezuela to northwest Argentina (Cadima Fuentes, 2006). Most cultivated mashua are tetraploid, with a basic chromosome number of x = 13 (2n = 4x = 52). However, cytological studies show conflicting results and other ploidy levels and chromosome numbers have been observed (Grau et al., 2003; Cadima Fuentes, 2006).

Mashua is the Andean tuber covering the smallest crop area in the region and has therefore received the lowest attention. Its culture has been maintained because of its frost tolerance, its resistance to diseases and pests and its stable yields in low-fertile soils of the Andean region (Grau et al., 2003). Mashua is cultivated on small plots around the farms, or close to the fields of more important cultures like potato and oca. According to Grau et al. (2003), mashua is mainly cultivated in Peru (more than 7,000 ha). The cultivated surface of mashua is estimated at about only 100 ha in Bolivia and 50 ha in Ecuador. Yield data in farmer's fields vary from 30 to 60 $t{\cdot}ha^{-1}$, which demonstrates the high production potential of mashua (Cadima Fuentes, 2006).

Mashua is an annual herbaceous plant 20-80 cm high. Stems are cylindrical, 3-4 mm thick, branching, and can vary in color from green to purple-grey with varying degrees of pigmentation. Foliage color varies from yellow-green to dark green. Leaves are 5-6 cm width, tri or pentalobate. In the same plant, tri and pentalobate leaves can be observed. Tubers are less variable in shape than those of oca and ulluco (Popenoe, 1989). Tuber color is variable, ranging from yellow-white to purple-grey and black. Tuber eyes (axillary buds) are always deep, wide and narrow, without bracts (Cárdenas, 1989). Unlike oca and ulluco, mashua flowers profusely and sets many viable seeds with high germination rates (Cárdenas, 1989). According to Grau et al. (2003) mashua is self-fertile. Flowers are solitary and zygomorph. Five sepals of intense red color are united at the base; the three higher forming a spur of 1-1.5 cm length. Seeds can be desiccated to low moisture levels at the ambient conditions of the Andean highlands and will germinate after several months of storage. So far, sexual seeds are currently not used for mashua conservation, which relies on clonal maintenance in fields (Grau et al., 2003).

3. ANDEAN TUBERS GENETIC DIVERSITY: FROM GENETIC EROSION TO RESOURCES CONSERVATION

Farmers' actions are without any doubt essential for the creation and the maintenance of Andean tubers diversity (Quiros et al., 1992). Marginalization of these species originates from numerous factors: difficulties in the product marketing, low social prestige (they constitute the staple foods of poor populations), laborious cooking processes, low economic return in a marginal agriculture (Hernández Bermejo et al., 1992). In addition, according to Iriondo et al. (2008), small farmers maintaining significant amounts of crop genetic diversity through local cultivars face several growing pressures, such as increased population, poverty, land degradation, environmental change, introduction of modern crop varieties and integration into national market economies. These factors contribute to the genetic erosion of Andean tubers. On the basis of field (passport data, morphological descriptors, socio-economical questionnaires) and laboratory (molecular analysis) studies, Tapia et al. (2001) showed that genetic erosion in the three Andean tuber species varies from 25% to 46,5% in Ecuador. Nevertheless, the extent of genetic erosion of Andean tubers remains controversial. In fact, even if large genetic variability is exposed to erosion problems, many of the rare genotypes are still used and subsist thanks to indigenous population, who adopt strategies to cope with biotic and abiotic risks through a wide range of traditional farming techniques (Brush, 1995). The conservation of crop diversity against genetic erosion is now recognized as a worldwide challenge. In this context, two fundamental approaches exist for the conservation of plant genetic resources:

– *ex situ* conservation, in which genetic variation is maintained away from its original location;
– *in situ* conservation, in which genetic variation is maintained at the location where it is encountered, either in the wild or in traditional farming systems (Brush, 2000; Iriondo et al., 2008).

Compared with *ex situ* conservation approach, *in situ* has an important advantage in that it maintains natural genetic interactions between crops, their wild relatives and the local environment; while *ex situ* techniques freeze adaptive evolutionary development, especially in the context of pest and disease resistance (Maxted et al., 1997; Hawkes et al., 2000).

First actions to conserve diversity were the creation of *ex situ* genebanks around the world (Sperling et al., 1990). Most recently, *in situ* conservation has been developed as a complementary method to *ex situ* conservation (Terrazas et al., 1998; Tapia et al., 2004). Complementarity between *in situ* and *ex situ* is commonly presented as essential to secure a sustainable conservation of plant genetic resources. Adopting complementary strategies for resources conservation is useful to overcome the advantages and impediments of both techniques (Maxted et al., 1997; Hawkes et al., 2000). Numerous accessions maintained, *in situ* as *ex situ*, are not well characterized and evaluated, leading to an underutilization and an insufficient exploitation of collections. *In situ* and *ex situ* constraint is the presence of a high number of redundant accessions, highlighting the need to characterize accessions and to define core collections.

3.1. *Ex situ* conservation of Andean tubers

As Andean tubers are vegetatively propagated species, the most appropriate method for *ex situ* conservation remains the establishment of genebanks in the field. Management of field collections and conservation costs are important in the case of vegetatively propagated species, mainly because of the need to regenerate varieties in the field and to maintain them as tubers. Alternative conservation of oca as botanical seed was experienced by Trognitz et al. (1998). They showed that botanical seed production is possible under controlled pollination conditions, and that the tristylus system of incompatibility seems to control the amount of seed produced. Cross-pollinations allowed the production of a higher seed quantity, which implicates that a botanical seed maintained in a genebank does not conserve genes of a unique oca accession, but genes of at least two different accessions. Moreover, it is known that oca rarely sets seeds in natural conditions, and that sterile clones have been reported (Trognitz et al., 2000). Therefore, accessions should be tested prior to their use for botanical seed production, in order to detect the possibility of sterility. So far, oca's germplasm conservation as seed is currently not applied.

3.2. *In situ* conservation of Andean tubers

On-farm conservation of plant genetic resources can be defined as the continued cultivation and management of a diverse set of crop populations by farmers in the agroecosystems where a crop has evolved (Jarvis et al., 2000). This dynamic method aims at maintaining the evolutionary processes that shape the diversity. In this context, the role of the farmers is essential for two reasons:

– crop diversity is not only the result of natural factors, such as mutation and natural selection, but also and particularly, of human selection and management;
– in the last instance, farmer's decisions define whether these populations are maintained or will disappear.

The maintenance of crop intra-specific diversity by farmers requires a better understanding of what, how and when they do it (Brush, 1991; Castillo, 1995). *In situ* conservation by farmers is not only related to the set of varieties they keep, but also to the management processes of these varieties and the knowledge guiding these processes, *i.e.* "farmers' management of diversity" (Castillo, 1995).

Farmers' management of diversity refers to the cultivation of a diverse set of crop populations that are named and recognized as farmers' varieties. The set of varieties is formed through a constant process of experimentation, evaluation and selection of old and more recent varieties. There are two levels of selection:

– the choice of the varieties to maintain;
– for each one, the choice of the seed stock that will be planted the next season.

This selection process is dynamic and is influenced by the supply of varieties from other farmers, villages, regions or even countries. Four components of farmers' management of diversity can be identified (Bellon, 1997):

– seed exchanges between farmers;
– variety selection;
– variety adaptation;
– seed selection and storage.

Sites for on-farm *in situ* conservation of Andean tubers have been identified and are under study in many Andean countries, *e.g.* in Peru (Huánuco, Cuzco, Cuyo Cuyo, Huancavelica; Tapia, 2000), Bolivia (Candelaria; Terrazas et al., 1998) and Ecuador (Las Huaconas; Tapia et al., 2004).

4. A CASE STUDY FROM BOLIVIA: ON-FARM *IN SITU* CONSERVATION OF ANDEAN TUBERS IN THE MICROCENTER OF CANDELARIA

The area of Candelaria, located in the Department of Cochabamba (Bolivia), is known for its traditional farming system of Andean tubers. It presents a high concentration of native oca, ulluco and mashua varieties and has been recognized as a microcentre of diversity for Andean tubers conservation (Terrazas et al., 2003). This site of on-farm *in situ* conservation is currently managed by the PROINPA Foundation (Promoción e Investigación de Productos Andinos, Cochabamba, Bolivia, http://www.proinpa.org), whose main goal is to maintain and promote Andean crops genetic diversity. The microcentre of Candelaria is located 63 km northeast of the city of Cochabamba (17°20' S 65°50' W). Mean annual temperature is 8-10°C, relative humidity ranges from 70-90% and annual rainfall is 900-1,000 mm (Gonzáles et al., 2003). The mean cultivated surface for a family is 18 ares for oca, 14 ares for ulluco and 1 are for mashua. Mean tuber yields are 15-20 $t{\cdot}ha^{-1}$ for the three Andean tuber species (Terrazas et al., 2003).

In 2002, the total diversity identified in the microcentre of Candelaria included 32 varieties for oca, 16 for mashua and 8 for ulluco (Terrazas et al., 2003). Each variety is characterized by agromorphological traits, such as tuber's color and shape, food value, culinary uses and medicinal properties, all used by farmers to identify them (Cadima Fuentes et al., 2003b). Unfortunately, this valuable germplasm seems to be under threat of genetic erosion. In fact, Terrazas et al. (2003) pointed out a decrease in the average number of cultivars used by a family in Candelaria. This reduction in cultivar number is mainly observed for oca.

Cropping system in the microcentre is influenced by ecological and topographic conditions. Soil heterogeneity, altitudinal gradient, humidity and temperature determine crop management system according to altitude. Farmers distinguish three altitude levels within the microcentre (Terrazas et al., 1998):

– the lower stage or pampa (3,000-3,350 m);
– the hillside or ladera (3,350-3,650 m);
– the step hillock or punta (> 3,600 m).

To each level correspond particular climatic, biotic and soil conditions requiring judicious choice of species and varieties and agricultural techniques (Terrazas et al., 2003). The way germplasm is handled by the farmers in Candelaria constitutes a model based on time and space. Varieties are distributed in a wide range of environmental (soil and climate heterogeneity, altitude levels), geographical (localization of the family in the microcentre) and social (migration, market pressure) conditions. In such a system, species and varieties are dispersed in the germplasm of several families, on numerous plots localized across the three altitude levels (Terrazas et al., 1998). Mosaic system is all but static and is continually modified through time by several mechanisms generating a "dynamic mosaic system" (Terrazas et al., 1998; 2003) where tubers of each variety are frequently transported from place to place. Farmers generally own plots of land located at different altitude levels. When seed is impoverished (due to viral accumulation and vegetative reproduction) and does not thrive in a plot, farmers move them to a plot located at another altitude level to revitalize their production. Varieties are consequently subjected to different environmental conditions and pressure selections, with the consequence to stop viral accumulation (Terrazas et al., 1998).

Diversity in Candelaria consists of the familial germplasm, *i.e.* a lot of tubers from several species and varieties of Andean tubers usually inherited from parents (Terrazas et al., 1998). Composition and structure of these familial lots is not static: quantity and quality of tuber-seed vary in time. Biotic and abiotic conditions (*i.e.* diseases, climatic, or other damages leading to the loss of the harvest or the disappearance of the variety) and exchanges between farmers (within or between communities) influence germplasm composition of each family. These processes create dynamic intra- and inter-communities tuber flow (Terrazas et al., 2003). In addition, markets and biodiversity fairs are important sources of new germplasm, gathering tubers from different families, farmers or communities (Espinoza, 2001). These practices are known to be very good sources of genetic diversity in the case of vegetatively reproduced crop species, like Andean tubers. In addition, Terrazas et al. (2007) analyzed the main factors that influence the farmers' decisions for Andean tubers diversity management in Candelaria. Favouring the direct training of farmers is an effective way to promote *in situ* conservation of Andean tubers in farmers' fields. However, it is necessary to expand research on the influence of other factors of socio-economic and ecological importance. Terrazas et al. (2007) showed that access to "Field Schools" and other direct training methods implemented in Candelaria, positively impacted on the conservation of a greater number of varieties per family. By contrast, other socio-economic factors, such as land area and animals owned by the family, exert a weak or no influence on the conservation of varieties in farmers' family.

To ensure the conservation of native varieties maintained in the *in situ* microcentre of Candelaria, tubers have also been maintained in an *ex situ* conservation centre located in Toralapa (Department of Cochabamba), at 3,430 meters altitude (Cadima Fuentes et al., 2003a). This germplasm, recognized as the national germplasm bank for roots and tubers in Bolivia, consists of about 500 accessions of oca, 200 accessions of ulluco and 80 accessions of mashua from the whole country. This *ex situ* collection is also managed by the PROINPA Foundation in a complementary way to *in situ* conservation in Candelaria.

5. CONCLUSION

Andean tubers are neglected tuber-bearing crop species, native to the Andean highlands. They have been cultivated for thousands of years for their edible tubers, through which they are propagated. For many centuries, they have continuously contributed to the food security of the Andean populations and are part of their culture and social expression. Phenotypic diversity of Andean tubers is very high. Biotic and abiotic pressures of the Andes, coupled with anthropic selection for food purpose and crop husbandry, have resulted in a large morphological variation. Andean tubers are exclusively vegetatively propagated and consequently have formed clonal varieties, with particular phenotypic characters and vernacular names given by the local people. But nowadays this valuable germplasm is subject to genetic erosion and the number of cultivated varieties is decreasing. Both *in situ* and *ex situ* conservation programs are developed. For a better conservation of Andean tuber genetic diversity under both systems, it would be extremely important to obtain additional information on the "farmers' management processes". Among the numerous data still needed to better understand the evolution of clonal crops in traditional agricultural systems, the following factors can be pointed out: the role of the cultural, economic and ecological environment; the impact of tubers' exchanges via markets, barters, biodiversity fairs; the influence of sexual reproduction in successive generations; the levels of diversity maintained by *in situ* and *ex situ* conservation methods.

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