

UNDER-UTILIZED ANDEAN FOOD CROPS: STATUS AND PROSPECTS OF PLANT BIOTECHNOLOGY FOR THE CONSERVATION AND SUSTAINABLE AGRICULTURAL USE OF GENETIC RESOURCES

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ABSTRACT

In line with the strategic recommendations of the Global Plan of Action for the Conservation and Sustainable Utilisation of Plant Genetic Resources for Food and Agriculture approved at the Fourth International Technical Conference on Plant Genetic Resources (ITCPGR), Leipzig, Germany, June 1996 and of the Global Plan of Action on Food Security approved at the World Food Summit on Food Security (WFS), Rome, November 1996, the Andean Countries of Latin America (LAC) face the need to strengthen the use of modern plant biotechnology for the conservation and sustainable agricultural use of genetic resources of under-utilized crops. Advanced biotechnologies as cell and tissue culture, molecular genome analysis, plant genetic transformation, molecular plant disease diagnosis and germplasm cryo-conservation can be successfully used to cope genetic erosion, to reinforce *ex-situ* collections and in *in-situ* conservation, to upgrade the supply of improved and healthy seed and planting materials to farmers and to integrate a new approach into the development programmes for food production and food security in mountain lands. Over the centuries, more than seventy crops have been domesticated by the Andes inhabitants. Presently, on twenty eight crop species, selected under the basis of adaptation to high altitude, agronomic use and yield, nutritional value and market potential, there are relative developments in term of agronomic cultural management and scarce genetic conservation activities. The Technical Co-operation Network on Plant Biotechnology (REDBIO) for the Latin American Countries (LAC), sponsored by FAO since 1990 have detected for this subregion technical constrains in terms of scarcity of human resources, limitation in technology development and use, infrastructure and lack of information/data banks on plant biotechnology. Eighty six plant biotechnology laboratories from the Andean Countries of LAC (Colombia, Peru, Ecuador, Bolivia, Venezuela are members of REDBIO. On several of these institutions there are research and transfer of technology projects, including plant biotechnology, on Andean under-utilized food crops as arracacha (*Arracacia xanthorrhiza*), achira (*Canna edulis*), yacon (*Polymnia sonchifolia*), mashua (*Tropaeolum tuberosum*), oca (*Oxalis tuberosa*), ulluco (*Ullucus tuberosus*), quinoa (*Chenopodium quinoa*), amaranto o kiwicha (*Amaranthus caudatus*), popping beans -"nuñas" (*Phaseolus vulgaris*), tarwi (*Lupinus mutabilis*), goldenberry-"capuli" (*Physalis peruviana*), cherimoya (*Annona cherimola*) and passion -fruit (*Passiflora sp.*). The paper summarizes the main parameters and characteristics of 13 selected crops including the state of the art of plant biotechnology in the Andean countries and main applications and discusses perspectives and future impact of plant biotechnology for the conservation and development of food crops.

INTRODUCTION

The two-million-square kilometer Andean region extends from southern Venezuela to northern Argentina and Chile, and includes Colombia, Ecuador, Peru and Bolivia. This ecoregion, one of the world's most fragile and least understood environments, is the home to more than 60 million people, half of whom are employed in farming and living in extreme poverty. An average Andean farmer earns about US\$300 a year (International Potato Center, 1992). Over the last 35 years, millions of Andean farmers have abandoned their fields and migrated to the coastal cities. Rapid population growth has led to degradation of the region's natural resources resulting in the erosion of soil, nutrients and biological resources. This region has been severely damaged by soil erosion, deforestation, overgrazing, contamination by mining wastes and poor water management (National Research Council, 1989).

Once the home to some of the world's most advanced cultures, the region is now one of the world's poorest because of a decline in farming, high rates of population growth, migration and misuse of natural resources. Hundreds of years before the arrival of European explorers, Andean farmers domesticated numerous species of edible root and tubers, grains, vegetables and fruits crops. Over centuries, Andean farmers developed more than 70 food crops (National Research Council, 1989). In some places these crops grow in frost-prone altitudes over 4,000 meters (Tapia, 1997).

In terms of biodiversity the Andean ecoregion is very rich, and no area is more threatened by natural disasters (earth-quakes, floods, avalanches, volcanic activity, drought) and/or man-made impacts like deforestation, agriculture caused soil erosion, terrorism, drug production and social violence (International Potato Center, 1992).

Much about this biodiversity, as well as the associated indigenous knowledge, is being lost. Today, more than a third of the world's foods are indigenous to the Region (as potato, races of corn, sweetpotato, beans, peppers, and tomato). Little known outside the Andes, many of the under-exploited Andean crops are fast disappearing because of social unrest and environmental damage. They may prove to have an important role world-wide as food, as well as for medicines, and industrial uses; some are grown as food in Brazil, New Zealand and Vietnam; others are found in Europe and the United States as gourmet foods. Table 1, summarized from Tapia, (1997) and National Research Council, (1989) provides information on altitude adaptation of twenty eight promising Andean under-utilized food crops.

ANDEAN CROPS AND BIOTECHNOLOGY

The crops presented and discussed in this paper have been selected on the basis of their relative development regarding the application of plant biotechnology for the propagation, characterization and conservation of promising genetic resources. There are eight Andean species with edible underground roots and tubers that play a major role in the Andean highland farming systems (Table 1). These crops are of great economic and nutritional importance to subsistence Andean farmers, and are often used as a substitute for expensive fruits and vegetables in the diet. These roots and tubers are threatened with extinction by the changing social conditions and by pressure on the environment; they are known in the Quechua Indian language as ulluco, oca, mashua, arracacha, yacon, achira, maca, and mauka (National Research Council, 1989). Aside from their ability to grow at high altitudes under extremely hard temperature and water stress conditions, these crops have a wide range and mix of desirable characteristics: high protein, vitamins, and starch content, high yields and important medicinal properties. Scientists believe that new uses of Andean roots and tubers can be found to help boost their demand, especially for export, thus creating economic opportunity in an area where family income are far less than the minimum required for food security. The promotion of production and consumption of root and tuber Andean crops in general, is in line with the strategic recommendations of the Global Plan of Action for the Conservation and Sustainable Utilisation of Plant Genetic Resources for Food and Agriculture approved at the Fourth International Technical Conference on Plant Genetic Resources (ITCPGR), Leipzig, Germany, June 1996 (FAO 1996) and of the Global Plan of Action on Food Security approved at the World Food Summit on Food Security (WFS), Rome, November 1996 (FAO 1996a).

The potential market, use, nutritional value, agronomic characteristics and research constraints of three selected root crops (arracacha, yacon and achira) are presented in Table 2. These are prominent examples of under-utilized or “new” crops with high potential for short term development. “New” uses for root and tubers include: oca and achira as starches; arracacha as baby food, and yacon as a sweetener for diabetics.

The status and potential of plant biotechnologies for the conservation and genetic improvement of germplasm includes the following technologies and applications: tissue culture [germplasm exchange, germplasm conservation (cryo-conservation, long term *in vitro* collection)], *ex situ* conservation, *in situ* conservation, widening genetic base (through inter-specific crosses); cellular or molecular markers (to be used for planning strategies for conservation, establishing points of geographic concentration, setting collection criteria, to study *in situ-ex situ* conservation, to rationalize collection size and duplications and gene flow); the use of genetic maps (for comparative mapping among species, gene identification for important agronomic traits), and genetic transformation. Plant biotechnology applications for the conservation and sustainable use of germplasm of arracacha, yacon and achira are presented in Table 3.

Clonal propagation of arracacha by meristem culture is being developed for the production of clean planting material in Brazil (Luz, et al 1993) and Ecuador by the INIAP (Castillo, personal communication). Use of isozyme markers for the identification of germplasm accessions of arracacha and yacon are also underway (Castillo, R.; Estrada, R., personal communication). As a first step towards a genetic transformation methodology, plants have been regenerated from a genotype of arracacha in Peru (Estrada, R., personal communication).

Table 4 shows the potential market, geographic adaptation, use, nutritional value, agronomic characteristics and research constraints of the tubers oca, oluco and mashua. Scientists also want to assess their usefulness in other high altitude countries where food production is a problem because of frost and the high cost of fertiliser and seed. An impressive work at national agricultural research systems and at the International Potato Center (CIP) is being developed to organise the world Andean tuber crop germplasm collection. More than 600 distinct clones representing eight species in both field and gene bank collections are present. The success of this project hinges on the production of virus-clean micropropagated material that is the main limitation as well the most developed plant biotechnology application (Table 5). If disease-free material is returned to Andean farmers it would greatly help assure sustained agricultural development at the village level without the use of high-yielding modern varieties that require more agricultural inputs to obtain higher yields. The value of this approach cannot be underestimated. Field experience has shown that, as an example, simple cleaning of potato germplasm without genetic improvement, for example, can increase farm yields 60 percent or more.

Micropropagation of olluco, oca and mashua is now well developed. This technique is being used to develop *in vitro* germplasm collections using shoot cultures and induced microtubers (Castillo, R.; Estrada, R., personal communication), from virus free clones produced by meristem tip culture and thermotherapy (Stone, 1982). In addition to isozyme fingerprinting, RAPD markers have been successfully tested to distinguish olluco accession in CIAT through collaboration with San Marcos University of Lima (Lopez, M., personal communication).

Among the Andean grains (pseudo-cereals) there are quinoa (*Chenopodium quinoa*), qañiwua (*Chenopodium pallidicaule*) and amaranto o kiwicha (*Amaranthus caudatus*). The seeds of amaranth contain high levels of protein and the essential amino acid lysine, which is usually lacking in plant protein. The kiwicha protein is almost comparable to milk's protein (casein) in nutritional quality, and complements the nutritional quality of foods that normally would be made from flours of corn, rice, or wheat. This makes kiwicha particularly beneficial for infants, children, and pregnant and lactating women (Lehmann, 1996). Although the seed of the Quinoa plant (Chenopodiaceae) is one of the best sources of protein in the vegetable kingdom, quinoa is hardly known in cultivation outside its upland Andean home (National Research Council, 1989). However, experience in the United States and England shows that the grain is readily accepted by people who have never tasted it before. Quinoa can be grown under particularly unfavorable conditions, at high elevation, on poorly drained lands, in cold regions, and under

drought (Mujica, Berti and Izquierdo, 1997). Already, much has been learned about this plant, which is becoming a commercial success outside the Andes.

Other promising under-utilized crops are popping beans -"nuñas" (*Phaseolus vulgaris*) and tarwi (*Lupinus mutabilis*). These two legume crops are of the most interest for the future development of the Andean crops. The nuña (Leguminosae) is a variety of the common bean, but it is the bean counterpart of popcorn. Dropped into hot oil, nuñas burst out of their seed coats. The popping is much less dramatic than with pop corn- nuñas don't fly up into the air-but the product has a delightful flavor and a consistency somewhat like roasted peanuts (National Research Council, 1989). In the case of tarwi, this lupin (Leguminosae) is one of the most beautiful crops, and its seeds are as rich, or richer, in protein than peas, beans, soybeans, and peanuts-the world's premier plant protein sources (Tapia, 1997). Also, they contain about as much vegetable oil as soybeans. Tarwi has been held back mainly because its seeds are bitter. The Indians soak them in running water for a day or two, to wash out the bitterness. Recently, engineers in Peru and Chile have developed machinery for more rapid and efficient operation (National Research Council, 1989). Also, geneticists in several countries have developed bitter-free varieties that need little or no washing. Table 6 points out the very high export potential of quinoa and amaranth as well as the agronomic characteristics of these two pseudo-cereals. Protein analysis, gene mapping and genetic transformation is on-going in research projects with amaranth in Mexico (Table 7).

Gene transfer techniques for quinoa, tarkwi and amaranth is advanced using embryo rescue from interspecific hybrids between (*Lupinus mutabilis* x *L. hartwegii* (Schaefer et al, 1989), and genetic transformation of quinoa (Komari, 1990) and amaranth transgenic plants were obtained by the group of Blanco in Irapuato Mexico (Blanco, A., personal communication); the main trait of interest being insect resistance.

Along the Andes are found several autoctonous fruits (Table 1). Among these, relatives of raspberry and blackberry *Rubus* species (*Rosaceae*), blueberry (*Vaccinium* species, *Rosaceae*), and some small berries (*Myrtus* species, *Myrtaceae*) that are rather like mini guavas. Collectively, they represent a source of new and interesting fruits (Tapia, 1997). The Uchuva or Goldenberry is a relative of the North American husk tomato. The goldenberry (*Physalis peruviana*, *Solanaceae*) is fresh tasting and makes one of the world's finest jams. Under harsh conditions it provides a wealth of yellow, marble-sized fruits that are beginning to attract international market for their flavor and appearance. Other under-utilized fruit crops of high interest, beautifully described by Dr. N. Vietmeyer (National Research Council, 1989) are: Highland Papayas. Although the papaya is one of the premier fruits of the world, its botanical cousin (*Carica* species, *Caricaceae*) of the Andes are all but unknown. Lucuma. The lucuma (*Pouteria lucuma*, *Sapotaceae*) can be considered a "staple fruit." Unlike oranges or apples, its fruits are dry, rich in starch, and suitable for use as a basic, everyday carbohydrate. It has been said that a single tree can feed a family year-round. The fruits are often eaten fresh and are very popular in milkshakes, ice cream, and other treats; dried they store for years. The lulo or naranjilla is related to, but wholly unlike, tomatoes, this fruit (*Solanum quitoense*, *Solanaceae*) is highly esteemed in Peru, Colombia, Ecuador, and Guatemala, but virtually unknown elsewhere. Its delicious, refreshing juice is one of the delights of the northern Andes, and it could become popular in the African and Asian tropics, where the plant could conceivably flourish. The paca is among the most unusual of all fruit trees. The paca (*Inga* species, *Leguminosae*) produces long pods filled with soft white pulp. This pulp is so sweet that the pods have been called ice-cream beans. Not only are the fruits attractive and popular, this nitrogen-fixing tree is extremely promising for reforestation, agroforestry, and for production of wood products. Pepino. A large, conical, yellow fruit (*Solanum muricatum*, *Solanaceae*) with jagged purple streaks, pepino's mellow flesh tastes like a sweet melon. It is beginning to enter international commerce. Already gaining popularity in New Zealand and Japan, the delicate pepino seems destined to become a benchmark for premium fruit production. Tamarillo (Tree Tomato). Inca gardens high on the mountainsides contained small trees that bore large crops of egg-shaped "tomatoes." Today these tree tomatoes (*Cyphomandra betacea*, *Solanaceae*) remain one of the most popular local fruits. They have bright, shiny, red or golden skins and can be eaten raw or cooked or added to cakes, fruit salads, sauces, or ice cream. Their succulent flesh looks somewhat like that of the tomato, but it is tart and tangy and has a piquancy quite its own.

Of all the Inca fruits, the cherimoya (*Annona cherimola*, Annonaceae) is cultivated substantially outside the Andes (Table 8). It is being grown commercially in Spain, Southern California, and a few other places. Such interest is understandable. Within the thin greenish skin of the cherimoya is a delicious, sweet, and juicy flesh with a creamy, custardlike texture. Its unique flavor tastes like a subtle blend of papaya, pineapple, and banana. *In vitro* micropropagation of the Anonas is highly desirable to expedite the diffusion of elite trees; however, only very limited successful work has been carried out using juvenile, not mature, explants (Bassi and Cossio, 1993). Recent work at CIAT using mature explants has resulted in axillary shoot elongation on the one hand, and *di novo* shoot regeneration from roots and stems. While the former can provide buds for micrografting the latter system offers potential for genetic transformation (Royero and Mejia, personal communication). A target trait for a transgenic approach in *Annona* is anthracnose resistance.

The Passionfruits (*Passiflora* species, Passifloraceae) are becoming popular in Europe, North America, and other places. With its concentrated perfume and flavoring ability, passionfruit "develops" the taste of bland drink bases such as apple juice or white grape juice (National Research Council, 1989). So far, all commercial developments have been based on a single Brazilian species. In the Andes are scores of other species, some of which are reputed to be superior to the Brazilian one. An active work of germplasm characterization including the use of molecular markers is under way in CIAT and CORPOICA, Colombia (Tables 8 and 9).

Out of the wide range of Andean crops described, the fruits have so far received more attention in terms of biotechnology development; this is probably due to the economic importance of these species, particularly for export. On the one hand, tissue culture micropropagation for the production of clean planting material is well developed for the Passifloras (Kawata, et al 1995). On the other, molecular markers have been fully developed for the analysis of the genetic structure of Passifloras using RAPDs, RFLPs and AFLPs in CIAT through a collaboration with CORPOICA, Colombia (Sánchez, et al 1996). Similarly, plant regeneration is available in several passion fruit species and used for genetic transformation of *P. edulis* (Manders, et al 1994); the main trait of interest being virus resistance.

CONCLUDING REMARKS AND ISSUES FOR FURTHER DISCUSSION

There are several Andean species with edible grains, roots, tubers and fruits that play a major role in the Andean highland farming systems. These crops are of great economic and nutritional importance for subsistence Andean farmers, and are often used as a substitute for expensive fruits and vegetables in the diet. Both, the Global Plant of Action for Plant Genetic Resources approved at Leipzig, Germany in 1996 and the Global Plant of Action on Food Security approved in Rome, in 1996 recommended as an important global issue, to focus on the conservation and sustainable use of Plant Genetic Resources as a food security key element, with very important socio-economic implications.

At the global level we are facing a tremendous scientific explosion. This explosion is due to our renewed ability to understand and manage the genetic code and its expression in living organisms. Now the identification of genes and its functions is being simplified and new mechanisms and technologies allow us to understand the molecular base at the genome. While investments in plant biotechnology are overwhelmingly high by the private sector on cash crops, a large concerted effort of public organizations from developing and developed countries is needed to prevent the biotech revolution passing by, without benefiting the Andean crops.

It is considered that returning under-exploited species to the Andean region will improve nutrition and welfare of rural poor. The Andean Countries of Latin America face the need to strengthen the use of modern plant biotechnology tools to cope genetic erosion, to reinforce *ex situ* and *in situ* gene banks and germplasm collections, to upgrade the supply of improved and healthy seed, and planting materials, to farmers and to integrate a new approach into the development programmes for food production and food security in mountain lands.

The state of the art of plant biotechnology in the Andean countries is still scarce and weak. Within this context the Technical Co-operation Network on Plant Biotechnology (REDBIO) for the Latin American Countries (LAC), sponsored by FAO since 1990, have detected for this subregion technical constraints in terms of scarcity of human resources, limitation in technology development and use, infrastructure and lack of information/data bases on plant biotechnology. Eight six plant biotechnology laboratories from the Andean Countries of LAC (Colombia, Peru, Ecuador, Bolivia, Venezuela) are members of REDBIO. On several of these institutions there is research and transfer of technology projects, including plant biotechnology, on Andean Crops like achira, arracacha, oca, quinoa, amaranth, popping beans, tarwi, cherimoya, passionfruit, goldenberry, and other Andean fruits.

There is evidence of severe genetic erosion in some root and tuber species. Large collections have been lost due to the lack of resources, or through civil strife. By protecting this genetic diversity, many national institutes are laying the groundwork for their eventual evaluation, improvement and utilisation. Comprehensive, sustained and biotechnology assisted program to reverse years of environmental damage across the Andes "may be the last chance to rescue this fragile ecoregion from devastation".

Considering the ongoing applications and further impact of the use of advanced plant biotechnology on selected under-utilized food crops, a consortium of national and international co-operation efforts, comprising agencies, international CGIAR centres and multilateral and bilateral assistance are needed in order to cope and embark on a large coherent emergency program to rescue wild and domesticated Andean food crop species threatened with biological extinction or severe genetic weakening. .

In spite of that, the research on plant breeding and crop management on under-exploited Andean crops is not new and not starting from zero level. The application of plant biotechnology for the propagation, characterisation and conservation of promising genetic resources (cultivars) is still not significant. There are more than 20 years of field work, germplasm exchanges, and international co-operation promoted by FAO and other bilateral agencies. There are important collection that are limitations in terms of budget and personnel. The academic work (thesis and publications) are abundant but scarcely distributed on diverse topics. Till now, the Andean countries have organised 9 congress with more than 1800 participants and 700 presentations. Against this background, a complex of national and international co-operation efforts, comprising agencies, international CGIAR centres and multilateral and bilateral assistance are needed in order to cope and embark on a large coherent emergency program to rescue wild and domestic Andean food crop species threatened with biological extinction or severe genetic weakening.

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Table 1 Altitude adaptation of twenty eight promising under-utilized Andean Food Crops. (mosl:meters above sea level).

| | Latin name | Adaptation / altitude (mosl) |
|---------------------|---|------------------------------|
| Grains | | |
| Qañiwa | <i>Chenopodium pallidicaule</i> | 3500-4100 |
| Quinoa | <i>Chenopodium quinoa</i> | 2300-3900 |
| Kiwicha | <i>Amaranthus caudatus</i> | 3000 |
| Legumes | | |
| Tarwi | <i>Lupinus mutabilis</i> | 500-3850 |
| Nuña | <i>Phaseolus vulgaris</i> | 1500-3500 |
| Root/Tubers | | |
| Oca | <i>Oxalis tuberosa</i> | 2300-4100 |
| Mashwa | <i>Tropaeolum tuberosum</i> | 3500-4100 |
| Bitter Potato | <i>Solanum curtilobum/ juzepczukii</i> | 4200 |
| Mauka | <i>Mirabilis expansa</i> | 2500 |
| Maca | <i>Lepidium meyeri</i> | 3900-4200 |
| Ahipa | <i>Pachyrrhizus ahipa</i> | 1500-3000 |
| Olluco | <i>Ullucus tuberosa</i> | 2800-4300 |
| Arracacha | <i>Arracacia xanthorrhiza</i> | 1000-2800 |
| Achira | <i>Canna edulis</i> | 1000-2500 |
| Yacon | <i>Polymnia sochifolia</i> | 1000-3000 |
| Vegetables | <i>Peppers Capsicum annum- C. pubescens</i> | 1500-2900 |
| Squashes | <i>Cucurbita maxima</i> | 0-2000 |
| Fruits | | |
| Berries | <i>Rubus/Vaccinum/Myrtus</i> | 3000 |
| Cherry | <i>Prunus capuli</i> | 1800 |
| Cherimoya | <i>Annona cherimola</i> | 2000 |
| Aguaymanto | <i>Goldenberry Physalis peruviana</i> | 500-2800 |
| Highland Papaya | <i>Carica sp.</i> | 2700 |
| Lucuma | <i>Pouteria lucuma</i> | 2700 |
| Naranjilla | <i>Solanun quitoense</i> | 2300 |
| Pacae | <i>Inga sp.</i> | 0-1800 |
| Tumbo, Passionfruit | <i>Passiflora mollisima</i> | 2000-3200 |
| Pepino dulce | <i>Solanum muricatum</i> | 0-3200 |
| Tree Tomato | <i>Cyphomandra betacea</i> | 500-2700 |

Sources: Tapia, (1997) and National Research Council, (1989).

Table 2 Potential market, adaptation, use, nutritional value , agronomic characteristics and research constraints of selected root: crops arracacha (*Arracacia xanthorrhiza*), yacon (*Polymnia sonchifolia*) and achira (*Canna edulis*)

| | ARRACACHA | YACON | ACHIRA |
|---|--|---|--|
| POTENTIAL MARKET | very high | very high | very high |
| PRODUCTION POTENTIAL and GEOGRAPH. ADAPTATION | low cost of production, very tasty. Potential use in: USA, EU, Puerto Rico, Nepal, Burundi | Andes, high potential USA, EU, JPN, ITA, NZ, Asia | Wide adaptation, MEX,ARG, AUS, Africa., Source of starch |
| USE | boiled,baked, fried,stew, soup | raw, boiled, baked, forage, diabetics food,high fructose syrup | raw, boiled, starch, fodder |
| NUTRITIONAL VALUE | CHO 25% , easily diggestible, Vit. A | Inulin | CHO 80% DM |
| PROPAGATION | shoots/roots | shoots | rhizome tips |
| YIELD (Ton/ Ha) | 15 - 40 | 15 - 38 | 22 - 50 |
| GROW. CYCLE m | 10 | 7 | 6 |
| MAX. ALT. (mosl) | 2800 | 3500 | 2500 |
| RAINFALL (mm) | 1000 | tol.dry season | sucept. drought |
| LOW TEMP. oC | suceptible to frost | suceptible to frost | -2 |
| HIGHT TEMP. oC | 25 | tolerant | 32 |
| DAYLENGHT | short | neutral | neutral |
| SOIL TYPE | sandy, pH6 | wide range | wide range, pH4.5 |
| CONSTRAINTS & RESEARCH NEEDS | germplasm characterization / collection; breeding for: daylenght, tolerance to mites/nematode; and cv. development | germplasm characterization / collection; breeding for: postharvest; virus free materials, propagation elite clones. | adaptation /agronomy, collection, characterization. |

Table 3 Plant biotechnology applications for the conservation and use of genetic resources of selected root crops: arracacha (*Arracacia xanthorrhiza*), yacon (*Polymnia sonchifolia*) and achira (*Canna edulis*)

| BIOTECH. APPLICATIONS | ARRACACHA | YACON | ACHIRA |
|---|-----------|-------|--------|
| micropropagation | ++ | ++ | + |
| <i>in vitro</i> conservation | + | ++ | ++ |
| transfer to soil | ++ | +++ | + |
| pathogen eradication | 0 | 0 | 0 |
| Virus diagnostics | ++ | 0 | 0 |
| cryo-conservation | 0 | 0 | 0 |
| biochem. characterization | + | + | 0 |
| RAPD | + | 0 | 0 |
| RFLP | 0 | 0 | 0 |
| callus culture | 0 | 0 | + |
| organogenesis | 0 | 0 | + |
| embryogenesis | 0 | 0 | 0 |
| <i>in vitro</i> selection/ clone variants | + | 0 | 0 |
| protoplast culture | 0 | 0 | 0 |
| anther culture | 0 | 0 | 0 |
| embryo rescue | 0 | 0 | 0 |
| cell suspensions | 0 | 0 | 0 |
| transgenic plants | 0 | 0 | 0 |

legend:+++=routine ++=available +=starting 0=not available

Table 4 Potential market, adaptation, use, nutritional value, agronomic characteristics and research constraints of selected tuber crops: ulluco (*Ullucus tuberosus*), oca (*Oxalis tuberosa*), and mashua (*Tropaeolum tuberosum*)

| | OLLUCO | OCA | MASHUA |
|---|---|--|---|
| POTENTIAL MARKET | hight | very hight | medium |
| PRODUCTION POTENTIAL and GEOGRAPH. ADAPTATION | Andes, increasing in PER, ECU. Pot.:Sri Lanka, Afri., China, USA, EU, JPN, CAN, ENG, NZ | Andes, wide adapt., NZ, USA, MEX, CAN, Afr., Asia, China | Wide, poor soils, Andes, Himalaya, NZ |
| USE | tubers,leaves, boiled,mashed, stews, freezing | tubers,raw,stew, soups, boiled, baked,stock feed | tubers,leaves, flowers, boiled,stew, anti-afrodisiac |
| NUTRITIIONAL VALUE | CHO, Vit. C | CHO, Prot., 30% starch DM | CHO, 11%Prot., Vit C |
| PROPAGATION | stem cuttings, stolons | tubers, stolons | tubers |
| YIELD (Ton/ Ha) | 5-9 | 5-40 | 20-50 |
| GROW. CYCLE (months) | 8 | 6 | 8 |
| MAX. ALTITUDE (mosl) | 4000 | 4000 | 4300 |
| RAINFALL (mm) | 800-1400 | 570-2150 | 700-1600 |
| LOW TEMP. oC | frost tol. | frost tol. | frost res. -4 |
| HIGHT TEMP. oC | sucept. | 28 | 20 |
| DAYLENGHT | | short | 12 |
| SOIL TYPE | wide range, pH5-6.5 | tol. acid soils | tol. poor alkaline soils |
| CONSTRAINTS and RESEARCH NEEDS | virus cleaning, (15 Tons, seed production, shorter cycle, tuber quality) | virus cleaning, breeding against bitter flavor(oxalic acid), insect res, daylengt, germ. conservation/ collection/400 accessions | virus cleaning/germp. collection/ bio-control application/ use of starch, photoperiod restriction |

Table 5 Plant biotechnology applications for the conservation and use of genetic resources of selected tuber crops: ulluco (*Ullucus tuberosus*), oca (*Oxalis tuberosa*), and mashua (*Tropaeolum tuberosum*)

| BIOTECH. APPLICATIONS | OLLUCO | OCA | MASHUA |
|---|--------|-----|--------|
| micropropagation | +++ | +++ | +++ |
| <i>in vitro</i> conservation | ++ | ++ | ++ |
| transfer to soil | +++ | +++ | +++ |
| pathogen eradication | +++ | ++ | ++ |
| <i>in vitro</i> tuberisation | ++ | + | + |
| Virus diagnostic | +++ | ++ | + |
| cryo-conservation | + | 0 | 0 |
| isozymes characterization | ++ | ++ | ++ |
| RAPD | 0 | + | 0 |
| RFLP | 0 | 0 | + |
| callus culture | ++ | +++ | + |
| organogenesis | 0 | +++ | 0 |
| embryogenesis | 0 | 0 | 0 |
| <i>in vitro</i> selection/ clone variants | + | 0 | 0 |
| protoplast culture | ++ | 0 | 0 |
| anther culture | 0 | 0 | 0 |
| embryo rescue | 0 | 0 | 0 |
| cell suspension | 0 | 0 | 0 |
| transgenic plants | + | + | 0 |

legend:+++=routine ++=available +=starting 0=not available

Table 6 Potential market, adaptation, use, nutritional value, agronomic characteristics and research constraints of quinoa (*Chenopodium quinoa*), amaranto o kiwicha (*Amaranthus caudatus*), popping beans -"nuñas" (*Phaseolus vulgaris*) and tarwi (*Lupinus mutabilis*)

| | QUINUA | KIWICHA AMARANTH | NUÑA | TARWI |
|---|---|---|--|--|
| POTENTIAL MARKET | very high, export crop | very high, export crop | high | high, export potential |
| PRODUCTION POTENTIAL and GEOGRAPH. ADAPTATION | Andes, wide adaptation, basic source of protein, USA, CAN, EU, FAO Food Security Crop/ 35.000 has. BOL | Americas, wide adaptation, MEX,CHI,USA, Nepal,,India, super quality protein crop, food security | Andes, snack crop, old relative of drybean, ancient crop, processing | Andes, MEX,CHI. EU, USA, NZ, Aust, S.Africa. Wide adaptation, to marginal soils, N fixation (400k/ha) / 6300 Has=GER |
| USE | flour, boiled, breakfast, beer, deserts, feed(4 Ton DM/ha), gourmet grain, malted | snack /bread, popping, flour, Alegria desert, health food, vegetable, fodder | popping bean, snack crop | vegetable oil(20%), protein source(46%), feed crop, cooked seeds, green manure crop |
| NUTRITIONAL VALUE | 16-23% Prot. 68% CHO DM very high biol. value | 13-18% Prot. biol. value | 22 % Prot(DM) | 40% Prot. oil content |
| PROPAGATION | seeds | seeds | seeds | seeds |
| YIELD (Ton/ Ha) | 3 - 5 | 1 - 5 | 1,2 - 2 | 2.5 - 4 |
| GROW. CYCLE (months) | 3 -5 | 4 - 6 | 4 - 9 | 4 - 5 |
| MAX. ALTITUDE (mosl) | 0 - 4000 | 3600 | 3000 | 3000 |
| RAINFALL (mm) | 300-1000 | 200, drought res. | 500-1500 | 200, drought res. |
| LOW TEMP. oC | -1 | frost sucept. | frost sucept. | frost tol. |
| HIGHT TEMP. oC | 35 | 40 | 25 | ? |
| DAYLENGHT | short-neutral | short-long | short | neutral |
| SOIL TYPE | wide range, tol. salinity | wide range, tol. alkaline/saline | well drained | wide, sucept. acid soils |
| CONSTRAINTS and RESEARCH NEEDS | collection, eval. gemp., breeding saponins eliminat. molecular salt tol. mechan. basis, super protein, proc | germplasm characterization, collection, (FAO Reg. Trial), breed daylength. , C4 advantage | etnobotany, wide adapt. breed. resist. anthracnose, day neutral, coll/charact. | breeding sweet cvs., reduct. alkaloid content, early maturity-short days |

Table 7 Plant biotechnology applications for the conservation and use of genetic resources of quinoa (*Chenopodium quinoa*), amaranto o kiwicha (*Amaranthus caudatus*), popping beans -"nuñas" (*Phaseolus vulgaris*) and tarwi (*Lupinus mutabilis*)

| BIOTECH. APPLICATIONS | QUINUA | KIWICHA AMARANTH | NUÑA | TARWI LUPINE |
|----------------------------------|---------------------------------------|--|---------------|--------------------------------------|
| Tissue culture/ embryo rescue | ++ | ++ | + | +++ protoplast fussion |
| Molecular markers | + saponins seed color, male sterility | + seed size, Fe digest, oxalic acid | ++ phylogeny= | + alkaloids anthracnose |
| Genetic Engeneering | ++ genetic transformation | +++ transg.plants= Protein studies=amilase inhib. insect. resist | 0 | ++ plant regeneration transformation |

legend:+++=rutine ++=available +=starting 0=not available

Table 8 Potential market, adaptation, use, nutritional value, agronomic characteristics and research constraints of cherimoya (*Annona cherimola*), passion -fruit (*Passiflora* sp.) and goldenberry-”capuli” (*Physalis peruviana*)

| | CHERIMOYA | PASIFLORAS | UCHUBA/ CAPULI |
|--|--|--|--|
| POTENTIAL MARKET | very hight, export crop | very hight, export crop | export potential |
| PRODUCTION POTENTIAL and GEOGRAPH. ADAPTATION | *Queen of the Andes*, premium fruit, 100 sp., cash crop, wide adaptation, Spain, NZ, Aust, low land, high price in USA | 40 sp., Andean sp. Curuba=P.mollisima Puerto Rico, Brasil, NZ, Aust,N,Guinea,Haw | Andes, wide geogrph. adaptation, potential as cash crop, good prospects INDIA,NZ,S.Afica,Ken ya |
| USE | fresh, juice,icecream,yogurt, deserts | juice, fresh, jam | fresh, jam, sauces, deserts, raisins |
| NUTRITIONAL VALUE | thimine, riboflavine, niacine | Vit. C | Vit. A(3000 IU/100 gr) |
| PROPAGATION | budding/grafting tissue culture | seed, cuttings | seed, cuttings |
| YIELD (Ton/ Ha) | 9 - 11 | 30 | 3 - 33 |
| GROW. CYCLE (months) | perennial | | 100 days after planting |
| MAX. ALTITUDE (mosl) | 1500 - 2200 | 3400 | 2600 |
| RAINFALL (mm) | 1200 | - | 800 |
| LOW TEMP. oC | -2 | -5 | 10 |
| HIGHT TEMP. oC | 30 | - | 30 |
| DAYLENGHT | neutral | - | neutral |
| SOIL TYPE | wide range, Ca | wide range | wide range |
| CONSTRAINTS and RESEARCH NEEDS | fruits with market size, breeding cvs., disease resist., pollination, germplasm evaluation and collection, tissue culture | germplasm characterization, collection, (IICA network), GR conservation (species: P.mollisima, P. liguraris, P.antioquiensis, P. popenovii, P.pinnestistipula, P. maliformis | Postharvest, breeding of fruit quality(sweetness), genetic selection, pest/disease resis. |

Table 9 Plant biotechnology applications for the conservation and sustainable use of genetic resources of cherimoya (*Annona cherimola*), passion -fruit (*Passiflora* sp.) and goldenberry-"capuli" (*Physalis peruviana*)

| BIOTECH. APPLICATIONS | ANNONA CHERIMOYA | PASSIFLORAS | UCHUBA CAPULI |
|------------------------------|--|--|----------------------|
| Micropropagation | ++ | ++ Microprop. | +++ |
| Molecular markers | ++ | +++ gen.diversity | + |
| Isoenzymes | + | ++ | |
| Genetic Engeneering | ++ plant regeneration Postharvest/ethilene | +++ plant regeneration Virus resits. | ++ |

legend:+++=rutine ++=available +=starting 0=not available