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ECONOMIC BOTANY OF THE ADEAN TUBER CROP COMPLEX: LEPIDIUM MEYENII, OXALIS TUBEROSA, TROPEAOLUM TUBEROSUM AND ULLUCUS TUBEROSUS

King, Steven Row, Ph.D.

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by

STEVEN ROW KING

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Executive Officer

Dr. Michael J. Balick, NYBG

Dr. Dwight T. Kincaid, Lehman College-CUNY

Dr. Stanley N. Gershoff, Tufts University

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Abstract

ECONOMIC BOTANY OF THE ANDEAN TUBER CROP COMPLEX: LEPIDIUM MEYENII, OXALIS TUEBEROSA, TROPAEOLUM TUBEROSUM AND ULLUCUS TUBEROSUS

by

Steven Row King

Advisor: Dr. Ghillean T. Prance

The economic botany of four species of tuber crops endemic to South America is given. These species, Lepidium meyenii, Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus, are cultivated in the Andes mountains for food and medicine. These crops are discussed in the context of global food production, mountainous environments, crop genetic resources and Andean culture and diet. Basic data on the prehistory, reproductive biology, indigenous classification, distribution, agricultural cycle and utilization of each species are presented. The nutritional value and variability of these crops, including previously unreported essential amino acid values, are included and compared to other major crops. The known secondary compounds present in these species are discussed in relation to their medicinal uses, including new data on oxalic acid levels in Oxalis tuberosa. One of these crops, Oxalis tuberosa, is cultivated outside of the Andean range in Mexico and New Zealand. The distribution, diversity, cultivations systems and utilization of Oxalis tuberosa in Mexico are presented. Finally, global agricultural research priorities are examined in relation to the present and future conservation and utilization of Andean tuber crop germplasm.

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This work is dedicated to farmers of mountainous regions of the world and to the memory of Nikoli Vavilov.

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The Andean region of South America is one of the eight centers of origin of cultivated plants described by Vavilov (1951). There is also strong evidence that the southern Peruvian Andes is one of four areas in the world where the independent invention of agriculture took place (Hawkes, 1983). In the Andean region there are more then twenty endemic crops that have been and are currently important sources of nutrition to more then 9 million people living between 2500 to 4500 m. The potato and the tomato have been the subject of worldwide crop development and are now commonly grown throughout the world. There are, however, many other important food crops that were domesticated in the Andes but they are poorly known scientifically. The subject of this thesis considers is four of these crops, *Lepidium meyenii* Walp., *Oxalis tuberosa* Mol., *Tropaeolum tuberosum* R. & P. and *Ullucus tuberosus* Caldas and the environment in which they were domesticated.

Selection Of Species For Research

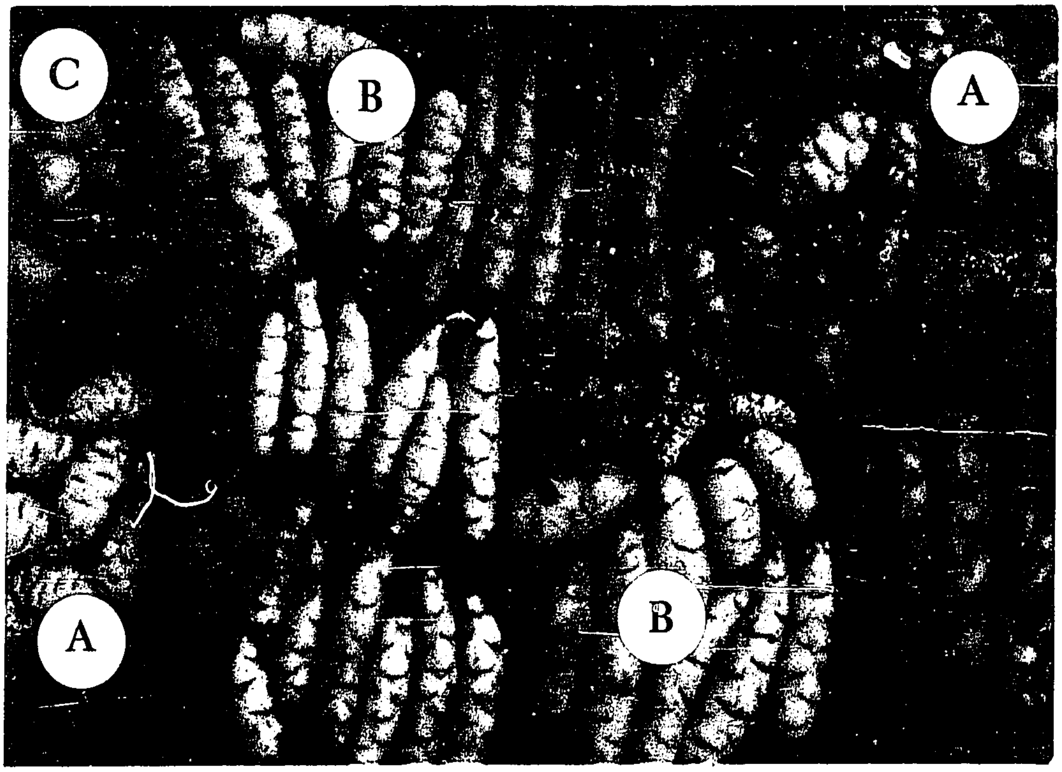
The first crop, *Lepidium meyenii* has been declared a cultigen in danger of extinction (IBPGR, 1982) and that, combined with its other unique crop characterisistics, is the rationale for including it in this research. *Lepidium meyenii*, in addition, contains specific secondary compounds also found in *Tropaeolum tuberosum* (Johns, 1981) which is discussed in Chapter 7.

Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus (Fig. 1) have been investigated as a group because they are related through Andean culture, morphology and ecogeographic distribution. These tubers are often grown together and if not, farmers will often grow some of each in separate fields. One other reason for examining these crops as a group is that published data on the crops is frequently inaccurate due to confusion caused by the morphological similarity of the tubers of Oxalis tuberosa and Tropaeolum tuberosum. With the exception of Lepidium meyenii, these crops are widespread in the Andean region, but several other roots and tubers are also cultivated in the Andes and some of them have been introduced to small scale growers in the United States and New Zealand.

International Research

In the past few years there has been an an emerging international research emphasis on little known crop genetic resources of the Andean region (King 1986; 1987; King & Gershoff, 1987; King & Vietmeyer, in press; Vietmeyer, 1985; 1986; 1987). In March, of 1984 the United States National Research Council (NRC) held a seminar on underexploited Andean crops. This meeting brought together the author and fifteen other researchers with expertise in Andean crops to discuss the future prospects for increasing the utilization and distribution of crop plants native to the Andean region. The Board on Science and Technology for International Development (BOSTID) of the National Academy of Sciences is now finishing a book on underexploited Andean crops.

Fig. 1. Morphological variation of three species of Andean tubers at one locality in La Paz, Bolivia. A. Tropaeolum tuberosum, B, Oxalis tuberosa, C, Ullucus tuberosus. Largest tuber is 170 mm x 25.0 mm


C
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B

The International Development Research Centre (IDRC) of Canada has also supported research on Andean crops through grants to individuals and most recently by providing support for the Fifth International Congress on Andean crops in Puno, Peru, in March 1986. The Instituto Interamericano de Ciencias Agrícolas (IICA) has also been supporting research on endemic Andean crops over the past 23 years (Fries & Tapia, 1986).

In 1971 several international donor agencies and the Food and Agriculture Organization of the United Nations (FAO) laid the groundwork for the creation of an organization to coordinate the activities of countries working to conserve crop plant genetic resources (Baum, 1986). As a result of these initiatives the International Board of Plant Genetic Resources (IBPGR) was created in 1974 and mandated to facilitate the collection, evaluation, preservation and distribution of crop plant germplasm (Pluncknett et al., 1983). The IBPGR is based in Rome at the FAO, and it is one of the 13 International Agricultural Research Centers (IARCs) that are supported by the Consultative Group On International Agricultural Research (CGIAR).

In April of 1982 the Junta del Acuerdo de Cartagena (JUNAC), the Board of the Andean Pact and IICA met in Lima, Peru, to assess the status and priorities of crop plant germplasm in the Andean region (IBPGR, 1982). Each country supplied a list of experts, holdings of collections, assessment of genetic erosion in crops, and conservation needs. All of the countries reported genetic erosion due primarily to the introduction of new and improved crops.

The group identified crops in which the situation was considered especially serious, and Andean tubers, as part of secondary Andean crop priorities, were designated as endangered crops. The priorities agreed upon by the member countries declared an emergency situation for Lepidium meyenii in Peru and the same for Oxalis tuberosa, Ullucus tuberosus and Tropaeolum tuberosum in Bolivia (IBPGR, 1982).

Crop Diversity and Global Food Supply

One of the aims of this research is to place these four minor Andean root and tuber crops within the context of world food production and the potential expansion of the global crop base. Presently 50% of the worlds calories derived from plants are obtained from three crops: wheat, rice and maize (Wilkes, 1983). The United States has tended toward utilizing fewer and fewer varieties, creating a narrow base of crop diversity and a high degree of genetic vulnerability (National Academy of Sciences, 1972). The effects of this crop vulnerability have been felt in the U. S. food production system. In 1970 the Southern Leaf Blight wiped out 15% of the hybrid corn in the America and cost farmers roughly one billion dollars in losses (Doyle, 1985). As Wilkes has pointed out, a similar crop failure in countries such as Guatemala or Kenya, where people derive half of their calories from corn, would be disastrous. However, in 1982, 40% of the United States potato crop was still planted to one variety, the Russet Burbank (Doyle, 1985). There are several economic and legislative reasons for this continued use of only a few "reliable" varieties but it is questionable as to whether the same trend should be advocated in lesser developed countries. This is especially true in regions where there is considerable genetic variation in endemic food crops and a high diversity of environments, as is the case in the Andes mountains.

Mountainous Environments

Worldwide it is estimated that as much as 10% of the population lives in mountainous regions and at least 30 million people live in the 3 million hectares of steeply sloping regions of the Andes, Central America and the Caribbean (Hawtin & Mateo, 1987). In Ecuador 20.5% of the rural population lives in the highlands, and the majority of these inhabitants are indigenous (Tola Cevallos et al., in press). In Peru 50% of the country is mountainous; 25% of the population lives there, and 21% of the nation's agricultural output is produced there (Mateo & Tapia, in press). In Bolivia, in 1970, it was estimated that 78% of the population live in mountainous environments, above 2500 m (Little, 1981a). Outside of the Andean region, large numbers of people live and farm in mountainous habitats.

In the Himalayas 85% of the population of Tibet live and produce food at elevations above 4000 m (Hong, in press). In 1986 the Himalayan kingdom of Nepal recorded a food deficit of 331,000 tons, and in Nepal 56% of the population live in mountainous regions that comprise 77% of the total area of the country (Bhattarai et al., in press). There are also mountainous regions in other countries of the

Hindu Kush-Himalayan region including Afganistan, Bangladesh, Bhutan, Burma, China, India and Pakistan. The total population of the Hindu Kush-Himalayan region has been estimated to be in excess of 125 million people (Maharjan et al., in press). There are also mountainous regions of Africa that are important areas of food production to significant numbers of people.

African mountainous environments (in this case land above 1500 m) are present in at least 20 different countries, and in these nations these environments are the main areas of habitation. Countries that have a high percentage of mountainous environments are Rwanda (84.4%); Burundi (45.8%); Ethiopia (40.1%); Reunion Islands (21.9%); Tanzania (20.2%) and Kenya (18.9%) (Getahun & Kirby, in press). In Ethiopia and Kenya 88% and 80% respectively of the population live in mountainous environments and similar to other mountainous regions, these areas are under great stress that has caused large outmigrations of population (Getahun & Kirby, in press). Mountainous ecosystems all over the world share several environmental limitations that affect human habitation and agriculture.

Mountainous environments are typified by extreme environmental conditions that have stimulated adaptive responses in humans, plants and animals. These conditions include: lower atmospheric pressure, low minumum temperatures; a large range of diurnal temperatures; low humidity, high winds; heavy seasonal rains followed by a dry season; poorly developed shallow soils that are prone to erosion; earthquakes; landslides and mud flow that produce rapid destructive changes; and high levels of cosmic and solar radiation (Little, 1981a).

The biological effects of high altitude on human beings in the Andean region have been the subject of multidisciplinary research (Baker & Little, 1976; Baker, 1978). One of the most predominant ecological characteristics of highland regions is the existence of micro-habitats that are the results of changes in altitude, slope, climate and orientation.

These micro-habitats have facilitated the evolution of a wide diversity of plant species and varieties, including plants selected for agriculture by humans. In the past two decades the large numbers of people living in demanding, fragile mountain ecosystems and the high diversity of crop plants that have been domesticated there have stimulated international development organizations to include mountain people and their resource base as part of their organizational priorities.

International research on mountain people and highland environments has been increasing over the past three decades for several reasons. The primary reason is that national governments, development organizations and scientists have realized the fragility of mountainous ecosytems. The technical understanding of the dynamics of highland areas is limited by a lack of thorough scientific data from many fields. In 1971 the first session of the international Co-ordinating council of the Man and the Biosphere programme (MAB) was held in Paris. At this meeting thirteen scientific projects were proposed and outlined, including Project 6, the impact of human activities on mountainous environments (Little et al., 1981).

The aims of project 6 were part of the now well known larger goals of the MAB programme (Unesco, 1973). The initial worldwide approach of studying mountain ecosystems evolved into a regional focus on the Andean zone that produced a state-of-knowledge report covering the entire Andean zone (Little, 1981b; Baker, 1982b and Johnson, 1982) The reports were produced with the involvement of specialists from six Andean countries. The findings of the reports are intended to illustrate problems and prospects that are applicable to other mountainous regions of the world. Several other international organizations are also now focusing on mountainous people and their environment.

In 1984 The International Centre for Integrated Mountain Research and Development (ICIMOD) began its activities in Kathmandu, Nepal. One of its first objectives was to review environmental management and development experiences in the Hindu-Kush-Himalaya region. In February of 1987 ICIMOD, the Nepali Ministry of Agriculture and the IDRC of Canada, sponsored a five day international workshop on Mountain Agriculture and Crop Genetic Resources (ICIMOD, 1987). Agricultural specialists from twenty mountainous countries in Latin America, Africa and Asia presented papers on mountainous crops and farming systems. A system was set up to facilitate the exchange of crops among these areas, and future scientific exchanges were planned. One of the financial sponsors of the workshop, the IDRC, has been supporting research and development aimed specifically at the problems facing mountainous regions of the world (Hawtin & Mateo, 1987).

The United States Agency for International Development (AID) has also recently created a program that is focusing on humid tropical lowlands and steep slopes in Latin America. The project, called the Fragile Lands Initiative, includes actions that are directed to immediate, medium, and long term objectives for addressing the problems of the deterioration of fragile lands in Latin America (Plunckett, 1987). One aspect of this program involves the creation of Development Strategies for Fragile Lands (DESFIL) project. The DESFIL group will conduct assessments of fragile land problems, develop strategies for addressing these problems, create data bases and research networks dealing with fragile lands issues and serve as the coordinating agency for long-term projects. The work of ICIMOD, IDRC and U. S. AID are only a few examples of research and development directed at mountainous environments.

Within the Andean region there has also been a re-emergence of interest in developing and promoting native Andean crop genetic resources. There are more then 20 crops that were domesticated in the mountainous regions of South America. The Conquistadores who invaded Peru in 1531 were primarily interested in minerals and other forms of transferrable wealth (Vietmeyer, 1986). With the exception of Solanum tuberosum, the potato, they paid little attention to the endemic crops that sustained Andean people. One of the lingering results of this attitude is that many residents of cities such as Bogotá, Quito and Lima know little or nothing of the nutritious, regionally adapted crops that sustained the numerous advanced civilizations of the Andes.

Because of this lack of interest, these crops have become stigmatized as "peasant or Indian food" and until recently most urban nutrition programs did not include these crops in their educational material on healthy diets.

Much has been published by Andean researchers on the these roots and tubers: (Blanco, 1977; Cárdenas, 1948; 1958; Cortés, 1977, Castillo, 1984; Leon, 1958; Nieto, et al., 1983; 1984; Rea, 1982; 1984b; 1985; Tapia, 1984 and numerous unpublished Andean thesis projects), but this information rarely finds its way into the international literature. There is one other group of Andean experts that has been working with these crops for several thousand years, the farmers themselves. The crops under investigation in this research are the products (coevolutionary products, sensu Johns, 1985) of human and plant interactions over centuries (Rindos, 1980).

The cummulative expertise that farmers possess about traditional cultigens is part of what has been termed indigenous agricultural knowledge (Richards, 1985). It has also been pointed out that agricultural research on traditional cultigens often does not attempt to integrate the knowledge of the farmers into crop improvement programs (Chambers, 1983; Pacey & Payne, 1985). Recent research in several geographic areas indicates that traditional peoples utilize and manage both wild and cultivated plants with sophisticated environmental knowledge.

Indigenous Agricultural knowledge

Research by Balée (1986), using a combination of botanical forest inventory techniques and anthropological interview methods in the Brazilian Amazon, demonstrated that the Araweté people utilize 82% of the trees collected in the inventory site. Each of the trees used has specific names in the Araweté language, and the useful characteristics of each species is common knowledge among the group.

Related research with the Kayapó Indians of Brazil by an anthroplogist and ecologist revealed that these indigenous people not only classify and use the resources of wild habitats, but they also actively manage savanna habitats (Posey, 1983; 1984; Anderson & Posey, 1985). These researchers demonstrate that the Kayapó actively create and manage "islands" of woody vegetation, using organic matter from termite nests. These islands of vegetation are protected during annual burning and provide a constant source of plant and animal resources for nearby villages. Research with cultivars of Manihot esculenta and the Aguaruna Indians of the Peruvian Amazon has shown that native people select and maintain a high diversity of varieties of this important tropical staple (Boster, 1985). Field studies with non-tribal mestizo populations in Amazonian ecosystems are also revealing sophisticated agroforestry systems utilizing annual, semi perenial and perennial crops that are consumed as well as sold for cash (Padoch et al., 1985). Investigations with Andean farmers have documented similar examples of human and plant interactions in mountainous ecosystems.

The indigenous agricultural knowledge of Andean farmers has been documented by several researchers. The Aymara Indians of Peru and Bolivia use clay to detoxify water-insoluble glycoalcaloids of bitter potato varieties (Johns, 1986a), and this may have been an important component of the domestication of the *Solanum* X *ajanhuiri* potato complex (Johns, 1985). Johns & Keen (1985) and Huamán (1975) observed that Aymara Indians utilize taste to evaluate their crops. The morphological and chemical variation of traditional potato cultivars is high. Researchers have documented as many as 32 *Solanum tuberosum* cultivars in one Peruvian field (Brush *et al*., 1981). Brush showed that the varieties recognized were distinct cultivars because tubers with distinct names from the same locality were morphologically similar and electrophoretically nearly identical at a high rate. In addition, the use of traditional agricultural management of a potato field in Peru produced yields as large as any of Peru's improved large scale agricultural operation (Valladolid *et al*., 1984). The above research suggests that tuber domesticates reflect the nutritional characteristics of high altitude ecosystems and that tubers selected by humans are the result of cultural and biological adaptations to the Andes.

Summary

Mountainous habitats provide a subsistence base to people all over the world, and they impose distinct environmental challenges to both plants and people. The diversity of crop plants upon which the earth's population depends is dangerously narrow; and crops selected in the Andean zone have great potential for utilization in other areas of the world. Several international research and development organizations are currently placing emphasis on mountainous people, crops and environments. International agricultural research directed towards Andean crops has been increasing over the past three decades. Andean farmers themselves are increasingly being recognized as agricultural experts that posses centuries of cumulative indigenous agricultural knowledge. More basic and applied research should be conducted to facilitate the preservation and improvement of many of these genetic resources.

This thesis was undertaken to answer basic research questions about these crops. These questions and the investigative approaches and methodology employed are outlined below.

General Research Questions and Goals

1) What is the distribution, agricultural cycle, method of utilization, vernacular names, specific cultivar names and current importance of these crops in the Andean region.

2) What is the variability of the biological food value of four Andean crops, and the importance of these crops in the diet of Andean people.

3) What is the status of the diversity of the germplasm of these crops and to what extent has any of these four crops been accepted outside the Andean zone.

4) How and where might these crops be distributed and utilized in other areas of the world.

Investigative Approaches and Methodology

1) The cultivation and utilization of four crops was examined in sixteen distinct localities in four countries in Central and South America. In each country multiple methods were utilized to obtain data. This included direct participation in and observation of the process of cultivation, and harvest. I interviewed men and women in the fields and in the household where the crops were prepared and stored. Market vendors were also important as sources of both tuber material and information about price, distribution and relative regional importance of the crops.

2) I examined the nutritional composition of these four species from nine of the above mentioned research localities. The analysis included proximate, essential amino acid and levels of oxalic acid. In order to test the effects of traditional, long term preservation on these crops, the material used was both fresh and several years old.

3) I studied the cultivation methods and cultural variation of the these methods in numerous regions. The research was conducted in the field with specialists from many disciplines including, Quechua speaking anthropologists, agronomists, taxonomists, ethnobotanists and economic botanists.

4) I worked with agronomists from the Andes, Nepal and New York in order to facilitate the exchange of knowledge and contacts between scientists in Andean countries, North America, Europe Africa and Asia. Experimental crop germplasm was distributed to scientists in the Old and New world.

Chapter 2 - Related Species of Endemic Andean Crops

In this investigation, four species (Lepidium meyenii, Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus) are discussed but there are several other endemic Andean roots, tubers, grains and legumes presented in Table I which are not discussed. Several Andean crop specialists from Latin America, North America and Europe have suggested that other Andean root and tuber crops be included in this research. The reasons for including these four crops were outlined above. Basic data on several other Andean crops are included as no discussion of endemic Andean crops would be complete without some information on these crops. The recent history of Andean crop research activities is then presented to place these crops in the context of the Andean crop research network.

Below Arracacia xanthorrhiza Bancr., Canna edulis Ker-Gawl, Polymnia sonchifolia Poepp. & Endl., Mirabilis expansa R. & P., and Pachyrhizus ajipa (Wedd.) Parodi are briefly discussed. One of the other widely cultivated root crops is Arracacia xanthorrhiza "arracacha," a member of the Umbelliferae family. Arracacia xanthorrhiza is a perennial crop that produces thick starchy roots. It is usually vegetatively propagated; and it is a common house garden crop from Venezuela to Bolivia at elevations of 1500-2500 m. Its cultivation was spread to Southern Brazil by Andean scientists in the late 1960's, where it was succesfully introduced (NAS, 1975; Rea, 1984a).

Table I

Selected Species of The Andean Crop Complex

Species	Common Name
Roots and Tubers	
Arracaia xanthorrhiza	arracacha
Canna edulis	achira
Mirabilis expansa	mauka
Pachyrhizus ajipa	ajipa
Polymnia sonchifolia	yacon
Grains	
Chenopodium pallidicaule	kañiwa
Chenopodium quinona	quinoa
Amaranthus caudatus	kiwicha
Legumes	
Lupinus mutabilis	tarwi
Phaseolus vulgaris var.	nunas

The area of greatest diversity and center of origin of Arracacia xanthorrhiza is reputed to be the Sibundoy valley of Colombia (Hodge, 1954). Several researchers have published information on Arracacia xanthorriza (Higiuta, 1968; 1969; Leon & Rea, 1967; Rea, 1984a; Sánchez, 1971). Arracacia xanthorriza was unsuccessfully introduced to Europe in the mid-19th century, as a potential replacement for the potato which had been devastated by Phytophthora infestans (Palmer, 1982). It was also recently introduced to New Zealand, thus far without success. The agricultural characteristics and potential of A. xanthorriza have been outlined (National Academy of Sciences, 1975; King & Vietmeyer in press).

There are germplasm collections of Arracacia xanthorrhiza in Colombia (12) Ecuador (74) Peru (44) Bolivia (2) and Brazil (16), (Piedrabuena & Esquinas-Alcazar, 1983; Rea, 1984a). The collections in Ecuador and Peru contain accessions from Colombia, Ecuador, Peru and Bolvia. Arracacia xanthorrhiza was one of several crops that was used in Andean cities of Peru and Bolivia to ease the potato shortage from 1981-1984 (Rea, 1984a). This is a crop that merits much greater emphasis from the international research community.

Canna edulis, "achira", a member of the Cannaceae family, is a perennial monocot that produces fleshy rhizomes which have been referred to as corms or tubers. It is best known for the related ornamental species that are cosmopolitan in distribution. In the case of Canna edulis the domestication process began more then 5000 years BP; remains of Canna edulis found at Huaca Prieta de Chicama in Peru have been dated to 4,487 BP (Bird, 1948). It is propagated vegetatively by planting terminal portions of the rhizomes. Harvest takes place in the Andean region 8-10 months after planting. Yields of 4 to 5 tons per hectare have been recorded. Currently Canna edulis is cultivated below 3000 m in the Caribbean, the Andes, Brazil, Hawaii, and in several countries in Southeast Asia. Its use in the Andean region is not widespread but it is likely to have been a more common cultigen prior to the Spanish conquest (Gade, 1966).

Canna edulis produces one of the largest starch grains of any plant and the rhizome is roughly 25 % starch (King and Vietmeyer, in press). In the Andean region the rhizomes are most commonly baked and in one village in Southern Peru in the Apurimac valley Canna edulis production, preparation and vending are the main sources of cash income (Gade, 1966). Outside of the Andean region Canna edulis is utilized by industry for its starch, and the rhizomes and leaves are used as feed for livestock.

Further data on Andean Canna edulis is available from Herrera (1940); Montaldo, (1977) and from Dr. T. Koyama of the New York Botanical Garden. No Andean country has reported the collection or maintenance of germplasm of Canna edulis, a reflection of the status of the crop in the region.

One of the least investigated Andean root crops is Mirabilis expansa. Mirabilis expansa "Mauka," a member of the Nyctaginaceae family, is an herbaceous perennial that is cultivated for its edible underground stems and roots. There is very little known about this endemic Andean root crop. It is propagated both by seed and vegetatively with harvests occurring 10-12 months after planting. Mirabilis expansa is only reported to be utilized as a minor crop in Ecuador, Bolivia and more recently in Peru, between elevations of 2500-3200 m (Rea, 1982).

Mirabilis expansa is prepared in several ways, and it may contain compounds that can produce an unpleasant effect on the lips and tongue (Rea & Leon, 1965). In Bolivia the roots and stems are placed in the sun for up to a week to "sweeten them" and to diminish the astringent compounds referred to above (Rea, 1982). They are then cooked with honey, or raw sugar (chancaca), and the liquid in which they were cooked is taken as a beverage. In Ecuador they are prepared in two ways, one method involves peeling and boiling freshly harvested stems and roots with salt (INIAP-CIRF, 1985). The other method requires burying the stems and roots in freshly dug holes and covering them with barley chaff and the aerial portion of Mirabilis expansa for one week. This latter process "concentrates the sugars" (Rea, 1982). The nutritional value has been reported as follows by Rea and Leon (1965) as follows: Dry weight, protein 6.58%, carbohdrate 86.9%, ash 4.20%, fibre 1.25% and fat .72%..

At this time there are only three germplasm collections of Mirabilis expansa "Miso" or "Tazo" in Ecuador (Tola Cevalos et al., in press). Researchers in Ecuador have reported that germplasm collection teams only encountered Mirabilis expansa under cultivation in two localities and that the cultigen is in danger of extinction (INIAP-CIRF, 1985) A similar situation exists in Bolivia where the collection priority for this crop has been listed as an emergency situation (Rea, 1985). Immediate research attention for Mirabilis expansa is necessary if this poorly studied food resource is to be examined for its potential in the Andes and in other mountainous regions.

Another Andean crop with good potential is Pachyrizus ajipa. Pachyrhizus ajipa "ajipa," is a member of the Leguminosae family, that is cultivated for its edible tuber. It is propagated by seed and vegetatively using small tubers. Pachyrhizus ajipa is related to the more cosmopolitan culitigen P. erosus "jicama" or "Yam Bean" which is reported to be endemic to Mexico and Central America (Towle, 1961). P. erosus is sold in markets of the United States, France, Germany, China, India and the Philipines.

Pachryhizus ajipa is reputed to be endemic to the eastern slopes of the Andes. Archaeological remains of roots of Pachyrhizus ajipa have been identified from pre-Inka sites at Paracas (Yacovleff & Herrera, 1934; Towle, 1952) and entire plants of Pachyrhizus ajipa have been cited as depicted in the art of Nazca and Paracas cultures (Yacovleff & Herrera, 1934; O'Neal & Whitaker, 1947).

Pachyrhizus ajipa is cultivated from sea level to 2000 m in the Andean region. Gade (1975) has reported its cultivation by the Machiguenga Indians of Peru but he did not encounter it in his study of the Vilcanota valley of Peru. There appears to be little interest in Andean countries in preserving and developing germplasm of Pachyrhizus ajipa. As of 1983 no Andean country reported collections of P. ajipa in their germplasm banks (Piedrabuena & Esquinas-Alcazar, 1983). The widespread use of the more well known Pachyrhizus erosus suggests that more collection and research are needed in order to investigate the agricultural potential of Pachyrhizus ajipa.

The final Andean tuber crop discussed in this section is Polymnia sonchifolia. Polymnia sonchifolia "yacon", a member of the Asteraceae, is a herbaceous perenial that produces numerous ellipsoid or cylindrical tubers. The tubers are eaten as a vegetable and may be cooked or eaten raw. Polymnia sonchifolia tubers contain inulin; and they may be useful as part of the diet of people suffering from diabetes. The main stem is eaten as a vegetable, and the dried leaves, which have a protein content of approximately 11-17 percent, are used as animal feed. Polymnia sonchifolia is propagated vegetatively from stems and matures 6-8 months after planting. In the Andes it is cultivated from Venezuela to Argentina at elevations of 900-2800 m with yields of up to 38 tons per hectare (Leon, 1964a).

Polymnia sonchifolia has been recently introduced on an experimental scale to both North America and New Zealand. In the United States it is cultivated in New Mexico, California and Oregon

(W. Bakker pers. comm.). In New Zealand it is cutlivated in the regions of Auckland and Christchurch and grows with little difficulty (W. Sykes, pers. comm).

Ecuador is the only Andean country that is maintaining germplasm collections of Polymnia sonchifolia. In Santa Catalina, Ecuador the Instituto Nacional de Investigaciones Agropecuarias is working with 25 germplasm collections from several departments (Tola Cevallos et al., in press). Ecuadorian researchers have reported that cultivation of Polymnia sonchifolia is disappearing and that only isolated individual plants were encountered during collecting trips (INIAP-CIRF, 1985). It is unusual that no other Andean country has reported germplasm collections of Polymnia sonchifolia because it is cultivated in Colombia, Peru and Bolivia. A low frequency of cultivation may partially explain this lack of preservation. There has been very little research,- agronomic, botanical, or nutritional,- on Polymnia sonchifolia, and much remains to be investigated. Further studies should be carried out in several countries so that existing diversity of this endemic Andean root crop is not lost.

Related High Protein Crops

Prior to discussing Lepidium meyenii, Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus, a few of the other important Andean crops and the evolution of the Andean research network are briefly discussed. This information is included to place the root and tuber crops under study within the context of the Andean crop complex as it contributes to the nutritional needs of highland people.

From the 1920's to 1950's only a few articles were published on native Andean crops. Most of these focused on Chenopodium quinoa Willd. "quinoa" and C. pallidicaule Aellen "kañiwa" (Fries & Tapia, 1986). Chenopodium quinoa is a highly nutritious pseudo-cereal that is cultivated at elevations of up to 4000 m. The achenes of quinoa contain between 12-19 percent protein with an excellent balance of amino acids, including lysine and methionine, which are often the limiting amino acids in highland Andean diets (Tapia, 1979). Quinoa also contains saponins that must be removed before consumption, and the traditional method in the Andes has been to simply wash the achenes several times.

In addition to quinoa another pseudo-cereal Amaranthus caudatus "kiwicha," is considered endemic to the Andean region. The seeds contain between 12 and 16% protein with very high levels of lysine, an essential amino acid that is present in insufficient quantities in major cereals such as wheat and maize (Seaft, 1980). A third, highly nutritious food are seeds of the legume Lupinus mutabilis Sweet "tarwi" is cultivated to elevations of 4,000 m. Tarwi contains between 30-48% protein and 14-25% oil, suitable for cooking. The balance of essential amino acids is not as good as the pseudo-cereals quinoa or kiwicha and tarwi also contains quinoline alkaloids that must be removed before consumption (Engelmann et al., 1983).

History of The Andean Crop Research Network

There has been a synergism of national and international research interplay focusing on the above mentioned pseudo-cereals, legumes and roots and tubers of the Andean region. In 1963 IICA published a work by León (1964a) on food crops of the Andean region, and in 1968 the first international convention on Chenopodium quinoa and C. palliducaule was held in Puno, Peru. In 1976, IICA helped organize the second international conference on Chenopodium quinoa and C. palliducaule which was held in Potosí, Bolivia. Because of the growing number of Andean scientists working on these and other Andean crops, it was decided that an international congress would be held every two or three years and that the crops to be included would be expanded to Andean crops in general. By this time the IBPGR had contributed support to build germplasm facilities, and IICA was providing resources for research on Andean crops in Colombia, Ecuador, Peru, Bolivia, Chile and Argentina.

In 1977 the third international congress on Andean crops was held in Ayacucho, Peru; and in 1979 a major collaborative work was published on quinoa and kañiwa (Tapia, 1979). By 1980, 1200 accessions of Chenopodium quinoa had been collected and agro-industrial machinery was being developed for harvesting and processing quinoa (Fries and Tapia, 1986). From 1980 to 1985 the Peruvian university system became extremely active with Andean crops and agricultural systems. Peru's Program Nacional de Sistemas Andinos de Producción Agropecuarios (PISCA), with support from the national government, IICA and IDRC, involved researchers from universities in Huancayo, Ayacucho, Cuzco and Puno, all working on Chenopodium quinoa, Amaranthus caudatus, Lupinus mutabilis, Lepidium meyenii, Oxalis tuberosa, Tropaeolum tuberosum, Ullucus tuberosus and other major crops. More then fifty agronomic research projects were funded and the selection and improvement of Chenopodium quinoa was undertaken.

At the same time, research on these crops was supported and conducted by several private and government organizations in North America and Europe. The Rodale Research Center held its First Amaranth Seminar in 1977, which was followed by subsequent international seminars and numerous publications (Rodale Press Inc., 1980). The United States government also become involved with Amaranthus research at an international level. The United States National Research Council published a study on future prospects for the international development of both grain and leaf amaranths (National Research Council, 1984).

The Board on Science and Technology for International Development (BOSTID) and U. S. AID awarded research grants to Peru, Mexico, Nepal, India, Thailand and other countries to develop Amaranthus as a high quality regional food source. The German government and the Food and Agriculture organization of the United Nations were also working with Andean nutritionists and agronomists to discover reduced alkaloid varieties of Lupinus mutabilis and methods for introducing its consumption to a wider national audience (Gross, 1982).

In 1981 in the United States, Sierra Blanca Associates, a private non-profit organization, was founded in Boulder, Colorado, with an emphasis on research and development of Chenopodium quinoa in both North and South America. Since that time, farmers and non-profit organizations in Colorado and New Mexico have been conducting research with some 47 varieties of Chenopodium quinoa (Boletín de Cultivos Andinos, 1984). The Colorado State University new crops agronomist has also been collaborating with this organization on Chenopodium quinoa research. As part of the international program of Sierra Blanca Associates, seeds of Chenopodium quinoa have been distributed to agronomists in China, Tibet and most recently to researchers from nine mountainous countries in Africa and the Hindu Kush-Himalaya.

In Ecuador, Peru and Bolivia, Lepidium meyenii, Oxalis tuberosa, Tropaeolum tuberosum, Ullucus tuberosus and the other crops described above are increasingly being viewed as important national resources. The president of Peru, Alan García has been encouraging farmers to plant more of the nutritious endemic Andean grains and tubers and he has supported urban nutrition education programs that are teaching people how to prepare and eat Chenopodium quinoa and other crops. In Peru this is part of a drive to increase the countries food self-sufficiency, an important goal since Peru imported 400 million dollars worth of food in 1986 (Rogers, 1987). In Ecuador, urban nutrition education programs are also being offered in Quito and other cities. The intention is, as in Peru, to re-introduce people to the nutritious crops that have been produced in the region for centuries.

Conclusion

The domestication of crop plants in Andean South America has produced numerous food plants that are well adapted to mountainous environments. These crops have supported highland people historically and continue to do so today. There is a growing network of scientist working on preserving and expanding the utilization of these crops both within and outside the Andean region. A few of these crops, such as *Lepidium meyenii* and *Mirabilis expansa* are poorly known and are in danger of extinction. This chapter places *Lepidium meyenii*, *Oxalis tuberosa*, *Tropaeolum tuberosum* and *Ullucus tuberosus* within the context of the other important endemic Andean crops. These crops, as a group, represent a rich agricultural heritage that merits intensified basic and applied research on the biological and agricultural characteristics of these species.

Chapter 3 - The Four Species

Prehistory

Botanical remains from Andean and Coastal Peruvian desert sites have usually been identified on the basis of external morphology (Martins, 1976). In most cases the identification has relied upon the remains of seeds, fruits and, in addition ceramic depictions of plants. In the case of the four species in this study, identification has been problematic. The remains of the vegetatively propagated crops *Oxalis tuberosa*, *Tropaeolum tuberosum* and *Ullucus tuberosus* occur in sites only as fragments of tubers which are morphologically very similar to each other and difficult to identify (Martins, 1976). In addition, as pointed out by Smith (1980), taxonomists rarely collect good specimens of underground parts of plants which compounds the difficulty of reliable determinations. *Lepidium meyenii* is propagated by seed, but it does not appear to have been a widespread or frequent crop in the Andes, as in the case of the other three species.

The difficulty of identifying archaeological remains of root and tuber crops has caused some disagreement as to the earliest period of domestication. There is, however, no doubt as to the importance of root and tuber crops in the cultural and agricultural evolution of Andean civilizations.

Sources for dating the presence and importance of Andean tubers include illustrations on wooden vessels (keros), ceramic urns and sculptures. Images of Oxalis tuberosa and Ullucus tuberosus have been documented on keros from the early post-Conquest era in Southern Peru (Vargas, 1981). A "pacheco" urn dated to 950 BP from the Central Peruvian highlands is decorated with paintings of Oxalis tuberosa, Solanum tuberosum, Tropaeolum tuberosum and Ullucus tuberosus (Yacovleff & Herrera, 1934; Sperling, 1987).

Botanical material from several coastal Peruvian archeaological sites was examined by Martins (1976) and compared with fresh and dried material of contemporary Andean crops. Martins identified starch grains, vessels and xylem elements of Oxalis tuberosa, Tropaeolum tuberosum, Ullucus tuberosus and six other crops. She found evidence of Oxalis tuberosa in the area of Ancón-Chillón at the Punta Grande site dating to ± 4000 to 3800 BP. A similar date, ca. 4250 BP is also recorded for Ullucus tuberosus and a sample of Solanum tuberosum is cited with an approximate date of 8,000 BP. Martins states that no evidence of Lepidium meyenii was found in the coastal ethnobotanical material that she studied.

It is important to note that the remains of these plants were transported to the coast from the highland region and were preserved in the dry coastal desert. These species, with the possible exception of wild Solanum species, do not grow in the ecological conditions of low altitude, high temperature and low moisture.

That these highland tubers were transported to the coastal region is not unusual as the movement of food, fiber, drugs and objects of ritual importance have been discovered far from their source of origin in archaeological sites throughout Ecuador, Peru and Bolivia. The simultaneous utilization, and at times control of diverse, geographically isolated Andean ecosystems has been described as a "vertical archipelago" by Murra (1972, 1987). Research by contemporary Andean ethnographers has documented that Murra's ethnohistorical description of communities utilizing multiple ecological zones for subsistence is still a common feature of Quechua communities. In the village of Uchucmarca, in northeastern Peru, Brush (1976) determined that land used by the community ranges from 800 to 4300 m. This altitudinal range covers 3500 m and provides for the cultivation of crops that have distinct environmental adaptations. I observed a similar land use pattern in Chinchero, Peru where the Quechua inhabitants utilize land from 2800 to ca 4300 m.

Research at Guitarrero Cave in the Callejón de Huaylas in Peru has provided archeobotanical material from an Andean site at 2500 m. The diet of the inhabitants of this site has been partially reconstructed by Smith (1980) and dates associated with tentative species identification have been presented. Smith indicated that during the earliest level of occupation, (complex IIa, 10600-7600 BP) the carbohydrate portion of the diet may well have been largely provided by rhizomes or tubers and that rhizomes of _Oxalis_ spp. are most clearly identifiable. He also suggested that remains of what may well be _Ullucus_ _tuberosus_ were present in complex II level.

Smith also provided a figure of tubers from complex IV (2500-1500 BP) and suggests that they might be Ullucus tuberosus. However even though their morphology strongly suggest Oxalis tuberosa or a related wild species. He also provides a figure of another tuber from complex IIe (10600-7600 BP) and suggests that the tubers resemble Oxalis tuberosa from the market, which, to this author they do not. The form of these tubers are not distinguishable as Oxalis tuberosa and could easily be Ullucus tuberosus or Tropaeolum tuberosum. In addition Smith indicates that his material classified as type B and C may be a species of Oxalis from as early as complex IIa.

It is important to note also that no mention is made of remains of Tropaeolum tuberosum from the Guitarrero Cave site. One scientist reports the necessity of growing out a specimen of Tropaeolum tuberosum to determine whether it was Oxalis tuberosa or Tropaeolum tuberosum (Hodge, 1946). Because the fresh tubers of Oxalis tuberosa and Tropaeolum tuberosum are difficult for plant scientists to distinguish it would be difficult for an archeobotanist to distinguish one species from the other on the basis of external morphology.

The tuber material from Guitarrero cave, if positively identified to species as Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosa, could aid in determining the earliest period in which these plants were domesticated. In order to draw tentative conclusions regarding the domestication of these tubers it will be necessary to be able to distinguish wild species from domesticated tuber remains.

The distinction between domesticated and wild in archaeological remains has proven to be problematic in the case of Zea mays and Manihot esculenta. Smith suggests that in order to determine the wild or cultivated status of the tubers at the site we need to know as precisely as possible the geographical distribution of the wild relatives of these species. This question is discussed below and is a critical issue in understanding the process of domestication of these species.

One other highland archaelogical site Tres Ventanas at 3925 m has yielded archeobotanical material of Solanum sp. (potato) and Ullucus tuberosus reputed to be from a time period 10,000 years BP (Engel, 1970). This dating of Ullucus tuberosus is the oldest report of any of the four species included in the present investigation. It my opinion that as more sites are investigated and as dating techniques become more sophisticated we will learn that the domestication of Oxalis tuberosa, Tropaeolum tuberosum, Ullucus tuberosus and perhaps Lepidium meyenii took place in the same time frame as the domestication of Solanum tuberosum.

General Morphology of Lepidium meyenii

The morphology of Lepidium meyenii (Fig. 1) is described below and it has also been described by León (1964). Lepidium meyenii is a small low

Fig. 2. Lepidium meyenii "maca" in Nincaca, Peru. Cultivated at 4100 m. This plant was harvested and replanted to produce seed. 35.5 mm in diameter.

matlike rosette forming perennial herb cultivated as an annual with an enlarged taproot-like hypocotyl. Leaves alternate, basal, crowded on a very short rarely branched stem, pinnate to pinnatifid, glabrous, bluegreen. Flowers regular, borne on short pedicels in open racemes. Sepals four, shorter than petals, white to cream. Petals, four, cruciform, sessile, clawed, spreading, white to cream yellow. Stamens four, erect, shorter than style. Ovary flattened, style simple. Fruits a compressed silicle.

Producing at and below the soil surface an enlarged bulbous hypocotyle (not a true tuber) often mistaken for a taproot. Hypocotyl color; cream, brown to dark purple.

Chromosome Numbers

I found no report of the chromosome number of Lepidium meyenii in the literature.

Taxonomic Classification

The classification of minor crop plants is often poorly understood for several reasons. One of these is the lack of herbarium specimens in major herbaria (Prance, 1987). Some major crops, such as Zea mays are well represented in specialized herbaria, including the edible part of the plant, and races of maize have been documented in numerous publications (Grobman et al., 1956; Brown, 1960). Research on biodiversity of tuberous Solanum species is also well developed, (Correll, 1962; International Potato Center, 1984) including documentation with herbarium specimens.

But these usually do not include the edible portion of the plant. Beacause tuber-bearing plants flower and form tubers at different periods of the growth cycle a voucher specimen of both the flower and the tuber often requires two visits to the collection locality. Systematic treatments of minor crops and their wild relatives are essential prerequisites to any programs aimed at improving the agricultural potential of little known crops.

Lepidium is a cosmopolitan and often weedy genus consisting of 150 species (willis, 1980). Lepidium meyenii walp. consists of three subspecies, L. meyenii subsp. meyenii, subsp. marginatum (Grisb.) Thell. and L. meyenii subsp. gelidium (Wedd.) thell. A further division of two forms of subsp. gelidium in Bolivia is reported by (Thellung, 1906) Lepidium meyenii subsp. gelidium forma rhombicum Thell. and forma rotundatum Thell. The most common is subsp. gelidium (Macbride, 1937).

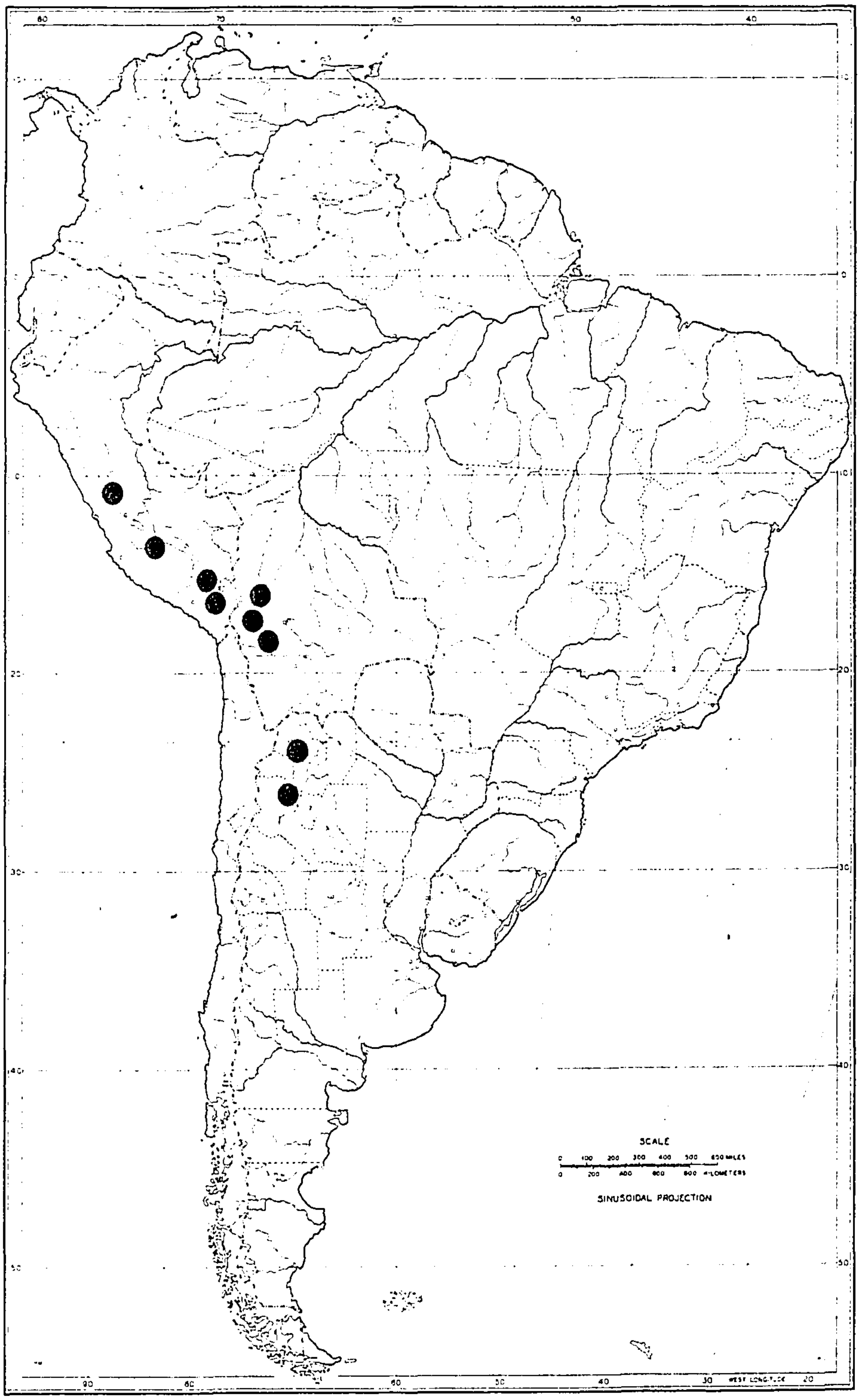
A taxonomic revision of this species was not undertaken but specimens examined from ECON, GH, NY contained no collections of cultivated Lepidium meyenii other than (Sperling & King 5338). The genus is in need of revision and the above listed subspecies were of wild Lepidium meyenii and forms should be viewed as provisional. All of the collections were of wild Lepidium meyenii from Peru, Bolivia and Argentina. The type specimen of Lepidium meyenii was a wild plant collected in Argentina (Meyen 13859); there are no reports of cultivated Lepidium meyenii in Argentina.

Wild Progenitors

The wild relatives of crop plants are extremely important genetic resources. Increasingly, the international agricultural community is recognizing the present and future potential value of wild species (Plucknett *et al*., 1987). The agricultural community also recognizes the important contribution that systematists make in global agricultural development by researching the evolutionary relationships between crops and their related wild species (Prance, 1987). The collecting emphasis of the IBPGR is also now shifting toward the collection and preservation of crop relatives (IBPGR, 1985). The tremendous potential of biotechnology to manipulate crop plants has also increased the value and importance of wild crop relatives (Pino & Strauss, 1987; Witt, 1985). In the case of *Lepidium meyenii*, *Oxalis tuberosa*, *Tropaeolum tuberosum* and *Ullucus tuberosus* the crops themselves are still in need of collection, to assess the diversity of these crops. The botanical understanding of the wild relatives of *Lepidium meyenii* and *Oxalis tuberosa* is incomplete. The status of the knowledge about the wild relatives is discussed below.

The distribution of wild *Lepidium meyenii* (Fig. 3) is in Peru, Bolivia and Argentina. Cultivated *Lepidium meyenii* is known only from a limited area of the Central Peruvian highlands.

Fig. 3. Distribution map of wild Lepidium meyenii.

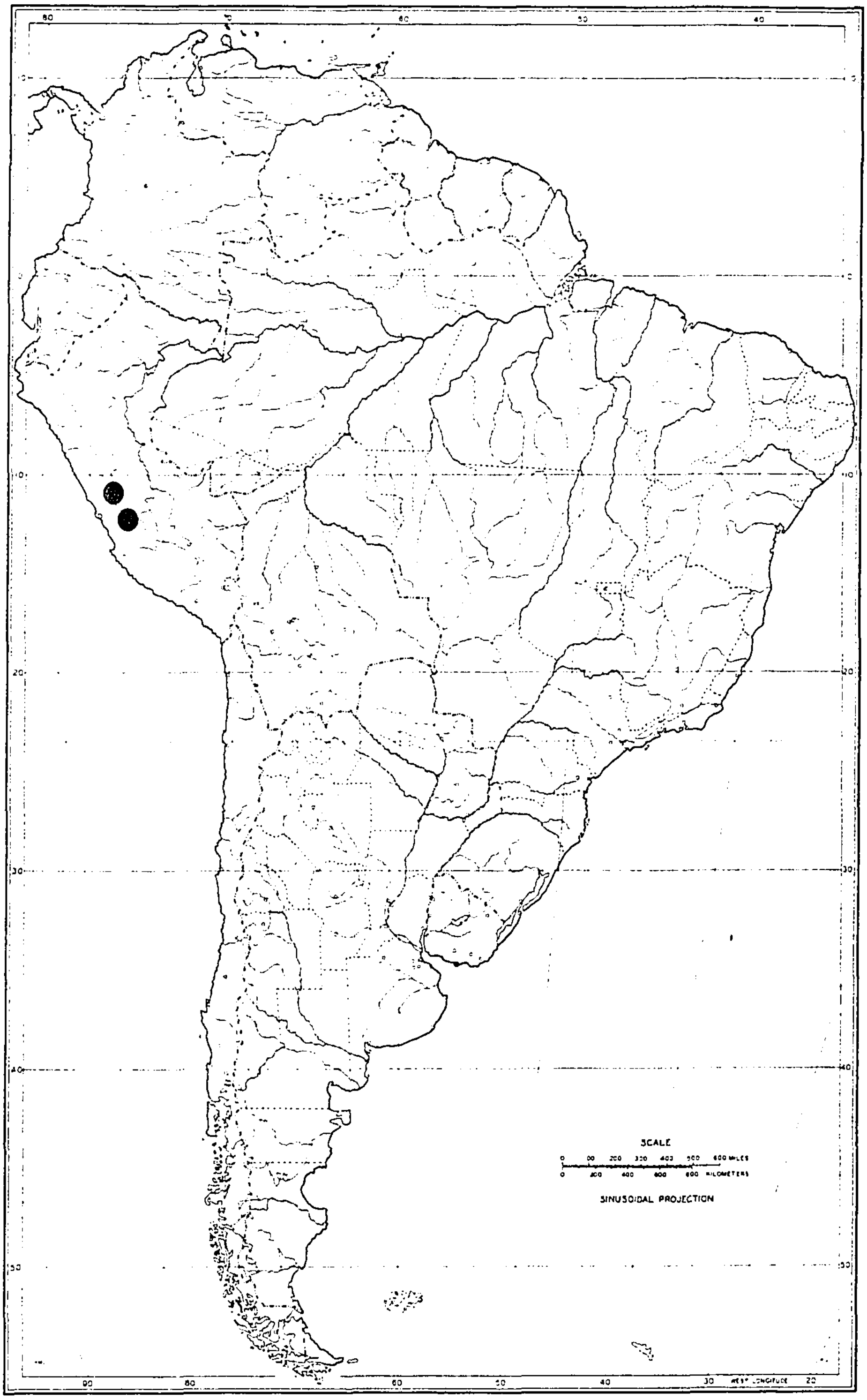

SCALE
SINUSOIDAL PROJECTION

Distribution and Ecogeograpic Limits

Cultived Lepidium meyenii is restricted to the departments of Pasco and Junín, (Fig. 4) in the Central Peruvian Highlands (León, 1964b). In the department of Junín Lepidium meyenii is cultivated on hillsides surrrounding Lake Junín. In 1981 the author encountered Lepidium meyenii being cultivated and sold in the same towns cited by León (1964b): Ninacaca, Carahuamayo and Haurye. Historically the cultivation of Lepidium meyenii in the region of Lake Junín was recorded by Vázquez de Espinosa (1948) in his "Visita" for the ruling Spanish government to Chinchacocha (Junín) in 1549. In the same document, Vázquez de Espinosa also referred to "300 cargas de media fanegada de maca" (300 loads of one-half of a grain measure of 120 kg of maca) that was paid in tribute to the regional Spanish "encomendaro". One fanega was equal to ca 120 kg (Beyersdorf & Blanco, 1984) so that the amount of Lepidium meyenii paid as tribute to the Spanish representative would have been roughly 18,000 kilos. This suggests that Lepidium meyenii was considered valuable and distributed to other individuals for use.

León (1964) also recorded the cultivation of Lepidium meyenii in the mountainous towns of Jarpa above the Mantaro Valley west of Huancayo. I did not survey this second area of reported cultivation. In Huarye, informants suggested that Lepidium meyenii was also cultivated in southern Peru in the region of Puno. García Díez de San Miguel also recorded Lepidium meyenii as cultivated and payed as tribute in Chuito, a town south of Puno near the Bolivian border (Matos Mendieta, N. D.).

Fig. 4. Distribution map of cultivated Lepidium meyenii.


SCALE
SINUSOIDAL PROJECTION

During the course of fieldwork in Puno in 1981, I questioned market vendors and farmers about the cultivation of Lepidium meyenii, using both the common name ("maca") and showing them samples of the dried edible hypocotyl. None of these vendors or other informants were familiar with either the plant or its common name.

One of the most important and distinguishing agricultural characteristics of the cultivated Lepidium meyenii is that it can be cultivated at altitudes where few crops can survive. Only two varieties of bitter potato, "Shiri" and "Mauna" can be grown in the Puna baja (sensu Mayer, 1979), which reaches a maximum altitude of 4500 m in the Mantaro Valley. Our informant in Ninacaca, indicated that Lepidium meyenii could be cultivated up to 5,000 m. I observed the plants cultivated at 4100 m in Ninacaca. The lowest observed altitude of wild Lepidium meyenii is 3500 m in Bolivia (Pennel 14215); and the highest record is 4500 m from Río Blanco, (Mabride 3022). The present low altitudinal limit of cultivation would have to be determined through further exploration.

The photoperiodicity of Lepidium meyenii has not been determined. The number of hours of daylight necessary for optimal growth and hypocotyl formation has not been established, although it is likely to be a short day plant, similar to the other species considered in this research. Experimentation with Lepidium meyenii in mountainous regions in North America, Europe, Africa and Asia needs to be carried out.

Vernacular Names

Because these four species are cultivated in nine countries and bear many different local names, they are referred to in this work by their scientific names. *Lepidium meyenii* is not presented in the tables because it is limited to one region of Peru where it is known as "maca" (Ruiz, 1952; Pulgar Vidal, 1946; Vásquez de Espinosa, 1948; Cobo; 1956; León, 1964).

General Morphology of *Oxalis tuberosa*

A description of *Oxalis tuberosa* (Fig. 5) is presented below. Morphological and anatomical studies of *Oxalis tuberosa* have been carried out by White (1975) and Obregozo (1956). Research on the relationship between the morphology of *Oxalis tuberosa* and productivity has also been carried out and published (Canales & Baldomero, 1977). The wide degree of morphological variation present in the tubers of *Oxalis tuberosa*, *Tropaeolum tuberosum*, and *Ullucus tuberosus* is discussed below.

Oxalis tuberosa is an erect spreading herb, with smooth slightly pubescent stem, white to reddish; perennial from annually produced tubers for which it is cultivated. Leaves are borne on spreading pedicels, trifoliate, each leaflet folded along the midrib, cleft at apex. Upper and lower surfaces with varying amounts of pubescence, darker green above than below. Flowers regular pedicellate, borne on axillary pedunculate

Fig. 5. Oxalis tuberosa "Oca". A, Flower and leaves, Puno, Peru. B, Plant aspect and immature tubers, soil removed to expose tuber formation. Chinchero, Peru 3800 m. C, Tuber variation from one market in Pasto, Colombia. Largest tuber 120 mm long.


A


C

cymes held above the foliage. Sepals five, free, yellowish; petals five united at base, spreading, yellow with red to purple venation (nectary guides), petal apex rounded. Stamens 10, in two fused whorles of five, inner whorl the longest, connivent about the style. Ovary five locular, elongate. Styles five, persistent, heterostylous, with two or three style morphs. Fruit an explosively dehiscent capsule, rarely observed, with few seeds.

Tubers produced on short axillary stolons formed on the below ground stem. Tubers elongate roughened with numerous nodes and triangular scale leaves. Tuber color varbiable from white, cream, yellow, orange, maroon, to red.

It is important to note that there is a high degree of intra-specific variation in Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus. The descriptions above give basic morphology without detailing the extent of the variation observed among the many cultivars.

Chromosome Numbers

Bolkhoskih et al. (1960) reported chromosome numbers for Oxalis tuberosa as 2n = 60, 63-64 and 68-70. De Azuke and Martínez (1983) reported the chromosome numbers of 20 species of the genus Oxalis from Bolivia, Argentina, Paraguay and Brazil as 2n= 10, 12, 14, 24 and 36 Oxalis tuberosa, is then, as pointed out by White (1975), a high polyploid and this is likely to be a key factor in the low fertility of this species.

Taxonomic Classification

Oxalis is a genus of 800 species, mostly in the New World and Africa. Several botanists have described tuber bearing plants of the genus Oxalis, including Oxalis crenata Jacq. from Peru, Oxalis carnosoa Mol. and Oxalis tuberosa Mol. from Chile and Peru (Bukasov, 1930). In Bolivia, Cardenas (1984) cultivated 100 tuber bearing Oxalis specimens from Mexico, Venezuela, Colombia, Ecuador, Peru, Bolivia and Chile and he determined that this collection represented only one species, Oxalis tuberosa. No work on the taxonomic classification of the Oxalis tuberosa complex has been conducted since the work of Cardenas. Alicia Lourteig of the Paris herbarium (P) is now in the process of preparing a much needed formal taxonomic revision and because this work is in progress it was not undertaken as part of this work.

Research on flavonoids (Del Pero Martínez & De Azuke, 1984), karyotype, nuclear volume, DNA content (De Azuke & Martínez, 1983), and micropropagation techniques (Ochatt & De Azuke, 1984) of numerous species of South American Oxalis are being conducted in Argentina at the Centro de Estudios Farmacológicos de Princípios Naturales (CEFAPRIN). One of the aims of this research is to identify which species are most closely related to Oxalis tuberosa.

Wild Relatives

Oxalis tuberosa is known only as a cultivated plant. The identity of the most closely related wild species is also not established.

Numerous species of the genus are eaten and used as medicine. One species in Mexico, Oxalis tetraphylla Cav., produces a bulb that is eaten but this bulb is morphologically distinct from the tubers produced by Oxalis tuberosa (King pers. obs.).

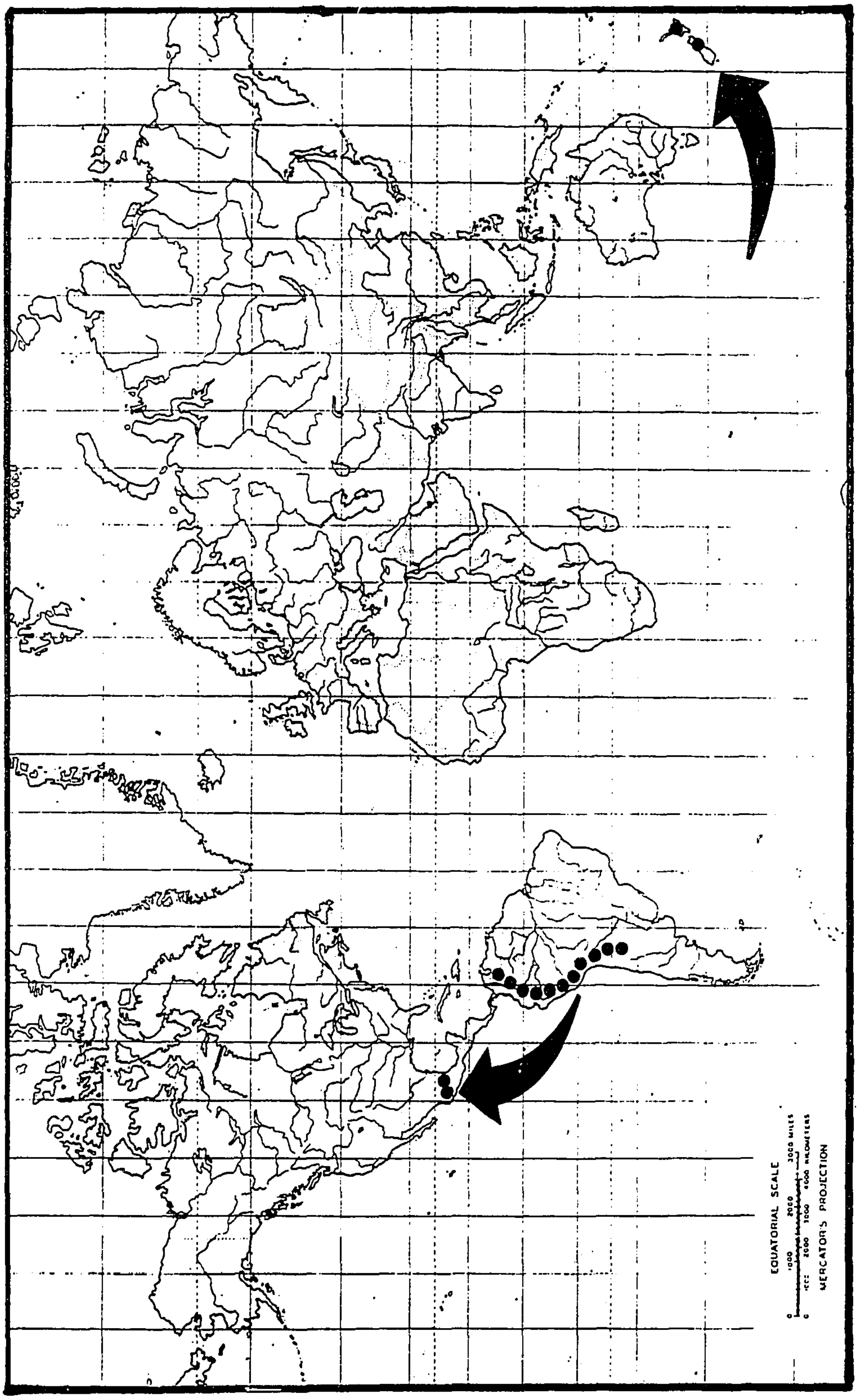
The work of Dr. Lourteig in Paris and the previously mentioned Argentinean researchers, Martínez & De Azuke, are providing data that will contribute to understanding the evolutionary relationship of Oxalis tuberosa and other related species. The identity of the potential wild progenitor of Oxalis tuberosa will require further field exploration and taxonomic data.

Distribution and Ecogeographic Limits

Oxalis tuberosa has the widest distribution (Fig. 6) of all the crops examined in this research. In the Andes it is cultivated from Venezuela, South to Chile and Argentina. More recently, Oxalis tuberosa has also been introduced to Mexico and New Zealand. A discussion of its cultivation in Mexico and New Zealand is presented below. It has also been experimentally grown in Costa Rica where tuber production was recorded at 2400 m (Obregozo, 1956). I observed the the cultivation of Oxalis tuberosa in Mexico, Colombia, Peru and Bolivia and found the greatest diversity of cultivars in southern Peru and northern Bolivia.

Recent reports of attempts to cultivate Oxalis tuberosa in the United States in Oregon have also been noted (Vietmeyer, pers. comm.), thus far without successful tuberization. Material from the Andes, Mexico and New Zealand has also been grown in the propagation houses

Fig. 6. Distribution map of Oxalis tuberosa.


EQUATORIAL SCALE
MERCATOR'S PROJECTION

of the New York Botanical Garden, also without tuber formation. One researcher (Hill, 1939) did experimentally cultivate Oxalis tuberosa in England and he reported that flowering and tuberization occured at "high elevations in the mountains near Innsbruck" in Austria, but not outdoors in England. Hill also mentioned that he sent tubers of Oxalis tuberosa to Kenya that did not flower but he did not mention tuber formation.

In the Andean region Oxalis tuberosa is usually encountered between 2500 and 4000 m with the greatest frequency of documented germplasm collections coming from between 3200 and 3900 m in Ecuador, Peru and Bolivia. The upper altitudinal limit of Oxalis tuberosa that I observed was 4100 m in central Peru and Kay (1973) has reported an upper limit of 4500 m. In Mexico Oxalis tuberosa is cultivated from 2400 to 3300 m. Field research was not conducted in New Zealand and data from that cultivation environment is lacking.

It is important to recognize the effective and absolute limits of cultivation as described by Gade (1975). The effective limit is the elevation where the production of a cultigen no longer produces enough yield to warrant the effort of cultivation and the absolute limit is the highest or lowest, where the crop does not produce at all. The factors affecting poor or no production are often related and include the extremes of heat, cold or moisture and increased insect or pathogen attack. The choice of where to plant crops is based on a sophisticated environmental knowledge of the characteristics of ecological zones. This knowledge and the associated agricultural technology is discussed below. The ecogeograpic limits presented here represent only the current environmental potential of Oxalis tuberosa.

Vernacular Names

Oxalis tuberosa has the widest distribution of any of the species discussed here and is known by numerous vernacular names presented in Table II. These names refer to the principle cultivated species and not to the numerous names given to cultivars. The most well known vernacular name for *Oxalis tuberosa* is "oca" which is etymologically similar to the Quechua term for mankind "orcco" (Johns, 1986b). The cultural significance of the name oca and its relationship to its growth form and uses of other Andean tubers is examined by Johns (1986b).

Table II

Vernacular Names for <u>Oxalis tuberosa</u>

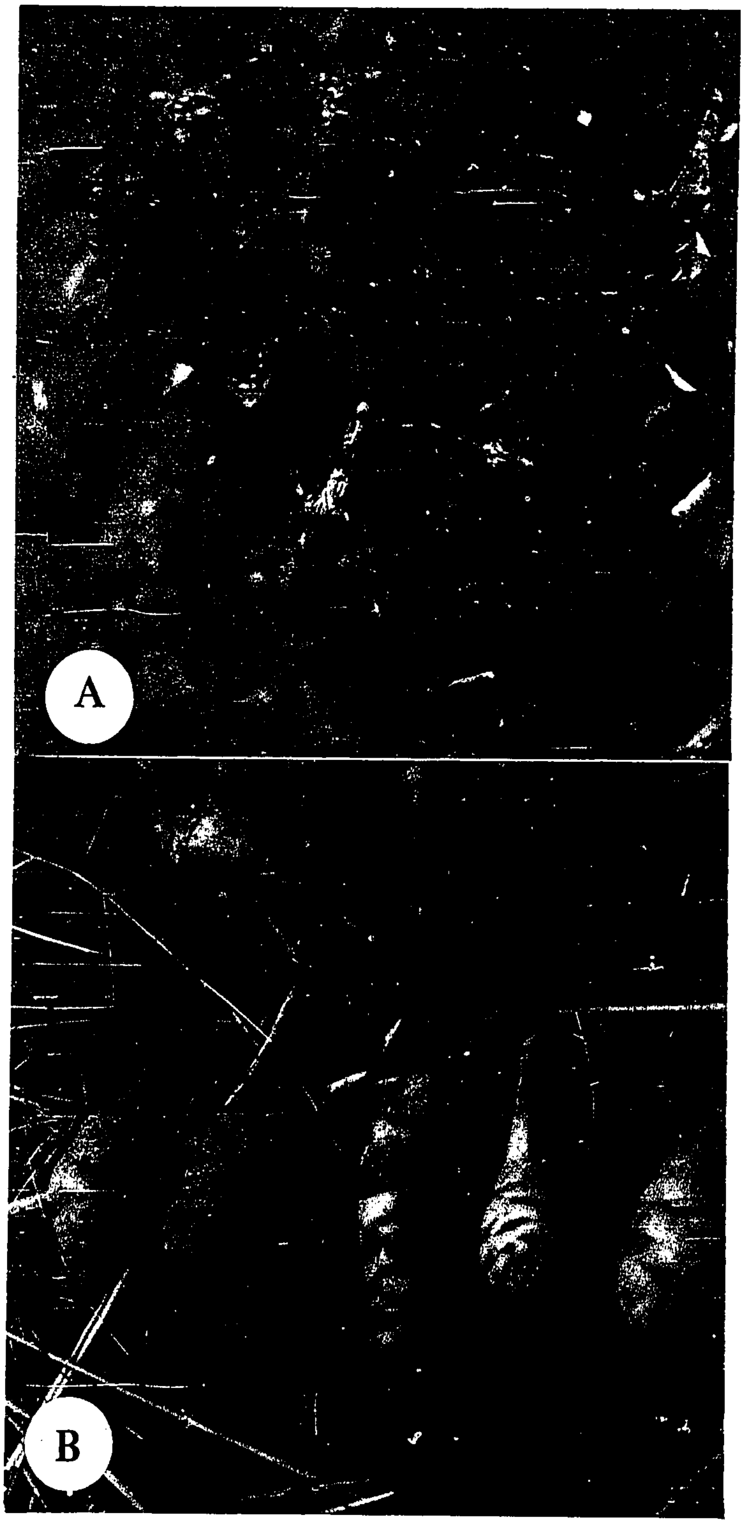
Name	Country (Language)	Reference
cuiba	Venezuela, Colombia	King pers. obs; White, 1975
huisisai	Venezuela, Colombia, Ecuador,	Bukasov, 1930; Montaldo, 1967
pighas	Venezuela	White, 1975
ibias	Venezuela, Colombia	King pers. obs; White, 1975
piga-mishi	Colombia (Guambiano)	Patiño, 1963
mishi-poulé	Colombia (Guambiano)	Patiño, 1963
oca	Colombia, Ecuador, Peru, Bolivia (Quechua)	Bukasov, 1930; King, 1987
oqa	Peru (Quechua)	Beyersdorf & Blanco, 1984
apilla, Apilja	Bolivia (Aymara)	Patiño, 1963
apiña	Bolivia (Quechua)	Beyersdorf & Blanco, 1984
macachin	Argentina	Montaldo, 1967
miquichi	Argentina	Montaldo, 1967
papa extranjera	Mexico (Spanish)	King, pers. obs.
yam	New Zealand (English)	Vietmeyer, 1986

General Morphology of Tropaeolum tuberosum

A description of Tropaeolum tuberosum (Fig. 7) is presented below. White (1975) also described the general morphology and anatomy of Tropaeolum tuberosum. A comparative study of the floral biology and morphology of ten varieties of Tropaeolum tuberosum is in Ramírez (1977). Studies on the relationship between the morphology and yield of T. tuberosum are also available (Nuñez, 1978). Because this morphological and anatomical work has been done, it was not repeated in this study.

Tropaeolum tuberosum is a herbaceous plant climbing by twining petioles, often forming a dense tangled mound; perennial from annually produced tubers for which it is cultivated. Stems smooth, dark green to purplish. Leaves alternate, simple, peltate, oval in outline, three to five lobed becoming palmate, glabrous above and below, upper surface dark green; petioles long, twining about vegetation. Flowers zygomorphic, borne singly on long peduncles in leaf axils. Sepals 5 , unequal, fused at base, forming a spured calyx, yellow orange to reddish. Petals 5, unequal, somewhat tubular, yellow to red, with darker veins. Stamens 8 in two whorls, spreading. Ovary superior, globose, trilocular. Style elongate, trifid. Fruit three seeded, spliting into three mericarps.

Fig. 7. Tropaeolum tuberosum "mashua". A, Flowers and leaves, note pollinator in lower left. B, Tuber variation in Chinchero, Peru; largest tuber 100 mm long. C, Growth form of T. tuberosum in field at Tahauco, Peru, near Puno.


A
B


C

Tropaeolum tubers produced on underground axillary stolons, elongate, roughened by numerous nodes and scale leaves. Tubers variable in pattern and color, some with veritical lines brown to black. Color variable from white, cream, orange, yellow, maroon to brown.

Chromosome Numbers

Bolkhovskiket et al, (1960) reported chromosome numbers reported for *Tropaeolum tubersoum* as 2n = 42, while the basic number for the genus *Tropaeolum* is n = 6 or 7 .

Taxonomic Classification

Tropaeolum is a genus of 86 species, occuring from Mexico to temperate South America (Sparre, 1973). Two subspecis of *Tropaeolum tuberosum* are recognized *Tropaeolum tuberosum* subsp. *tuberosum* and subsp. *silvestre* (Sparre, 1973).

The main distinction between the two subspecies is that subsp. *tuberosum* produces tubers and subsp. *silvestre* does not. This taxonomic distinction is supported by research conducted by Johns & Towers (1981). The cultivated subsp. *tuberosum* releases methoxybenzal isothiocyanate, while the wild subspecies was characterized by benzyl, 2-propyl, and 2-butyl isothiocyanates (Kjaer *et al*., 1978; Johns and Towers, 1981).

Wild Progenitor

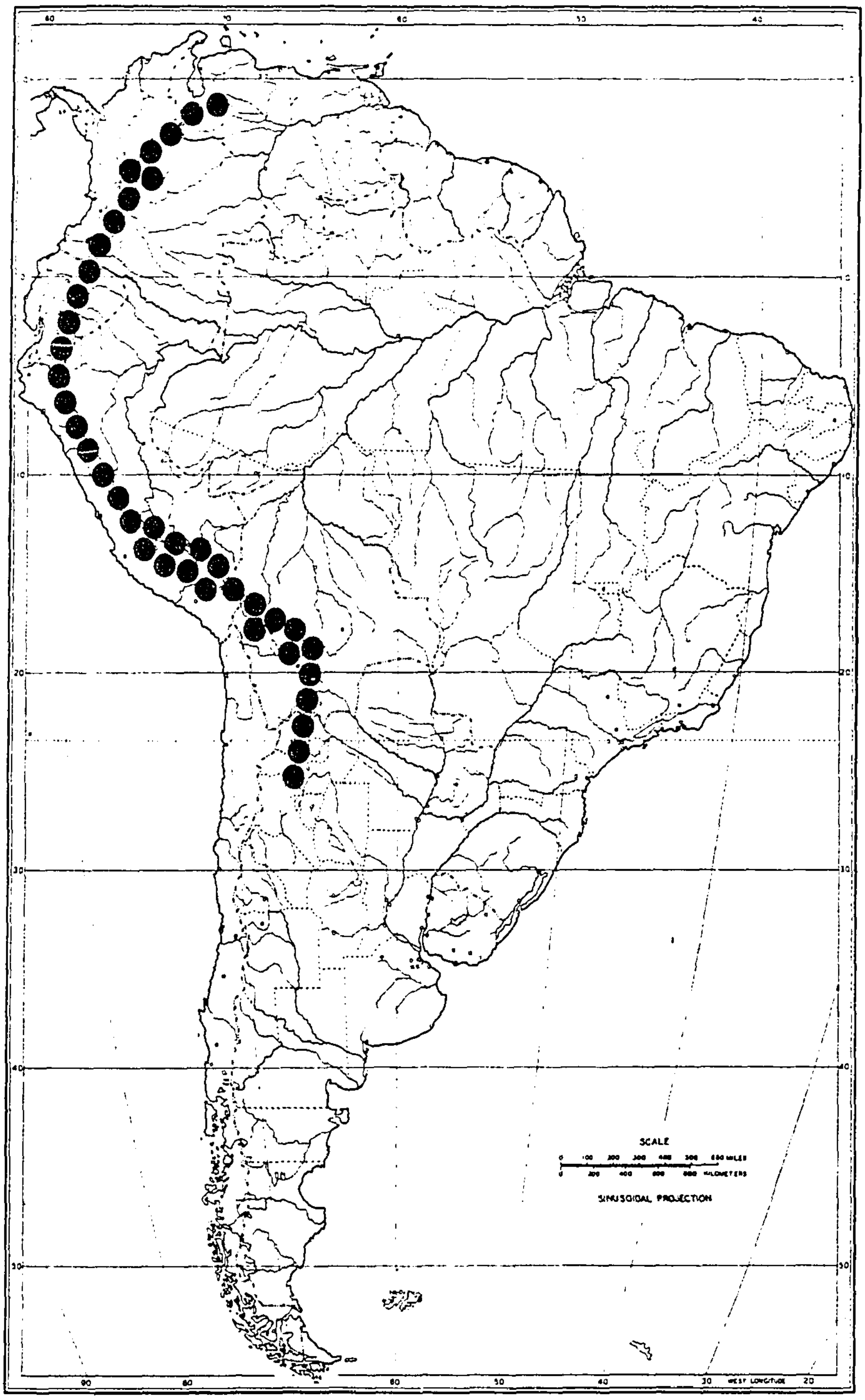
The taxonomic distinction between Tropaeolum tuberosum subsp. tuberosum and subsp. silvestre described by Sparre (1973) is based, as mentioned, on the presence or absence of tubers. The smaller size of the flowers of the subsp. silvestre was also noted by Sparre but he suggests that this character is "very approximate." The following species names are considered synonyms for Tropaeolum tuberosum subsp. silvestre: Tropaeolum buchenauianum Hieron., T. hieronymi Buch., and T. septemlobatum Heilb. (Sparre, 1973).

Tropaeolum tuberosum subsp. silvestre is found between 2400 to 3950 m in Colombia, Ecuador, Peru, Bolivia and Argentina. The research by Sperling (1987) on the "wild" forms of Ullucus tuberosus is likely to provide useful data for a comparative analysis of the relationship of the cultivated and wild subsp. of Tropaeolum tuberosum described by Sparre. The identity of other closely related species merits further investigation for future potential breeding work.

Distribution and Ecogeographic Limits

The distribution of Tropaeolum tuberosum subsp. tuberosum (Fig. 8) is primarily in the Andean region from Venezuela to Argentina. It is likely to also be cultivated in Chile but no specimens or references to its cultivation in Chile have been encountered. Tropaeolum tuberosum has been cultivated experimentally in the regions of

Fig. 8. Distribution map of Tropaeolum tuberosum subsp. tuberosum.



Christchurch and Auckland New Zealand where it does produce tubers (B. Sykes & A. Endt pers. comm.). There has been one incorrect citation of Tropaeolum tuberosum being purchased in a Mexican market in the State of Veracruz (Williams, 1978), which is discussed below.

The ecogeographic limits of cultivation are similar to those presently known for Oxalis tuberosa. Tropaeolum tuberosum is cultivated between the elevations of 2780 to 4200 m (INIAP/CIRF, 1985; Rea & Morales, 1980). It it is probable that Tropaeolum tuberosum would be productive at the same low altitude of 2400 m as Oxalis tuberosa in Central America and Mexico.

Vernacular Names

The vernacular names for Tropaeolum tuberosum are presented in Table III. The most frequently used names for Tropaeolum tuberosum are "mashua" in Ecuador and "añu" and "isaño" in Peru and Bolvia.

Table III

Vernacular Names for *Tropaeolum tuberosum*

Name	Country (Language)	Reference
cubio	Colombia	Bukasov, 1930; King, 1987
hubios, hubias	Colombia	White, 1975
navo	Colombia	King pers. obs.; White,
pane	Colombia (Guambiano)	1975 Patiño, 1963
puel	Colombia (Paez)	Patiño, 1963
mashua, maghua	Colombia, Ecuador, Peru	White, 1975; Montaldo, 1967
	Bolivia	Mejía Xesspe, 1931;
mashwa	Peru (Quechua)	Beyerdosrf & Blanco, 1984
añu	Peru, Bolivia (Quechua)	Patiño, 1963; King, pers
obs		
isaño, isañu	Peru, Bolivia, Argentina	Patiño, 1963; Johns, 1981
miswha	Bolivia (Aymara)	Mejía Xesspe, 1931
allausu	N.D. (Quechua)	Mejía Xesspe, 1931
apiña mama	Bolivia	Johns, 1986b

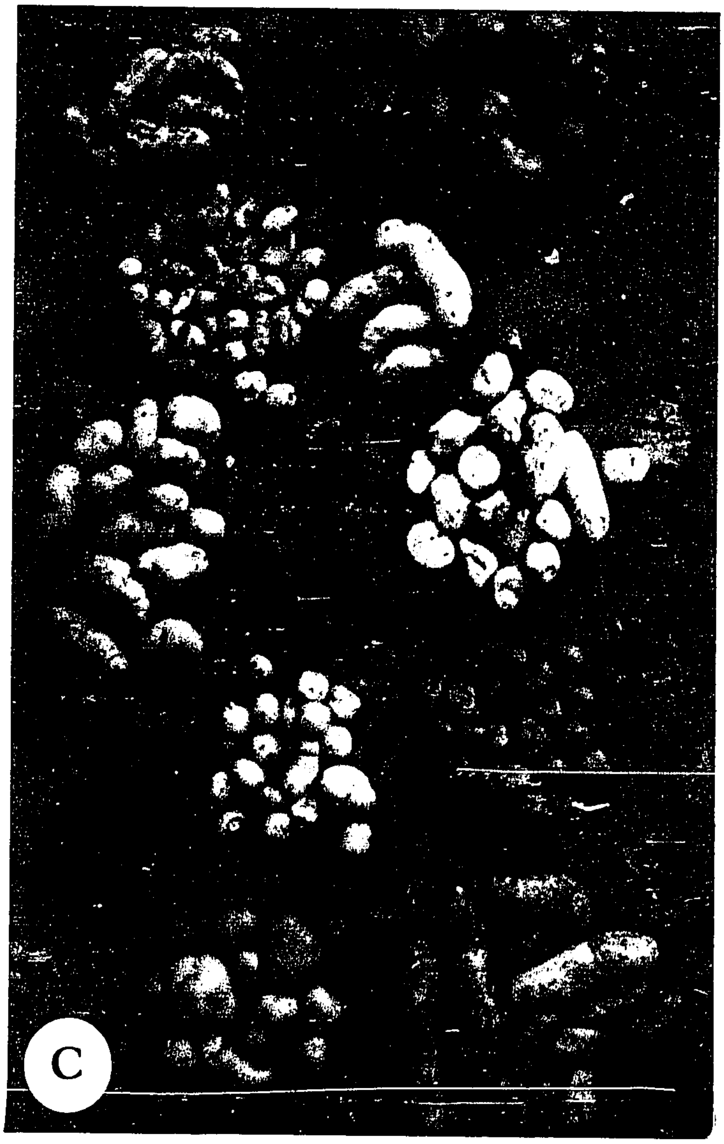
General Morphology of Ullucus tuberosus

A morphological description of Ullucus tuberosus (Fig. 9) is presented below. Recent work on the variation within the cultivated Ullucus tuberosus has documented the fruit morphology and significant morphological variation between clones from Southern Andean Peru (Sperling, 1987; Rousi et al., 1986).

Ullucus tuberosus is an erect or trailing succulent and mucilaginous herb; perennial from annually produced tubers for which it is cultivated. Stems ridged green yellow or reddish. Leaves alternate, simple and sagitate to reniform in outline with acute or rounded apices, upper and lower surfaces are glabrous, light to dark green or reddish; the erect petioles are groved. Flowers regular, borne on short pedicels in axillary racemes, pedicels topped by a small pair of hornlike bracts immediately below the two bractlike sepals which are yellow to reddish. Petals five or abnornally in rare cases up to 13, yellow to red with long attenuate tips. Petals are fused at the base into a shallow floral cup, becomming accrescent about the rarely formed fruit. Stamens are short, erect, yellow. Ovary superior, short and globose, style simple. Fruits are rarely produces but are globose with warty surfaces and ridged, embryo annular as in most members of the Centrospermae.

Fig. 9. Ullucus tuberosus "ulluco" A, Leaves and flower detail. B, Plant aspect and immature tubers, soil removed to expose tuber formation. Chinchero, Peru 3800 m. C, Tuber variation in market in Ayacucho, Peru. Largest tuber 140 mm long.


A
B


C

Ullucus tubers are borne on elongate axillary stolons produced on the above ground or below ground stem, becoming positively geotropic burrowing into the soil, rarely branching before enlarging into elongate or spherical terminal tubers. Tubers smooth with few nodes and minute scale leaves. Great pattern and color variation. Tubers at times mottled with several color spots or lines. Tuber colors white, green, cream, yellow, orange, pink and red.

Chromosome Numbers

Cardenas & Hawkes, (1948) and Rousi *et al*., (1986) reported chromosome numbers of *Ullucus tuberosus* as 2n = 24 and 2n = 26.

Taxonomic Classification

Ullucus tuberosus is a monotypic genus. Sperling (1987) has revised the Basellaceae and he has classified the wild progenitor as *Ullucus tuberosus* subsp. *aborigineus*. Sperling considered the cultivated plant as *Ullucus tuberosus* subsp. *tuberosus*. A complete taxonomic history of *Ullucus tuberosus* is included Sperling's revision.

Wild Progenitor

Ullucus tuberosus subsp. *aborigineus* (Fig. 10) is described and discussed by Sperling. The information presented below is a partial summary of Sperling's data. This wild subspecies occurs (Fig. 11)

Fig. 10. Ullucus tuberosus subsp. aborigineus (Sperling & King 5404). Sorata, Bolivia.

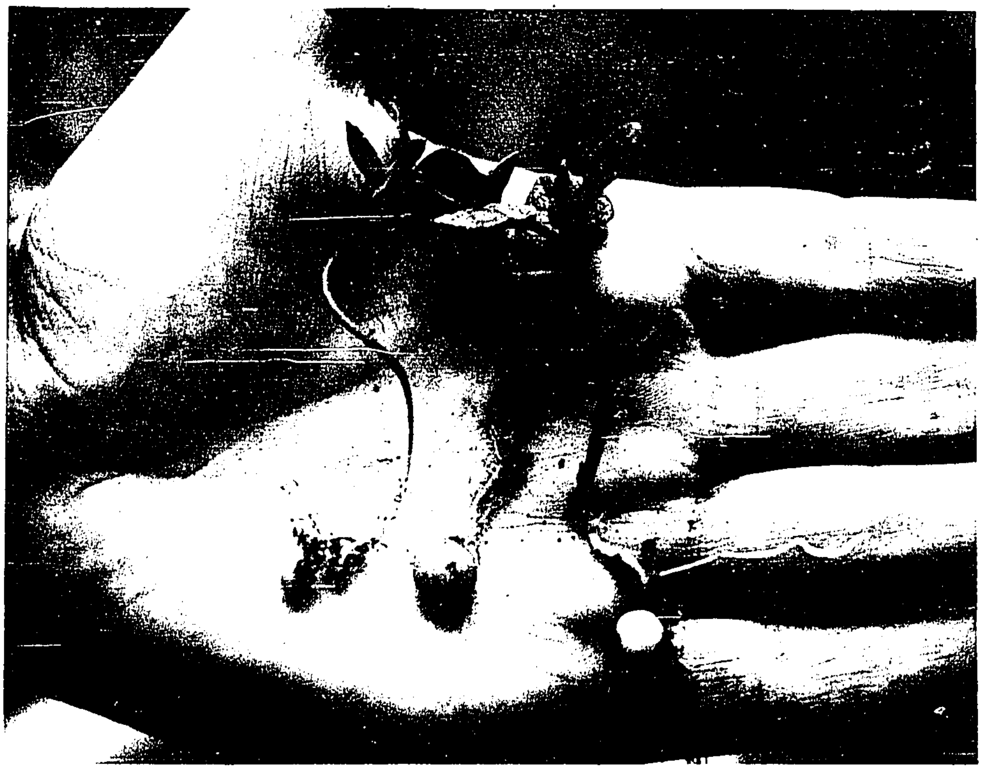
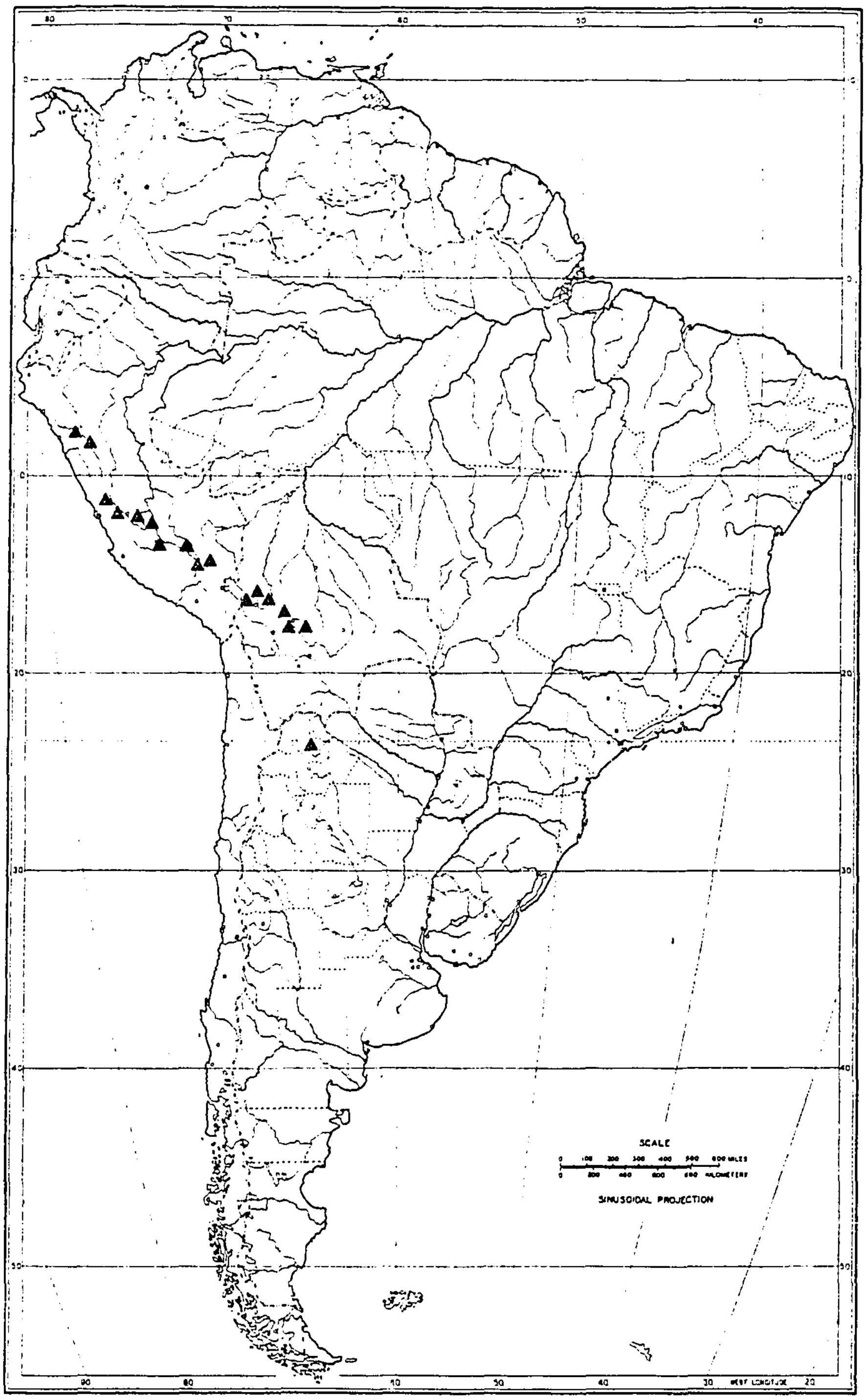


Fig. 11. Distribution of Ullucus tuberosus subsp. aborigineus. After Sperling, 1987.


SCALE
SINUSOIDAL PROJECTION

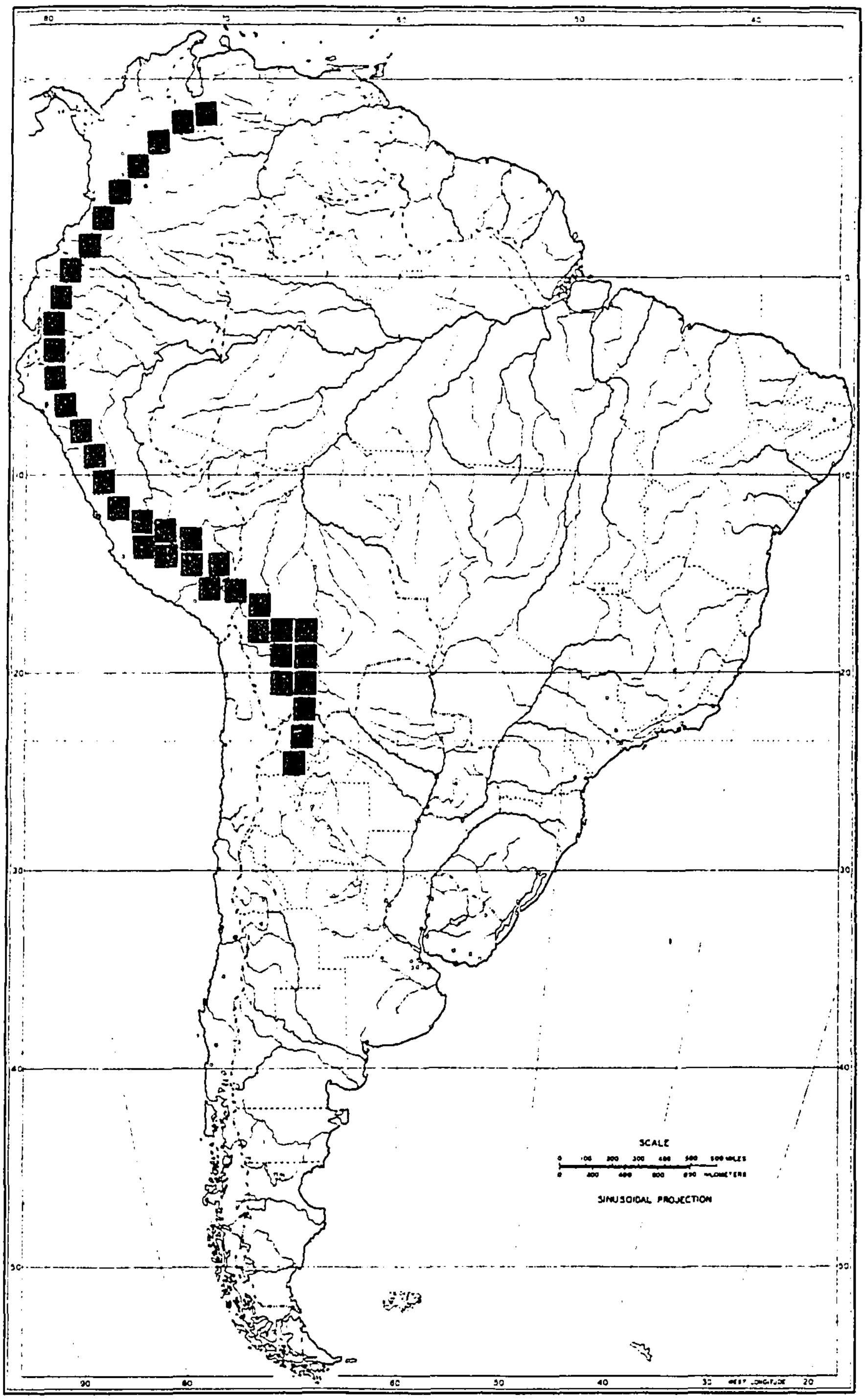
from central Peru to northern Argentina. The wild form may form shoots above or below ground but tubers are always formed below ground. The wild tubers are small, 10-20 mm in diameter, usually pink, dark maroon to red or infrequently white in color. The wild form is a vining in habit and grows in semi scrub, shrubby, and rocky environments. The wild form has not been found to produce viable seed (Brücher, 1967; Sperling, 1987).

In addition to the wild form collected on rocky slopes outside of Cninchero, Peru, there was a limited number of plants of Ullucus tuberosus subsp. aborigineus growing on the rock walls in the village. These plants and those from the other more isolated collection locality were called by two Quechua names. These names, "atok lisa" or "atok ullucu" (atok = fox) and "k'ita lisas" (k'ita = wild and or unplanted) were used interchangeably for the plants classified as Ullucus tuberosus subsp. aborigineus collected in both the village and on the side of the mountain called Antikillqa (Sperling, 1987). Phytochemical investigation comparing the cultivated and wild subspecies is likely to provide important data on the differences between the cultivated and wild Ullucus tuberosus.

Distribution and Ecogeographic Limits

The distribution of Ullucus tuberosus subsp. tuberosus (Fig. 12) is very similar to that of Tropaeolum tuberosum. It is cultivated from Venezuela to Northwest Argentina. The greatest diversity of landraces observed during this study was in the region of southern Peru and northern Bolivia. Ullucus tuberosus was introduced briefly r

Fig. 12. Distribution of Ullucus tuberosus subsp. tuberosus.


SCALE
SINUSOIDAL PROJECTION

to Europe in 1848 after the potato famine as a potential alternative root crop, but according to Rousi _et al_. (1986), interest in the crop died due to low yields. More recently a Finnish research team conducted experiments with _Ullucus tuberosus_ that indicate tuber formation and viable seed set can be obtained in Turku, Finland (Rousi _et al_., 1986, in press). To date no variety of _Ullucus tuberosus_ has been introduced to North America that produces tubers under natural outdoor conditions.

The current ecogeographic limitations of _Ullucus tuberosus_ are similar to those of _Tropaeolum tuberosum_ and _Oxalis tuberosa_. I observed it most frequently under cultivation between 3000 and 4000 m. The lowest collection of _Ullucus tuberosus_ is from the village of Matus Alto, Ecuador, at 2600 m (INIAP/CIRF, 1985) and Sperling (1987) has reported it being cultivated at 2400 m. _Ullucus tuberosus_ is resistant to low temperatures and can tolerate frost but it is not cultivated at the highest elevations where _Lepidium meyenii_ is successfully cultivated.

Vernacular Names

The most widely used vernacular names for _Ullucus tuberosus_ are "melluco," "olluco," "ulluco," "papa lisas" and "lisas". It has been suggested by Sperling (1987) that the origin of the genus name _Ullucus_ is likely to come from the Quechua word "ullu," which means the genital member of any male animal. The association of the word "ullu" is with the phallic shape of the tubers of some cultivars of _Ullucus tuberosus_.

Table IV

Vernacular Names of <u>Ullucus</u> <u>tuberosus</u>

Name	Country (language)	Reference
michirui	Venezuela	Sperling, 1987
michuri, miguri	Venezuela	Sperling, 1987
michunchi	Venezuela	Sperling, 1987
mucuchi	Venezuela	Sperling, 1987
ruba, rubas	Venezuela, Colombia	Bukasov, 1930, King, Pers. obs.
tiguiño, timbó	Venezuela, Colombia	Bukasov, 1930; Sperling: 1987
camróne de tierra	Colombia (Spanish)	King, pers. obs.
chigua, chuguas	Colombia	Bukasov, 1930; Patiño, 1963
hubas	Colombia	Sperling, 1987
melluco	Colombia, Ecuador	Hodge, 1946; Bukasov, 1930
olluco	Colombia, Ecuador, Peru	Bukasov, 1930; Patiño, 1963
	Bolivia, Argentina	Fries & Tapia, 1986
ulluco	Colombia, Ecuador, Peru	Bukasov, 1930; Patiño, 1963
	Bolivia	Rea, 1985, King pers. obs.
millucu	Ecuador	INIAP/CIRF, 1985
papa lisa, lisas	Peru, Bolivia (Spanish)	King, pers. obs.
ulluma	Argentina	Sperling, 1987

Chapter 4 - Indigenous and Campesino Cultivar Taxonomies

The vernacular names of the four species distinguish these crops in the various areas where they are cultivated. In addition, there is a tremendous amount of intraspecific variation within each of three species, Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus. In Chapter 9, this intraspecific variation is discussed in relation to the large international germplasm collection of each of these species.

In this chapter the indigenous classification of these crops is discussed and in this discussion the term "indigenous" includes both native Amerindians and mestizo or campesino Andean people. The agricultural knowledge of both of these groups is based on centuries of experience. The distinction between indigenous and mestizo or campesino is also increasingly more difficult to define because of the rapidly changing socio-economic pressures that encourage Amerindians to abandon the visible characteristics of their cultural heritage. Placing these two groups together may be unacceptable to Andean social scientists but it facilitates the discussion of the indigenous taxonomy of these crops.

Folk Taxonomies

There is a large body of ethnographic and geographic literature on folk classification of plants, animals, insects, soils and many other features of the environment of indigenous people (Balée, 1986; Berlin et al., 1973; Boster, 1985; Conklin, 1972; McCamant, 1982).

There is also a growing awareness in the international development community that understanding indigenous systems of classifying the natural world can be important to the successful integration of development programs (Chambers, 1983; Posey, 1983).

In the Andean region, the classification of the natural world by indigenous people is complex, in part due to the high degree of ecological change that results from dramatic changes in elevation over short distances. In order to understand the subtle interactions between humans and wild or crop plants, it is necessary to speak both the language and to observe the cultural and agricultural activities that take place during the annual agricultural cycle. Research by a native english speaking ethnbotanist who is fluent in Quechua (Franquemont, 1987) provides an example of an integrated approach to understanding the complex interactions of humans, their cultural behavior, and the natural environment. A portion of the data presented below was collected by Franquemont and myself as part of collaborative fieldwork over a three month period in Chinchero, Peru, in 1982.

Several researchers working in the Andes have reported on indigenous taxonomies applied to cultivated potato varieties e.g. (Brush, 1980; Brush et al, 1981; La Barre, 1947). Indigenous names applied to cultivars of Andean tubers have been listed in the past (Bukasov, 1930; Hodge, 1946; and León, 1964a), but there is no literature examining the indigenous classification of Oxalis tuberosus, Tropaeolum tuberosum and Ullucus tuberosus.

The work of Stegemann and co-workers (1988) on biochemical differentiation of clones of Oxalis tuberosa included the indigenous names with a translation of their meaning. They reported that cultivars of Oxalis tuberosa are divided into three general Quechua categories, each with a Quechua name, "Huaynuca", "Caya" and "Cahui." These three categories reflect the morphology of the tubers, which affects the method of storage, the preparation and utilization of the tubers. These clones are part of the germplasm collection of the Universidad Nacional de Huánuco "Hermilio Valdizán"in Peru. In Southern Peru the category of tuber used to make "Caya" (dehydrated and or freeze-dried tubers) was also recognized (pers. obs.)

Germplasm collections of Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus from Ecuador and Bolivia have also been recorded including in varying degrees, indigenous names and the characteristics of the collection (INIAP/CIRF, 1985; Rea & Morales, 1980). The indigenous cultivar classification, its translation, if known and the characteristics of the cultivar, if given, from Ecuador, Peru and Bolivia are presented below.

Cultivar Names

The number of specific cultivar names for Lepidium meyenii is low compared to the other three species. My fieldwork and the literature indicates that there are four cultivars known. These are recognized by color: black, purple, cream-yellow and cream-purple (León, 1964b; Pulgar Vidal, 1946).

No reports on the distinguishing characteristics between these cultivars are known and further investigation into the genetic variation of the these cultivars is currently being conducted (J. Rea, pers. comm.),

The cultivar names of Ecuadorian germplasm collections (Table V) are usually Spanish and are mostly based on the color of the tuber (INAIP/CIRF, 1985). The information presented in Table V is a summation of the data presented and does not include every germplasm collection of each of the three species. The published names of the cultivars from Ecuador do not contain detailed information on the indigenous classification of the these crops.

The cultivar names presented from the germplasm collection of Oxalis tuberosa (Table VI) are from the University of Huanuco in central Peru (Stegemann et al., 1988). These 23 cultivars where selected by the authors of the previously mentioned paper to be a sampling of the 60 collections at part of that Universities germplasm collections of Oxalis tuberosa. The names associated with these collections include more detailed morphological description but provide little information about other characteristics of the clones.

The data presented from Chinchero, in Southern Peru (Table VII) represents the diversity of cultivars of Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus in one Quechua community. The collections were made when the cultivars were in flower prior to the production of tubers.

Table V

Ecuadorian Cultivar Classification*

	Oxalis tuberosa "Oca"	
Name	English Gloss of Spanish Name	Catalog #
oca alargada	elongated oca	04-0029
oca redonda	round oca	04-0041
oca chaucha		04-0031
oca blanca	white oca	04-0036
oca mancha Roja	oca with red spots	04-0040
oca amariila	yellow oca	10-0017
oca negra	black oca	17-0016
oca algodona	cottony oca	06-0022
oca candunga		06-0024
oca morada	purple oca	06-0047
oca cambrai		03-0004

	Tropaeolum tuberosum "Mashua"	
	English Gloss of Spanish Name	
mashua negra	black mashua	04-0016
mashua blanca	white mashua	04-0019
mashua amararilla.	yellow mashua	17-0020

Table V
Continued

mashua colorado	red mashua	17-0021
mashua púrpura	purple mashua	06-0041
mashua shira	cold resistant or light mashua	03-0001
mashua remedio	medicinal mashua	03-0011
mashua peruana	peruvian mashua	03-0009
mashua zapallo	squash or pumpkin mashua	03-0006

	Ullucus tuberosus "Melluco" English Gloss of Spanish Name	
melluco riñón	kidney melluco	04-0024
melluco blanco	white melluco	04-0025
melluco rojo	red melluco	04-0082
olluco largo	long olluco	04-0049
olluco redondo	round olluco	04-0054
olluco rosado Largo	long Pink olluco	04-0055
mellucu jaspeado	marbled or Mottled olluco	10-0028
melluco amarillo	yellow melluco	17-0034
melluco colorado	red melluco	01-0029

*The names presented are those listed INIAP/CIRF (1985). Several collections of each species were listed without names and several of the names presented were listed for different collection numbers from distinct regions of Ecuador.

Table VI

Cultivar Classification in Huánuco, Peru*

Oxalis tuberosa "Oca"

Name	English Gloss of Quechua or Spanish Name	Coll.#
golua	gift of the earth	105
capish delgado	thin stolon	107
shullacchumpac	sweetish lizard	115
anajhuatu cobe	hard stolon, pink	116
combo	mallet head	121
yuraj	white Oca	106
garqaricra	yellow arms	101
chilcano	sweet orange	111
yanachumpac	sweetish black	113
yanapahuay	black bunch	118
shullac	lizard	120
anajhuata	hard stolon	103
anajhuata puca nahui	hard stolon with red eyes	124
papa oca	potato oca	127
capish grande	thick stolon	133
pumajactay	sleeping puma	135
yuraj papa oca	white potato oca	138
anajhuato ojo grande	hard stolon with big eyes	140
piña oca	pineapple oca	166
capish rosado	pink thin tuber	155

*Entire table after Stegemann *et al*., 1988.

Table VII

Cultivar Classification in Chinchero, Peru*

<u>Oxalis</u> <u>tuberosa</u> "Oca"

Name	English Gloss of Spanish or Quechua Name (and Other Characteristics, if Given)	Coll. #
paucar oca	red oca	King 153
higos oca	fig oca	King 154

<u>Tropaeolum</u> <u>tuberosum</u> "Añu"

Name		Coll. #
yaña añu	black añu	King 155
platano añu	plantain añu	King 276
k 'ita añu	wild añu	Davis 1463

Table VII Continued

<u>Ullucus</u> <u>tuberosus</u> "Lisas"

phantasma lisas	(tubers orange with red dots)	King 235
zanahoria lisas	carrot lisas (yellow orange tubers)	King 156
papas lisas	potato lisa (white with red spots)	King 157
arequipa lisas	lisas from Arequipa (like oranges)	King 158
yurac lisas	white lisas	King 234
tejteharo lisas	(long tubers, white and red spots)	King 236
atoj ulluco	fox ullucu	Davis 1681
atoj lisa	fox lisa	Davis 1775

* All of the Chinchero collections were made as part of a research project on the ethnoecology of Chinchero. This data does not intend to suggest that no other varieties existed. See Franquemont (1987) for further discusssion.

Table VIII

Bolivian Cultivar Classification*

Oxalis tuberosa "Oca"

Name	English Gloss of Quechua, Aymara or Spanish Name and (other Characteristics, if Given)	Coll. #
janko keni	white bitter	1
yurac	white	3
chola oca	oca	4
niña Oca	girl oca	5
waca liki	cows food	6
anko chisme	bitter	9
janko luki	white (for making freeze dried oca)	10
huari chuchulli		11
oca blanca	white oca (resistant to worms)	12
kellu zappallo	yellow	57
oca zapallo	yellow oca (sweet after five days in sun)	63
kellu oca	yellow oca	67
amarillo	yellow	68
mistiza apilla	mixed oca	81
oca potosi	potosí oca	82
luli		84
kachachiki		85
chipuspuri		87

Table VIII Continued

pucañahui	red eye (tuber yellow)	91
kollari		97
pucañahui kello camote	red eye, yellow sweet potato	122
ojos rojc	red eyes (eat directly)	131
piña	pineapple	132
keacha	(with starch, very soft)	134
keni mami ta ajanu	pink, (susceptible to everything)	135
janko keni quilima	white pink	136
keni	pink	137
humakhuakollo	(not good for freeze dried oca contains much water)	142
amajaya	(sweet with good production)	145
sahuasira		146
sakampaya	(starchy, needing little sun exposure)	147
castro oca	(sweet, eaten fresh, little sun exposure)	152
chisme amarillo	bitter yellow. (only for freeze dried oca)	157
manzanilla	small ball or knob	160
alajita	(a "mutation")	180
cayara	(from Peru)	182
umakoyui keni	pink	188
keni cenizon	pink	191
huari chucho		204
luki cuy	bitter guinea pig	244
mura alka	(very sweet and starchy)	306

Table VIII Continued

jokopampa		314
paceña		335
chiar apilla		338
achacana	(for making freeze dried oca)	335
renaco		362
pili runta		385
icari	(fiberous)	407
yurac rosado	white pink	408
puca chole	red	411
titicana		413
señorita		417
calisto		420

Tropaeolum tuberosum "Isaño"

isaño blanco	white isaño	3001
janko	white (does not yield well)	3005
pararillo Kypa	(escaped from cultivation)	3006
kellu isaño	yellow isaño	3021
chimi	(low yield)	3022
zapallo	(this type tastes like *Ullucus tuberosus*)	3025
piticalla		3039
puckañawi	red eye	3057

Table VIII Continued

achacaña	(resistant to worms)	3076
azul-Ñawi	blue eye (eaten cooked, after exposed to sun)	3079
isaño amarilo	.yellow isaño	3080
azuti		3092
ckusillo		3099
puya		3106
morado		3124
chiar-isaño	(needs much time exposed to sun to eat)	3126
asuti	(high protein)	3132

<u>Ullucus</u> <u>tuberosus</u> "Ulluco"

kita ulluco	wild ulluco (abundant mucilage)	2001
jancko	white (low mucilage, requires 3 washes)	2005
chejje rosa		2010
cheje	(low mucilage)	2016
kellu	yellow	2018
amarillo huevo	yellow egg (much mucilage, requires 4 washes)	2023
sumac liza	beautiful liza (eaten directly)	2025
komer liza	(sweet, consumed directly)	2039
runtu	(good yield)	2043
liza verde	green lisa	2044
chogo	(good yield, much water)	2045
imill-palta	(produces well, no mucilage)	2073

Table VIII Continued

luqui kellu	bitter yellow. (resistant to frosts)	2059
willa	(much mucilage, requires four washings)	2114
puka	red (produces well, is disappearing)	2118
willa-keni	(cooked like potatoes)	2123
willa-luky	(takes longer to cook)	2125

*The names in this table are translated when possible. The cultivar characteristics, distinguished by parentheses, are not indicated by the name but are included as collection data associated with each accession. The bulk of these germplasm collections exist only in germplasm banks in Peru as the Bolivian collection was destroyed (see Chapter 9).

The indigenous nomenclatural data collected on Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus by Rea & Morales (1980) in Bolivia (Table VIII) is the most detailed information available. Combined with the lists of names from Ecuador and Peru this list is important for understanding the cultivar characteristics of these three crops. A treatment of the folk taxonomy of the three crops is beyond the scope of this study. The above list of names suggest both a high degree of intraspecific variation and a significant indigenous knowledge of the characteristics associated with this variation.

This indigenous knowledge about these crops is likely to be useful to any future breeding work undertaken with these species. Cultivar characteristics such as resistance to frost or insect attack may prove invaluable to future work aimed at genetic improvement of these crops. A summary of the types of characteristics recognized by farmers in the three countries (Table IX) indicates the numerous characteristics which Andean farmers use to distinguish cultivars. It should also be noted that different cultivars are valued for distinct purposes: some are eaten fresh with no processing or cooking, while others are bitter and must be processed but are then easily stored. One variety of Tropaeolum tuberosum was identified as "medicine" and is likely to be used as medicine and not as a food staple. The secondary compounds that influence these classifications are discussed in the section on ethnopharmacology in Chapter 7.

Table IX

Andean Tuber Cultivar Characteristics

Described From Ecuador, Peru and Bolivia

Characteristics
1. color of leaves, tubers & "eyes"
2. shape of tuber
3. number of "eyes"
4. taste
5. level of sweetness
6. presence, absence and level of bitterness
7. presence, absence and level of mucilage content
8. water content
9. texture
10. yield
11. relative starch & fiber content
12. resistance to frost & insect damage
13. general resistance of plant, vigor
14. edible directly, no processsing necessary
15. number of days necessary to leave tubers in sun prior to consumption
16. suitable or unsuitable for freeze-drying process
17. reputed place origin and relative abundance of variety, germplasm status
18. wild or escaped distinction

Chapter 5 - Reproductive Biology, Agricultural Cycle and Utilization

Lepidium meyenii

Propagation and Seed Production

Lepidium meyenii is propagated by seed, in contrast to Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus which are propagated asexually. The cropping system of Lepidium meyenii is complex and involves active human selection of seed at at each harvest. When Lepdium meyenii is harvested, 10 to 30 of the largest plants are left in the ground and the crown of leaves is removed. The remaining portion of the plant is then transplanted to special plots with a spacing of 350-400 mm in all directions (Fig. 13). Sheep manure is added to the plots and they are covered with 25-50 mm of soil.

Within two months, in December or January, new inflorescences appear seeds form and fall to the ground. The seeds are then collected and used to replant the next seasons crop. The seed is called "pita" (Fig. 14) and is reported to remain viable for 2-3 years. A field of 15 x 15 m requires 350-450 grams of seed (León, 1964b).

Cultivation System, Daylength, and Yield

Lepidium meyenii is planted in small plots in September or October. The harvest takes place 9-10 months later from June to August.

Fig. 13. Field of _Lepidium meyenii_ replanted after harvest to produce seed. Huarye, Peru 4100 m.

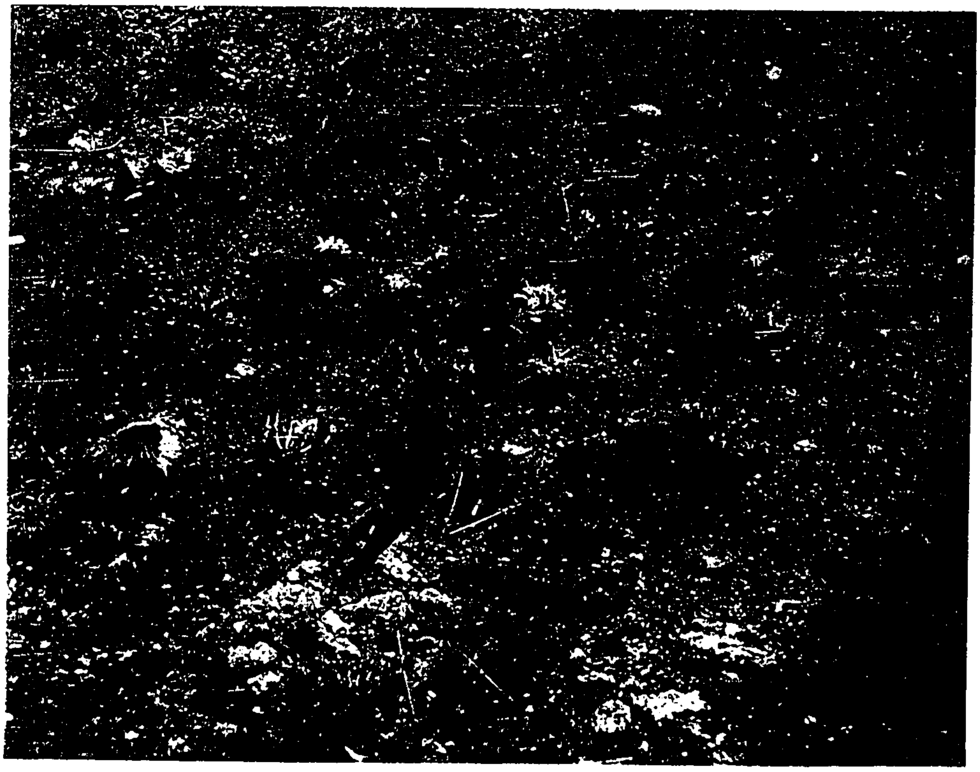
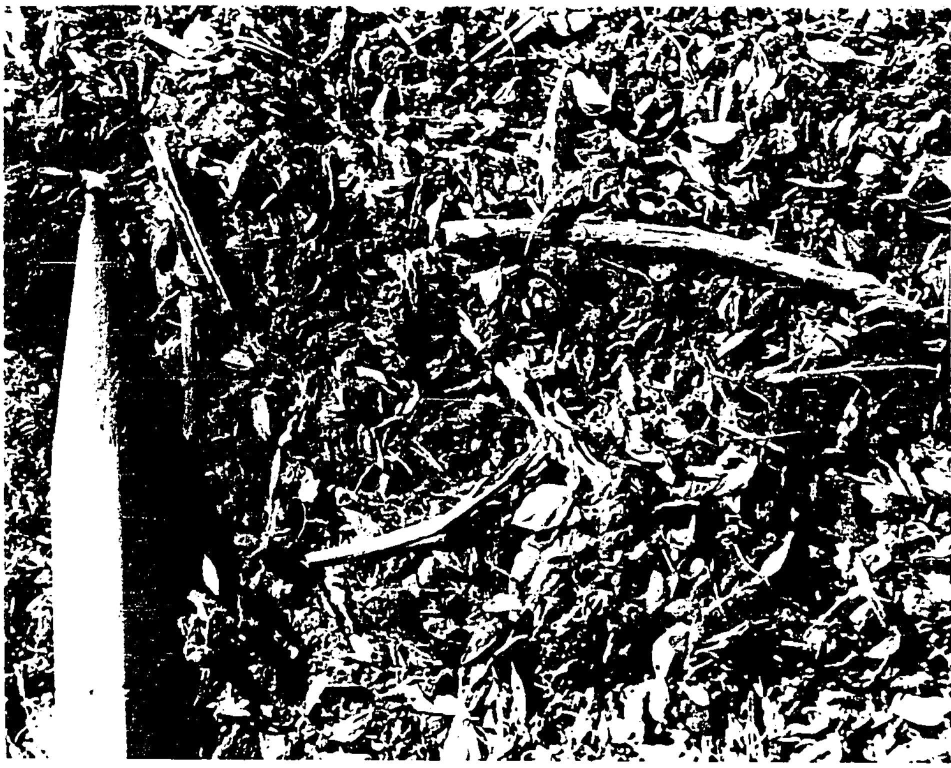


Fig. 14. Seeds of Lepidium meyenii, "pita". Huayre, Peru.



seeds from the previous harvest are mixed with soil and are broadcast planted into cultivated plots. Planting occurs in the morning when there is little wind. Sheep are often released into the seeded plot, serving two functions: as the sheep graze on other puna perennials they press the seeds into the soils and add manure to the ground as they walk through the plot.

The daylength requirement of Lepidium meyenii has not been determined. The number of hours of daylight necessary for optimal growth and hypocotyl formation has not been established, although it is likely to be a short day plant, similar to the other species in this work. Experimentation with Lepidium meyenii in mountainous regions in North America, Europe, Africa and Asia need to be carried out.

Lepidium meyenii is apparently not planted with other crops. The yield of Lepidium meyenii at 4500 m is reported to be 4-5 kg per square meter.

Inputs

During this field investigation several individuals reported adding phosphorous and sheep manure to their fields. León (1964b) reported that fertilizer generally is not applied. Several authors mention long fallow periods after one cycle of Lepidium meyenii planting (Vásquez de Espinoza, 1948; Cobo, 1956). Vásquez de Espinoza wrote that a field planted to Lepidium meyenii remained unproductive for up to three decades. One of the farmers we interviewed told us that it was necessary to wait several years before replanting but that this period could be reduced by adding fertilizer to the plot. One weedy species, Lepidium virginicum is known to inhibit germination and seedling growth of other plants (Bieber and Hoveland, 1968). This allelopathic activity may influence fields where Lepidium meyenii was formally cultivated but only further research will answer this question.

Disease and Insect Predation

There have been no reports concerning pathogens or insect pests affecting Lepidium meyenii. Informants in the Junín region denied having seen diseased plants. Lack of insect pests may in part be due to the presence of alkaloids in Lepidium meyenii, which are discussed in Chapter 7).

Consumption

Lepidium meyenii is consumed in numerous ways and for several purposes. It is most commonly taken as food but it is also reputed to be "medicine" to enhance fertility or cure swollen ovaries (see Chapter 7). Entire hypocotyls of Lepidium meyenii are taken as a porridge in the morning mixed with milk and freeze-dried potatos, dried Oxalis tuberosa and/or with Chenopodium quinoa. It is also served with water and dried ground maize in a dish known as a "mazamorra de Maca". Lepidium meyenii is also used after meals as a dessert and a sweet beverage is also produced by grinding the dried hypocotyls and adding milk or water. This beverage made from Lepidium meyenii has an aroma similar to butterscotch. An alcoholic beverage is also prepared by blending grated hypocotyls with rum. When freshly harvested, Lepidium meyenii is baked in earthen ovens in a method similar to that traditionally employed for one variety of fresh potatoes. The resulting fresh baked Lepidium meyenii is considered a delicacy.

Processing and Storage

Lepidium meyenii is sometimes prepared in a fresh state, but it is most commonly prepared after it has been dried. The drying process does not involve a freezing phase as in the case of the other tuber crops. After the harvest in June, maca hypocotyls are placed in the sun for a month until they are dried. In this condition they can be stored and eaten for up to five years. León (1964b) reported that the taste of Lepidium meyenii deteriorates after the second year. We cooked three-year -old dried Lepidium meyenii hypocotyls in water and served them to several non-Andean individuals who had never tasted this food and were not aware of its age. Several of these individuals indicated that the taste was pleasant and compared the texture and taste to figs. Dried hypocotyls of Lepidium meyenii collected in 1981 have been analysed nutritionally and were found to contain high quantity and quality of essential amino acids. This data is presented in the next chapter. Dried Lepidium meyenii can be stored and eaten many years after its harvest.

Market Value

In the region of its production Lepidium meyenii was available for sale at many households but not in shops. In the village of Carahuamayo, Lepidium meyenii was sold for roughly $ US 0.20/lb in 1981. It was reported to be eaten often in this village, in some houses as a daily morning meal. In Lima, the price was much higher. Four urban markets were inventoried for venders selling Lepidium meyenii. One medicinal plant vendor was encountered selling it by the individual hypocotyl at the high price of about US $ 1.00. I was unable to buy more then five roots at this price as the vendor claimed Lepidium meyenii was difficult to get in Lima and that she had promised the remaining roots to regular customers. This vendor said she sold them to woman who had trouble with their ovaries. The sale of Lepidium meyenii as a specialty medical item is an unusal case and does not reflect its common market value.

Industrial Potential

The potential for producing Lepidium meyenii on a larger commercial basis should be investigated. If it can be introduced to other mountainous regions such as Tibet or Nepal, an international appreciation and utilization could be developed. The reputed fertility enhancing-effect, if confirmed, would likely be a strong marketing characteristic. The high food value of Lepidium meyenii might also create an international demand for it similar to the current demand for the high protein Andean grain Chenopodium quinoa. At this time, a wider utilization of this nutritious food crop should be vigorously promoted in the Andean region.

Oxalis tuberosa

Propagation and Seed Production

The reproductive biology of *Oxalis tuberosa* has been examined by Gibbs (1976). *Oxalis tuberosa* exhibits tristyly, an outbreeding mechanism common in the Oxalidaceae. A partial correlation between style length and tuber color was proposed by Hill (1939), but this was not confirmed by this author or other researchers working with a large number of *Oxalis tuberosa* cultivars (Cárdenas, 1958). *Oxalis tuberosa* is propagated vegetatively and apparently botanical seed has not been used for propagation by Andean farmers.

This species, however, retains the capacity to produce viable seed. Seed has been obtained by several research groups although it is uncommon to encounter seed being produced in farmers fields (Cárdenas, 1958; Gibbs *et al.*, 1978). The seeds are formed in capsules with explosive dehiscence; this may increase the difficulty of encountering ripe seed in agricultural fields (Cárdenas, 1958). Plants with all three types of style morphs are capable of producing viable seed. Germination of *Oxalis tuberosa* seed requires an average of 18 days (Cortés, 1977).

Cultivation Systems, Daylength and Yield

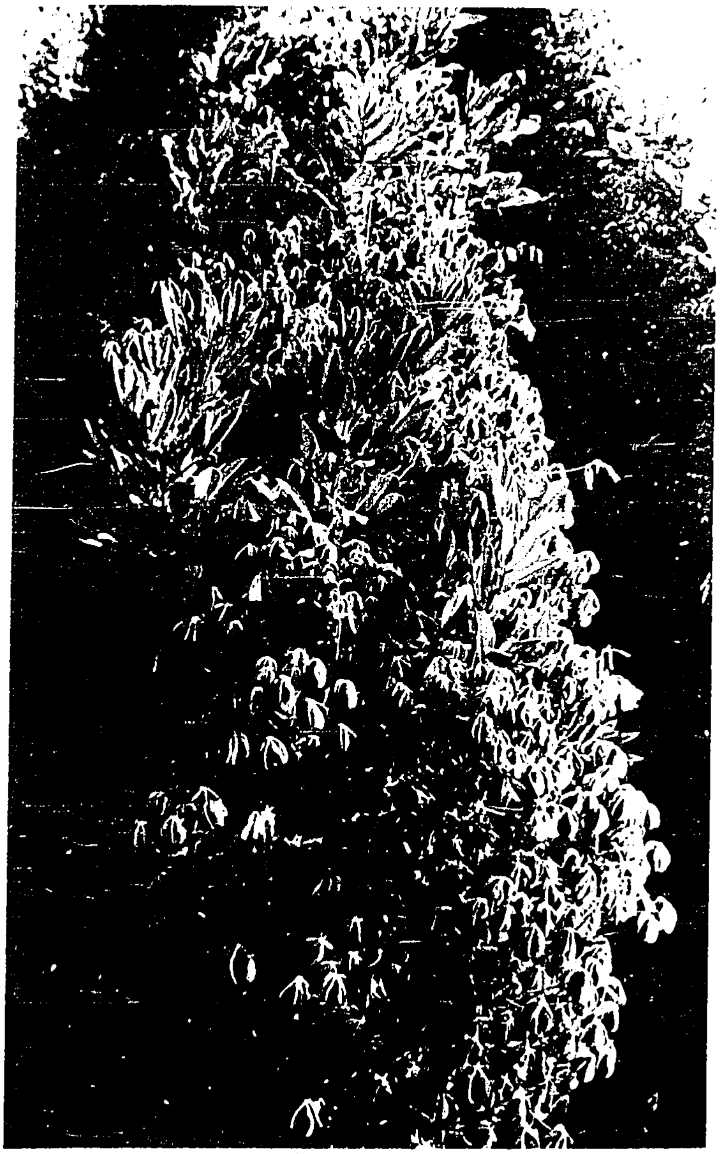
Seed tubers of *Oxalis tuberosa* are planted from 40 to 140 mm below the soil surface. Experiments in the region of Ayacucho at 3600 m with 33 clones of *Oxalis tuberosa* have indicated that optimum yields are obtained with a distance between rows of 750 mm and a distance between plants of 200 mm (Canales & Baldomero, 1977).

In the central and southern region of Peru, Oxalis tuberosa is planted in October and November and harvested April and May. Research conducted with 400 germplasm collections of Oxalis tuberosa in Cuzco has shown the vegetative cycle to range between 220 to 269 days from planting to harvest (Cortés, 1977). Tuberization is in part initiated by the onset of shortened daylength. In experiments with 10 of the above mentioned Cuzco collections tuberization began after 110 days, and the period of maximum tuber growth ranged from 170 to 230 days after planting (Cortés, 1977). Informants in Colombia and Bolivia reported similar vegetative cycles of 7 to 9 months between planting and harvest, although one report of an 11 month cycle has been reported in Colombia (White, 1975).

There is a high diversity of cultivation systems utilized by Andean farmers. Monocroping Oxalis tuberosa is not uncommon but it is also frequently intercropped with Tropaeolum tuberosum, Ullucus tuberosus (Fig. 15), tuber bearing Solanum species, Arracacia xanthorrhiza, Zea mays and several other crops. Direct interplanting in the same row with Vicia faba (Fig. 16) is practised; in the same row so that the Vicia faba grows up through and above the Oxalis tuberosa plants. In addition, Oxalis tuberosa is frequently interplanted with Allium species, a practice which is reported by farmers to decrease insect damage. Fields that mix all of the above mentioned species have also been observed in Peru and Bolivia. Oxalis tuberosa is also often cultivated in house gardens with a mixture of culinary herbs, medicinals and ornamentals.

Fig. 15. *Oxalis tuberosa* interplanted with *Ullucus tuberosus* and *Tropaeolum tuberosum*. Chinchero, Peru.

Fig. 16. Oxalis tuberosa interplanted with Vicia faba. Region of Tunja, Colombia.



Oxalis tuberosa in Colombia, Ecuador and Peru is considered a short day plant, requiring 11-12 hours of daylength for optimum plant growth and tuber formation. In Bolivia, collections of *Oxalis tuberosa* cultivated under the same daylength, at 17 °S, and at elevations of 2560 m and 3400 m exhibited greatly reduced flowering at the lower elevation (Cárdenas, 1958). The amount of precipitation required during the growing season has been suggested as ranging from 350-452 mm spread over the entire season, while an 11 year average of precipitation for an 8 month growing season in Puno, Peru was reported as 602 mm (Lescano Rivero, 1984). Canales & Baldomero (1977) recorded 610 mm in one season and noted it as a typical year.

The commercial cultivation of *Oxalis tuberosa* in New Zealand at latitudes of 40°-46° S suggests that there are varieties of *Oxalis tuberosa* that are less sensitive to daylength (Palmer, 1982). The environment where *Oxalis tuberosa* is cultivated in New Zealand is typified by mild winters, a long growing season, and is very similar to the environmental conditions near the equator at 2000 to 3000 m (Dawes, pers. comm.) The material grown now in New Zealand is likely to have originated in Central or Southern Chile where *Oxalis tuberosa* may be less daylength sensitive. Cárdenas (1958) suggested Chile as a source for *Oxalis tuberosa* germplasm with less daylength sensitivity. He found that Chilean *Chenopodium quinoa* varieties produced seed in England when Bolivian *C. quinoa* would not (Cárdenas, 1958).

Yields of Oxalis tuberosa are dependent upon the cultivars planted, soil conditions, environmental features, soil inputs and cropping method. Yields range from 7 to 30 tons per hectare (t/h), with an average of 21.1 t/h for 7 ecotypes of Oxalis tuberosa from Peru and Bolivia (Tapia, 1984). Experiments under controlled conditions in southern Peru have produced yields of up to 97 t/h, although this high a yield has not been reported by farmers (Cortés, 1977). A positive correlation between high yields and large leaf diameter has also been reported by Canales & Baldomero (1977). The average production in 1982 for tuber bearing Solanum species in the Andean region was 46 t/h (International Potato Center, 1984). This yield is in part the result of decades of international agricultural research and costly inputs aimed at improving the yields of tuber bearing Solanum species. It is likely that yields of Oxalis tuberosa could be improved with similar inputs.

Inputs

In the context of traditional Andean agricultural practices, fertilizers, herbicides and insecticides are not commonly applied to fields of Oxalis tuberosa, in part due to the rustic nature of the crop. Manure from cattle and sheep is infrequently applied to Oxalis tuberosa fields but is often reserved for other crops that have a stronger market, such as potatoes. Micronutrient deficiencies in Oxalis tuberosa plants have been identified and a key to their symptoms prepared (Lescano Rivero, 1984).

Experiments conducted on the effect of nitrogen (N), phosphorus (P) and potassium (K) on yield have been conducted in the Cuzco region of Peru. The results indicated that adding these nutrients increased yields from 30 t/h to 44.5 t/h with N, 26.5 t/h to 45.5 t/h for P and 27.5 t/h to 45.6 t/h for K (Cortés, 1977). Cost benefit data regarding the price of fertilzer per hectare versus the value of the increased production was not included in this study.

Preliminary comparative research on the use of herbicides to control weeds has also been conducted. Yields from fields that were treated with several commercial herbacides, (Tribunil, Lorox, Karmex, Aflon and Sencor) were compared to fields that were weeded by hand as well as a control left untouched. The data indicated that yields from fields that were treated with herbicides were equal to or less then the fields that were manually cleared of weeds (Cortés, 1977).

Disease and Insect Predation

There are several diseases that are likely to reduce the crop's productivity. The case of Ullucus tuberosus is discussed below. Clones of Oxalis tuberosa from Bolivia have been found to carry arracacha B virus (AVB) and mycoplasm-like bodies (MPLB), and these pathogens appear to cause severely diseased plants (Jones & Kenten, 1981; Atkey & Brunt, 1982).

Using meristem-tip culture techniques these diseases can be eliminated from Oxalis tuberosa. Elimination of these diseases from Oxalis tuberosa may increase the yield by up to 30-40 % but this has yet to be tested in agricultural fields in the Andes. Future experimental introduction of this crop to other areas of the world will require disease-free germplasm.

The most frequently cited insect pests of Oxalis tuberosa are Chrysomelid beetles of the genus Coleoptera, ("gusano de la oca") and nematodes of the genus Heterodera ("nematodo de oro") (Cortés, 1977; Kay, 1973; Lescano Rivero, 1977). Coleoptera sp. attacks Oxalis tuberosa at two stages of its life cycle. In the adult stage the insect eats the leaves and in its larval stage it devours the stolons and tubers (Cortés, 1977). The larve stage appears shortly after tuberization. The larva are often encountered in stored seed tuber, which then hatch again after planting to renew the infestation in the next season. Experiments with multiple clones of Oxalis tuberosa have revealed nearly complete resistance to both Coleoptera and Heterodera. Experiments with germplasm accessions in Southern Peru showed that 39 accessions were not affected by the Coleoptera beetle with 5% of the tubers being damaged in 130 accessions (Cortés, 1977). Tests with insecticides resulted in a reduction in the incidence of Coleoptera infestation (Cortés, 1977).

In the case of the Heterodora nematode, observations on 145 germplasm accessions in Puno suggested that 22% of the varieties were highly resistant, 63% were resistant, 12% were susceptible and 3% were highly susceptible to Heterodora attack (Lescano Rivero, 1977).

Among other insects that attack Oxalis tubersosa, the most damaging to the underground portion of the plant is Copitarsia tubata H. S. ("gusano de tierra") and the most damaging species to the above-ground portion is Macrosiphum euphorbiae Thomas (Lescano Rivero, 1977). Lescano listed three species as being beneficial to Oxalis tuberosa: Coleomegilla maculata De Greer ("Mariquitas"), Aphidus colemani Viereck ("Avispas") and Syrphus sp. ("Moscas siroides"); the type of benefit to Oxalis tuberosa was not described.

In reference to the incidence of pre-harvest crop loss due to insect pests it is important to note two traditional agricultural practices associated with tuber crop cultivation. Fields of Oxalis tuberosa are routinely planted with many cultivars of Oxalis tuberosa, which, given the variable susceptibility cited above, reduces the percentage of crop loss. It is also a common practice for farmers periodically to travel to other regions and exchange or purchase varieties of Oxalis tuberosa that are "new" to their fields, which introduce new clones that may be resistant to insect attack.

Fasciation

It is common to encounter fasciated stems and tubers in fields of Oxalis tuberosa. Comparative research on the yields of fasciated and normal plants has shown that there is no significant difference between fasciated and normal plants (Cortés, 1977). A discussion of the possible origin of fasciated Oxalis tuberosa plants is presented by White (1975).

Consumption

Oxalis tuberosa is consumed raw and cooked in numerous distinct dishes throughout the Andes and New Zealand. In the Andean region the tubers are used in soups and stews, steamed, (Fig. 17) boiled, baked like potatoes, or served as a sweet. In Colombia and Venezuela several other additional products have been reported including a type of candied _Oxalis tuberosa_, a fermented beverage "chicha de oca" and a hot sauce (White, 1975). In New Zealand, _Oxalis tuberosa_ is used in several dishes and is especially popular as a side dish roasted with lamb. The taste of _Oxalis tuberosa_ has frequently been described as pleasantly sourish (Vietmeyer, 1986). A second important use of _Oxalis tuberosa_ involves a freeze dried product known in Peru as "caya" that enables growers to preserve and store the tubers for several years.

Processing and Storage

The production of "caya" is similar to several of the ancient well known processes used to make freeze dried potatoes known as "chuño" or "tunta", or "moraya" (Werge, 1979; Woolfe, 1987). The production of "caya" involves several steps as follows. After harverst, the tubers are spread outside to freeze in the low tempertures of the Andean winter, June and July, for 3 to 5 nights. During this phase of the process the tubers are covered during the day to protect them from damage caused by exposure to sunlight (Cortés, 1977). Moisture is then pressed out of the tubers, usually by stepping on them, in the late afternoon (Fuentes, 1982).

Fig. 17. Steamed _Oxalis tuberosa_, sold in the streets of Lima, Peru.

the pressed tubers are then placed in a stream or lake for 8 to 40 days, as determined by the farmer. Finally the tubers are removed from the water and placed in the sun until dry. The finished product (Fig. 18) is a freeze-dried tuber that can be reconstituted and used in soups or stews; it will not spoil for several years. This method provides food insurance against years of disaster and low crop yield. The nutritional qualities of "caya", discussed in Chapter 6, appear to be reasonably high.

Some landraces are well suited for "caya" production while others are not. Hodge (1946) suggested that tubers reputed to be high in calcium oxalates, termed "bitter tubers", are often made into "caya". Some varieties are considered bitter and only suited for the production of "caya" (Rea & Morales, 1980). It is implied that the process of making freeze-dried Oxalis tuberosa removes calcium oxalate crystals that cause the tubers to be unpalatable. It has been proven that the process of freeze-drying potatoes with high glycoalkaloid levels (bitter potatoes) lowered the glycoalkaloid content by 41 to 89% (Christiansen, 1977). However no studies comparing levels of calcium oxalate before and after the "caya" making process have been conducted. The question of calcium oxalate levels and human nutrition is discussed in Chapter 6.

In Bolivia at least four varieties are made sweeter by being placed in the sun for one to several days and this is a common practice throughout the Andes (Rea & Morales, 1980; Cortés, 1977). Cortés (1977) reported that glucose levels in fresh tubers increased an average of 40% after being placed in the sun. Because oxalic acid is partially soluable in water the "caya" making process likely to

Fig. 18. A, Processed freeze-dried Oxalis tuberosa "caya" for long term storage. B, Freeze dried Ullucus tuberosus. C, freeze-dried potatoes. Ayacucho, Peru.


A
C
C
B

diminish the concentration of oxalic acid and thereby make them more palatable. In Peru only 10% of the crop is devoted to the production of freeze-dried "caya". When cooked in regional dishes, "caya" does not impart a strong taste; and it is a ready carbohydrate additive. By processing tubers into "caya", a portion of the crop can be stored for future use.

Numerous methods are utilized to store Oxalis tuberosa. Tubers are tied together and suspended from ceilings in Colombia; throughout the Andean region tubers are stored in wool and cloth bags, usually in cool dry areas of homes. The condition of the tubers is periodically checked for deterioration, especially seed tubers. Peruvian researchers point out that loss during postharvest storage is far more serious then damage from disease. Insects can cause crop loss of up to 38% (Cortés, 1984; Delagado et al., 1982). The organism responsible for these losses is a species of the genus Rhizopus sp. (Mucoraceae) (Delgado et al., 1982). Improved methods of crop storage aimed at controlling sprouting and reducing losses in potatoes have been developed at the International Potato Center (Monares, 1980; Werge, 1977) Similar research on storage systems for Oxalis tuberosa should be undertaken with the aim of reducing crop loss.

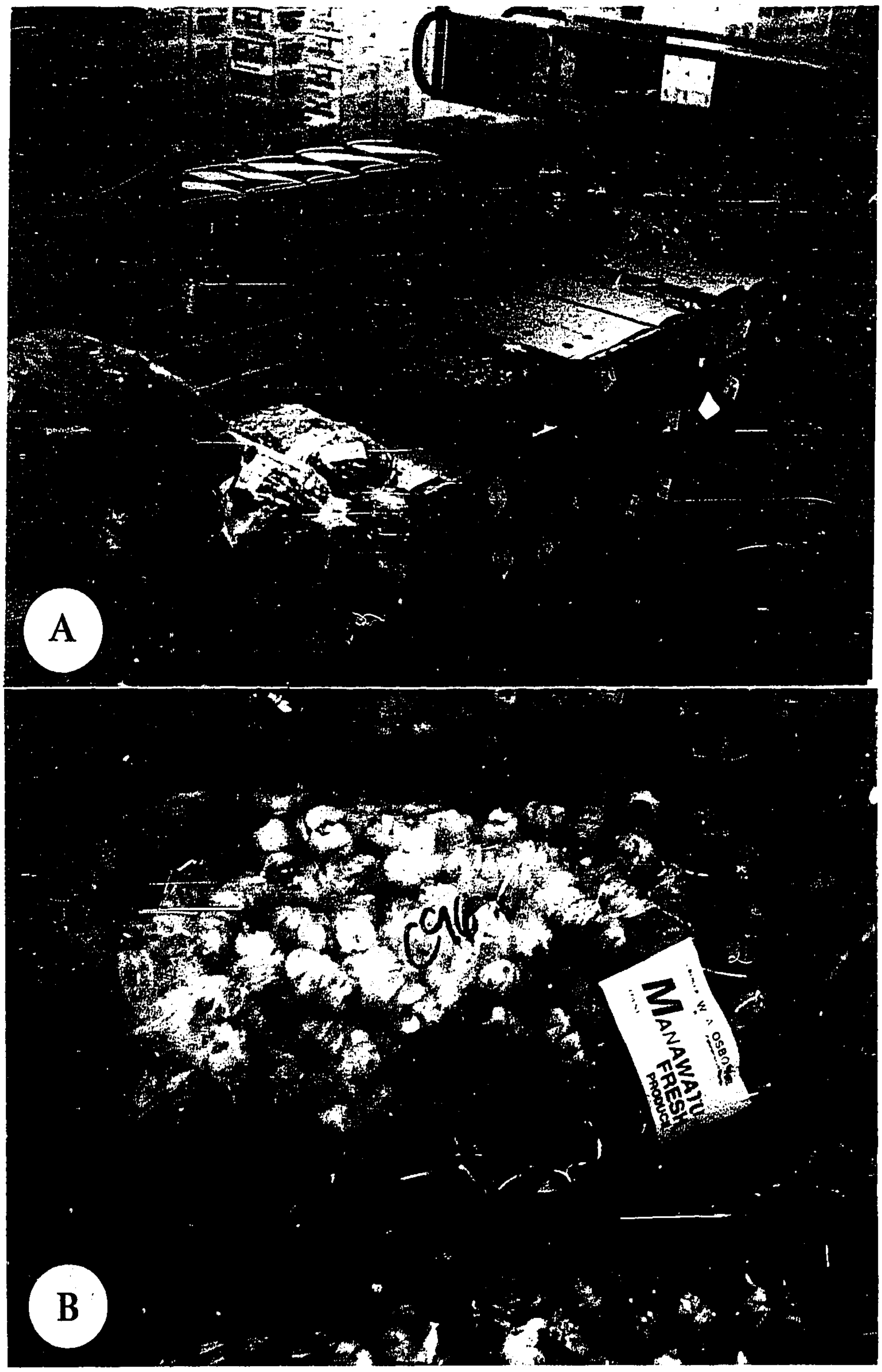
Market Value

The market value of Oxalis tuberosa in the Andean region is usually 10-20% lower than the price of preferred varieties of potatoes. This lower market value reflects, in part, the status of the crop on a national level. It is considered a rustic crop of the mountains that is not in great demand in urban areas. It is estimated that 32,000 hectares of Oxalis tuberosa were under cultivation in 1983 in Ecuador, Peru and Bolivia (Tapia, 1984). The tubers are also traded in traditional Andean markets for fruit, vegetables and coca. In Mexico the market value of Oxalis tuberosa was reported to be 20-50% less than potatoes (see Chapter 8). As previously mentioned, there is an increasing demand for Oxalis tuberosa in New Zealand, where it is marketed by Turners & Growers Ltd. in Auckland on a wholesale basis (Fig. 19). Outside the capital city of Auckland, Oxalis tuberosa is also marketed by small scale producers, and the price has been reported as comparable to potato prices.

Industrial Potential

Several Andean researchers have suggested that due to a high dry matter content there is a strong, as yet unexploited theoretical potential for utilizing Oxalis tuberosa as a source for starch, flour and alcohol (Cortes, 1977; Ochoa et al., 1981). Experiments with 356 clones of Oxalis tuberosa yielded an average of 24% dry matter, 16% starch and 21% flour. The characteristics of the starch were reported as follows: grain size 0.02 mm, temperature of gelatinization 68° C, apparent density 0.78 gr/cc and true density 1.511 gr/cc (Cortés, 1977). One kilo of Oxalis tubers produced an average of 173 cc of 45% alcohol that contained 70% ethanol (Cortés, 1977).

Fig. 19. A, *Oxalis tuberosa* for sale in wholesale market in Auckland, New Zealand. B, Detail of same. Photographs courtesy of G. Samuels.


A
B
MANAWATU
FRESH

Tropaeolum tuberosum

Propagation and Seed Production

The floral biology and pollen morphology of *Tropaeolum tuberosum* has been examined (Cárdenas, 1958; Huynh, 1968; White, 1975; Ramírez 1977). In contrast to *Oxalis tuberosa*, this species produces considerable quantities of viable seed (Cortés, 1984). One Bolivian scientist has recently conducted breeding work with seed aimed at producing a high protein variety of *Tropaeolum tuberosum* (Rea, 1984b). He selected a variety of *Tropaeolum tuberosum* that contains high protein levels (see Chapter 6). When sexual seed is produced, germination rates are reported to be high (Cortés, 1984). Farmers do not use sexual seed for propagation. *Tropaeolum tuberosum*, like *Oxalis tuberosa* and *Ullucus tuberosus* is always propagated by seed-tubers selected from the previous year's harvest.

Cultivation System, Daylength and Yield

The planting methods are similar to those described for *Oxalis tuberosa*: seed tubers are planted 50-150 mm below the soil surface. Experiments with the density of planting in Puno, Peru have demonstrated optimum production with a distance between rows of 800 mm and a distance between plants of 250 mm (Lescano Rivero, 1984).

The agricultural cycle of Tropaeolum tuberosum is quite similar to that described for Oxalis tuberosa. Seed tubers are planted in September or October and harvested 7-9 months later in April or May. Experiments conducted in Puno and Cuzco, suggest that the vegetative phase of Tropaeolum tuberosum from planting to harvest varies between 185 to 245 days (Cortés, 1984; Tapia, 1984).

Tropaeolum tubers are cultivated in monospecific fields, especially in the departement of Boyacá, in northern Colombia (Fig. 20). It is also cultivated with Solanum juzepczukii and Solanum curtilobum in Bolivia (bitter potatoes). The list of crops interplanted with Oxalis tuberosa also applies to Tropaeolum tuberosum.

Tropaeolum tuberosum is also considered a valuable companion plant because the tubers contain secondary compounds that are reputed to have nematocidal and insecticidal properties. Farmers have reported that they interplant Tropaeolum tuberosum with other tuber crops because they believe "it is resistant to pathogen attack and capable of protecting other tubers from destruction" (Johns et al., 1982). At 3800 m and above, the planting of Tropaeolum tuberosum and the other tubers is often rotated over a 10 year period with 4-6 fallow years (Mateo & Tapia, in press). A common cropping sequence for 4 years would be bitter potatoes, followed by 2 years of intercropped Tropaeolum tuberosum with Ullucus tuberosus and a final year of barley before the fallow phase (Mateo & Tapia, in press).

Fig. 20. Harvesting commercial field of Tropaeolum tuberosum in the region of Tunja, Colombia. 3600 m.

Tropaeolum tuberosum is also a short-day plant, with optimum daylength for flowering being 10-12 hours and 9 hours for tuberization. Experiments aimed at producing flowering and tuberization under long-day conditions in Leningrad, U.S.S.R., Russia were not successful (Bukasov, 1930). *Tropaeolum tuberosum* is cultivated in New Zealand and does form tubers, although it is not yet commercially in demand (Palmer, 1982). In New Zealand, *Tropaeolum tuberosum* is reported to be frost sensitive (Sykes, pers. comm.). The optimal temperature and moisture requirements of *Tropaeolum tuberosum* have not been systematically studied but appear to be similar to the requirements of *Oxalis tuberosa*.

The yields of *Tropaeolum tuberosum* are reported to range between 20 - 30 t/h with a wide degree of variation among ecogeographic areas (Tapia, 1984; Lescano, 1984). Experiments with 25 varieties in Cuzco, Peru, have resulted in yields of up to 50 t/h (Cortés, 1977).

Inputs

There are very few reports of high levels of organic or synthetic fertilizer applied to fields of *Tropaeolum tuberosum*. Informants from commercial production zones in northern Colombia did not report using fertilizers on their fields. The addition of small amounts of sheep, llama and cattle manure to fields being prepared for *Tropaeolum tuberosum* planting has been observed in a few fields in Southern Peru.

Disease and Insect Predation

Tropaeolum tuberosum has been found to contain numerous viruses which have not been previously described (A. Brunt pers. comm.). Recently *Tropaeolum tuberosum* has been found to carry potato leaf virus (J. Martineau, unpubl. data). Research is now in progress by Brunt and co-workers to identify and describe these viruses.

The only known insect pest of *Tropaeolum tuberosum* is *Spongospora subterranea* (White, 1975). Bukasov (1930), did report that tubers of *Tropaeolum tuberosum* are much attacked by "insect larva" but he did not elaborate. The tubers of *Tropaeolum tuberosum* contain isothiocyanates and Johns *et al*. (1982) has shown that these isothicyanates show insecticidal and nematocidal activity. The utilization of *Tropaeolum tuberosum* as deterent to pathogens strongly suggests that it should be introduced along with the other species discussed in this research to any new area as an allelopathic deterrent to nematode and insect damage.

Fasciation

Fasciation of *Tropaeolum tuberosum* is reported as being an infrequent morphological growth form of this species (White, 1975). This abnormal growth form occurs in both the above ground stems and in the tubers. No comparative data has been encountered on the relative frequency effects on yields of fasciated plants.

Consumption

Tubers of <u>Tropaeolum</u> <u>tuberosum</u> have been historically and are currently cultivated for use as food and Medicine (Johns <u>et</u> <u>al</u>., 1982). Discusion of its medicinal properties are presented in Chapter 7. In the department of Ancash, Peru, <u>Tropaeolum</u> <u>tuberosum</u> is considered to be suitable as food for women but men do not eat it believing that it will cause impotence (Johns, 1986b).

<u>Tropaeolum</u> <u>tuberosum</u> tubers are rarely consumed raw. It has been suggested that the noticeable odor, a known feature of isothiocyanates, and most cultivars require cooking first. Those tubers cultivated for food are eaten in stews, soups, and a number of distinct regional dishes. One especially delicious preparation sampled by this author in Southern Colombia included sauteéd tubers, onions, peppers, salt and two eggs. In Bolivia, tubers are cooked and then frozen to be sold in the markets by the name of "tcayacha" (Bukasov, 1930) and these have also been reported to be consumed with molasses (Johns <u>et</u> <u>al</u>., 1982).

Processing and Storage

In contrast to <u>Oxalis</u> <u>tuberosa</u> and <u>Ullucus</u> <u>tuberosus</u>, there does not appear to exist a freeze-drying process used to preserve tubers of <u>Tropaeolum</u> <u>tuberosum</u>. Tubers are stored in cool dry areas of homes.

Market Value

The market value of _Tropaeolum tuberosum_ depends upon whether the tubers purchased are considered medicinal or food. In the region of Northern Colombia food tubers predominate and the price was lower then potatoes or _Oxalis_ tubers. In southern Colombia medicinal tubers were not sold by weight but by the tuber, and they were sold in the medicinal plant section of the market in an area distinct from the food selling section. The price of the medicinal tubers, compared to food tubers on an equal weight basis, was considerably higher. This division of medicinal versus food tubers was encountered only in Colombia. In comparison with _Oxalis tuberosa_ and _Ullucus tuberosus_, _Tropaeolum tuberosum_ is the least preferred.

Industrial Potential

Rea (1984b) suggested that _Tropaeolum_ tubers be used for cattle feed. In an experiment in Peru cattle were fed _Tropaeolum_ tubers and compared with commercial feed. The results suggest that _Tropaeolum tuberosum_ is a high quality feed comparable to regional market products. Cortés (1984) has suggested that the 30 percent dry matter content of _Tropaeolum_ tubers could be processed into commercial flour.

Ullucus tuberosus

Propagation and Seed Production

Ullucus tuberosus is most often considered an asexual crop that rarely or never produces fruit or seed (León, 1964a; Brücher, 1977; Galeway & Risi Carbone, 1983; Sperling, 1987). Recently however, fruit and viable seed of Ullucus tuberosus have been produced and described under controlled conditions in Finland (Rousi et al, in press). The formation of more then 1000 fruits in Ullucus tuberosus suggests that future breeding efforts may be able to utilize seed to improve the crop (Rousi et al., 1986).

Both the cultivated and wild subspecies of Ullucus tuberosus produce viable pollen. Sperling (1987) reported that the rarely produced seeds encountered in cultivated Ullucus contain an apparently aborted embryo. Sperling has suggested that apmoxis may be responsible for the occurrence of fruit production reported by the Rousi et al. (1986). One clone of Ullucus tuberosus encountered in southern Peru has been reported as producing seed and growing in a field adjacent to a population of the wild subspecies (Sperling, 1987) and the potential cross-pollination of cultivated and wild species has been suggested as a possible stimulus of fruit initiation.

In the Andean region Ullucus tuberosus is propagated vegetatively. In that area I never encountered farmers cultivating this species from seed. Among the four species included in this research Ullucus tuberosus exhibits the greatest diversity of tuber form, shape and color. One explanation for the origin of such diversity in a crop that has become routinely sterile, is that the variation is produced by somatic mutations. Rousi et al. (1987), have suggested that it is likely that sexual reproduction did occur in the early stages of the domestication of this crop.

Cultivation System, Daylength and Yield

Tubers are planted 50-150 mm below the surface of the soil. The prefered size of seed tubers in Puno, Peru was 50-60 grams each (Tapia, 1984). The average distance between rows and plants has been reported as 800-1000 mm between rows and 500 mm between plants (Rea, 1975). In Colombia planting takes place from March to August with harvest 180 to 360 days later (Sperling, 1987). In Peru, the planting and harvest cycle is similar that of Oxalis tuberosa and Tropaeolum tuberosum with planting occuring in September or October and harvest 7-9 months later in April or May. The period of time between planting and harvest varies in each of the above mentioned countries and is dependant upon the seasonal variation and micro-climate in which they are planted.

The monoculture of Ullucus tuberosus for wholesale distribution was observed in the region of Silvia, Colombia. In Peru it is estimated that 15,000 hectares of Ullucus tuberosus were under cultivation in 1983 (INPA, 1983). It is often interplanted with Allium sp. (Fig. 21) and with many other crops (Fig. 22), as described for Oxalis tuberosa and Tropaeolum tuberosum. There are two distinct growth forms documented for Ullucus tuberosus, one is an erect form and the other is a scandent trailing form (Fig. 23).

Fig. 21. Ullucus tuberosus interplanted in the same row with Allium sp. region of Silvia, Colombia.

Fig. 22. _Ullucus tuberosus_ intercropped with _Oxalis tuberosa_ in Huancavelica, Peru. 3700 m.

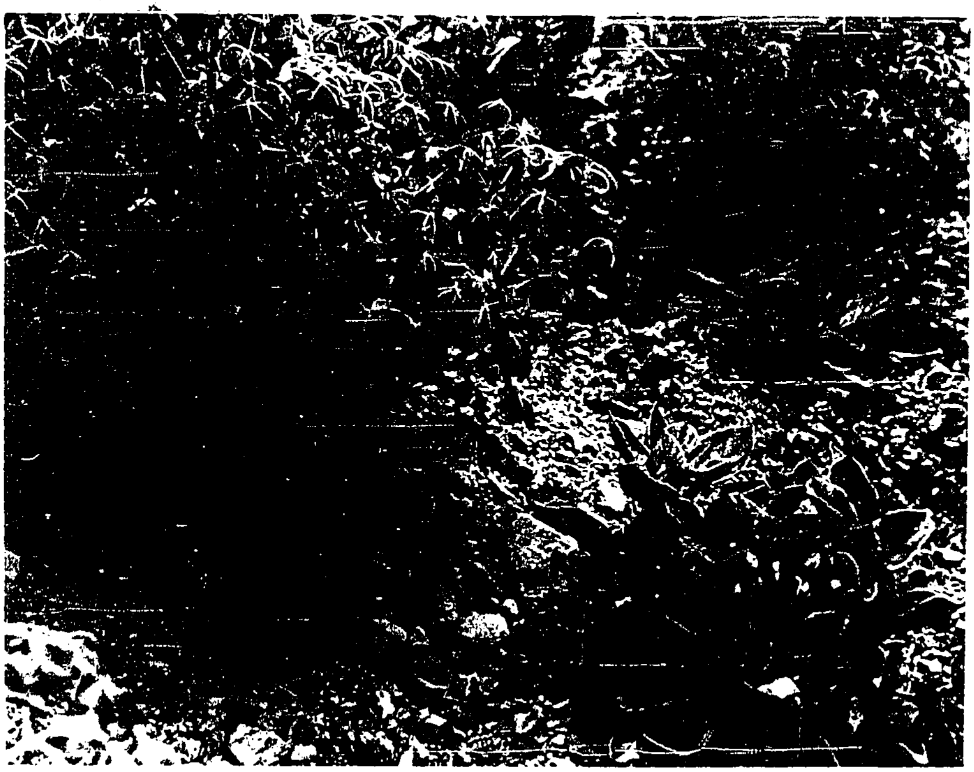


Fig. 23. Two growth forms of Ullucus tuberosus, A, scandent trailing form and B, Erect form. Region of Silvia, Colombia.


A
B

Ullucus tuberosus is also a short-day plant requiring 11 to 13 hours of daylength for the initiation of tuberization (Sperling, 1987). Rousi *et al*. (1986) compared the yields of tubers under short and long daylengths and found the that the mean yield for plants under short days was 270 grams per plant and 20 grams per plant under long days.

Flowering and then stolon formation occurs 80-100 days after planting (Sperling, 1987) and tuberization take place 111-150 days after planting (Benavides, 1967). Sperling (1987) reported that longer days initiate vigorous flowering and that the subsequent shortening of daylength favors tuber production.

The data for yields of *Ullucus tuberosus* indicates a wide degree of variation. Reports have been cited between 2.2 t/h in Ayacucho, Peru to 10.6 t/h in Cuzco, Peru and one researcher reported yields to 19 t/h (Rea, 1975; Cortés, 1984; Tapia, 1984).

Inputs

As in the case of *Oxalis tuberosa* and *Tropaeolum tuberosum* there are very few reports of the use of organic or commercial fertilizer on fields of *Ullucus tuberosus*. Experiments have been conducted on the effects of adding a mixture of NPK to fields of *Ullucus tuberosus*. This research suggested that the largest yield of 15.48 t/h was obtained using the largest quantity of 11 levels of NPK (Cortés, 1984).

Disease and Insect Pests

Ullucus tuberosus contains a complex of three or four viruses. These viruses have been identified as potexvius (PMV/U) a tobamovirus (TMV/U), a potyvirus (tentatively designated Ullucus mosaic virus, UMV) and a newly recognized comovirus (Ullucus virus C) (Brunt et al., 1982a; 1982b).

The potexvirus (PMV/C) was found to infect Ullucus tuberosus but produced no symptoms. The tobamovirus (TMV/U appears to induce conspicuous necrotic lesions in Nicotiana glutinosa. The Ullucus mosaic virus (UMV) alone in Ullucus tuberosus induced leaf symptoms indistinguishable from the chlorotic mottling and distortion found in naturally infected plants. Plants infected with Ullucus virus C stunted and showed some chlorotic leaves but plants infected experimentally with Ullucus virus C alone remain symptomless (Brunt et al., 1982b).

All four of these viruses have been experimentally eliminated from Ullucus tuberosus using meristem-tip culture and chemotherapy (Stone, 1982). Comparative field trials on the effects of these viruses on plant growth have not yet been conducted but it is suggested that elimination of these viruses would dramatically increase plant vigor and yield (A. Brunt, pers. comm.). In order to conduct field trials with Ullucus tuberosus in countries outside of the Andean range it will be necessary to have virus-free material.

Reports of the insect pests of Ullucus tuberosus are few, one is larva of the genus liriomyz (Cortés, 1984). The other pests reported for Ull‹‹us tuberosa is "gorgojo de los andes" (Premnotrypes) and the nematode Heterodera rostochiensis (Fries & Tapia, 1986).

Consumption

Ullucus tuberosus is prepared in numerous types of dishes throughout the Andes. Most commonly the tubers are cooked in soups or stews with meat and vegetables. Cooked, the texture of the tubers is smooth and the taste is pleasant, and distinct from the flavor and texture of potatoes. In markets of southern Peru they are often sliced into thin strips and sold in piles soups and salads. Two popular dishes in both urban and rural areas of Peru is "olluquito con charqui" (Fig. 24), (Ullucus steamed or sauted with dried meat), and "aji de lizas", (a dish prepared with hot capsicum peppers and the tubers) (Fries & Tapia, 1986). In Ecuador tubers are boiled, mashed and fried into tortilla like patties (Sperling 1987). The leaves of Ullucus tuberosus are also reported to be infrequently eaten as salad greens and in a special soup dish made at Easter (Sperling, 1987).

Fig. 24. Ullucus tuberosus eaten as part of urban diet, Bogotá, Colombia.

Processing and Storage

The tubers Of Ullucus tuberosus are characterized by varying levels of mucilage content. In Peru certain varieties are lightly processed by boiling the tubers twice, changing the water after the first boiling (Fries & Tapia, 1984). Ullucus tuberosus is also processed into a freeze-dried product known as "lingli" but its production is diminishing (Fries & Tapia, 1984).

The method of production of "lingli" is similar to that employed for making freeze-dried potatoes. The moisture is pressed out of the tubers by stepping on them. The tubers are then exposed to sunlight and freezing temperatures typical of the postharvest season (Sperling, 1987). The process requires up to several weeks of alternating drying and freezing. The final product is rehydrated (Fig. 25) and added to soups and stews. In this state, the "lingli" lasts for several years.

Fresh tubers are stored in cool dark areas of homes and are reported to remain in good condition until the next harvest and in Peru inside cone shaped structures made of barley, wheat or oat chaff (Fig. 26).

Market Value

Ullucus tuberosus is valued in both rural and urban markets of Colombia, Ecuador, Peru and Bolivia. In Cali, Colombia it is sold in urban supermarkets at prices equal to or higher then potatoes. In Peru urban consumers consider it a delicacy and the annual Peruvian market

Fig. 25. Freeze dried Ullucus tuberosus "lingli". A, Equal amounts of product after rehydrating and B, before. Ayacucho, Peru.

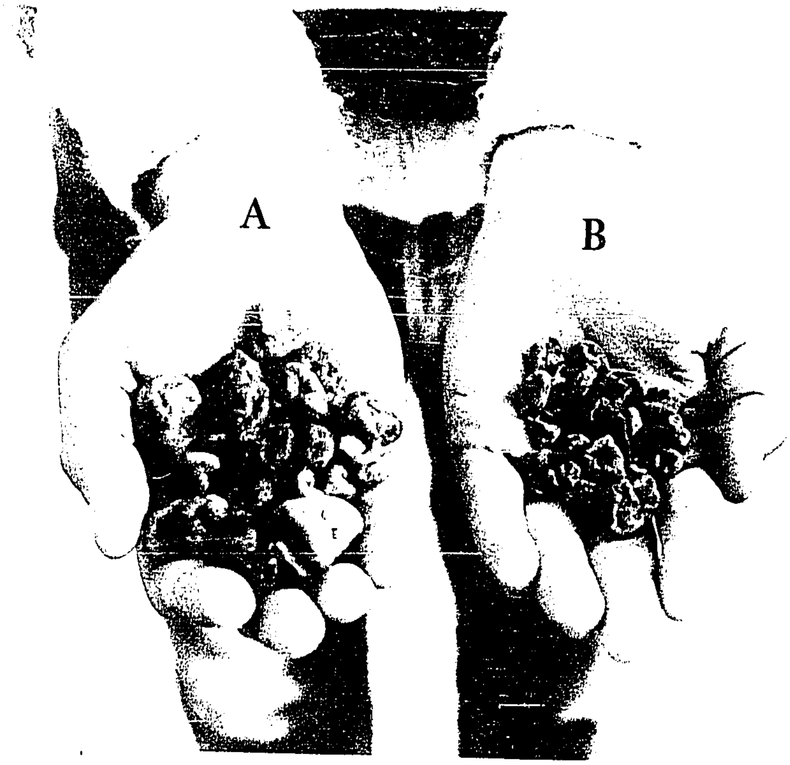
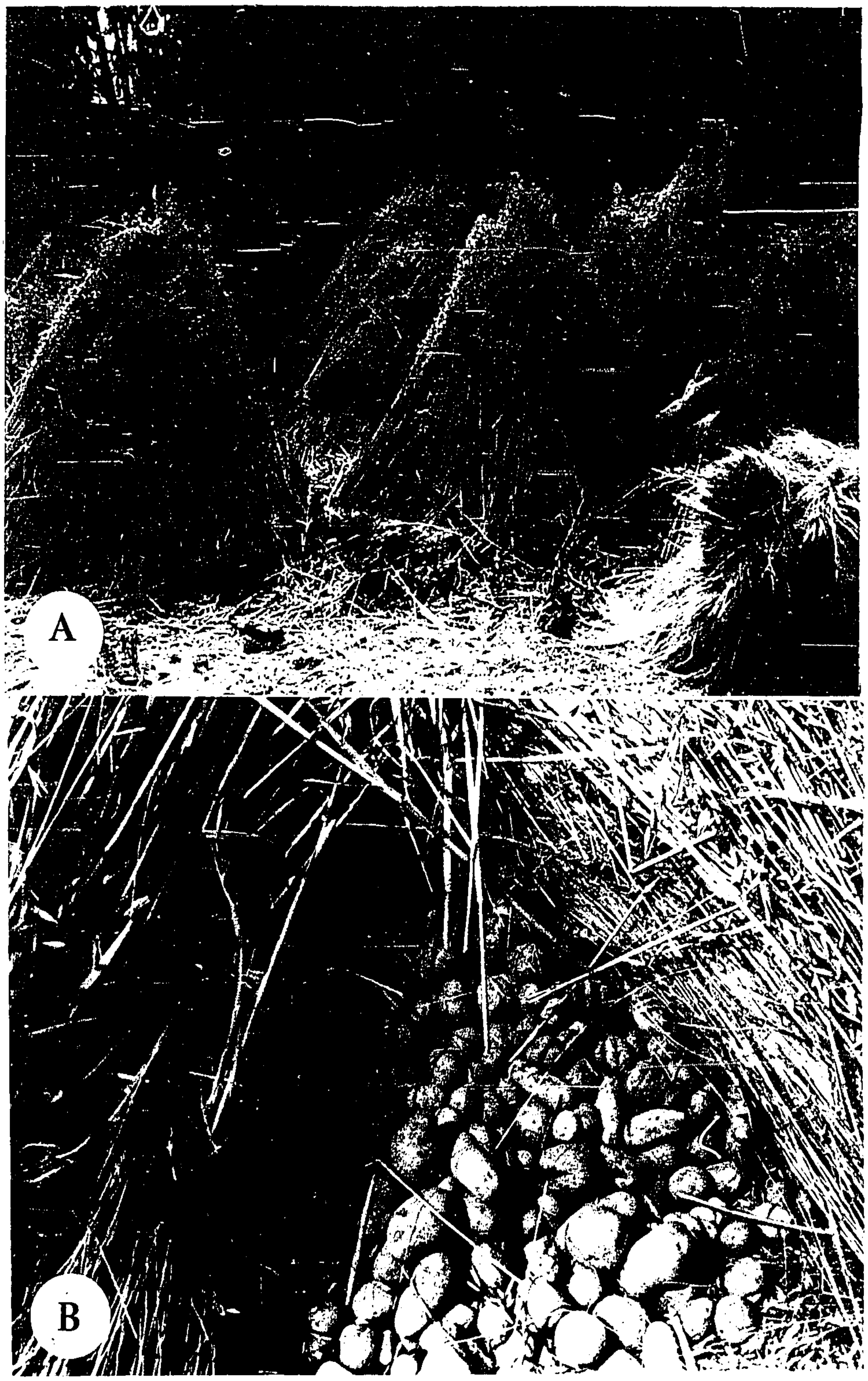

A
B

Fig. 26. A, *Avena sativa* used as short term storage structure for *Ullucus tuberosus*. B, *Ullucus* tubers inside storage structure. The same method is used for *Oxalis tuberosa* and *Tropaeolum tuberosum*, species normally stored in separate structures. Chinchero, Peru.



demand in 1983 was reported as 60,000 tons per year (Vietmeyer, 1985). In Ecuador, farmers consider it a valuable cash crop and produce it specifically for sale. It is also exchanged in traditional markets for other fruits and vegetables (Fig. 27).

Industrial Potential

Ullucus tuberosus is now availible outside of the Andean zone. Canned tubers (Fig. 28) are imported to the United States by Incas Food, Mahwah, New Jersey and are sold in 7 major cities by stores that carry Latin American food products. The price in Boston, New York and Washington varies between $ US 2.00 - 3.00/can. Because of its great diversity of form and color it is considered aesthetically attractive to a wide range of people. There is a high potential for creating an expanded market in North America and Europe as a new food, especially if it can be cultivated in these regions.

Fig. 27. Ullucus tuberosus being offered for barter or cash in traditional market in Chinchero, Peru.

Fig. 28 Canned Ullucus tuberosus purchased in hispanic market in Washington, D.C. Photograph courtesy of C. Sperling.


INGREDIENTS:
Tuberosas Caldis
In Water and Salt
INGREDIENTES:
Melloco, Papa Lisa
En Agua y Sal
and Distributed By:
Import Company
New Jersey 07430
Phone: 201-529-3708
OLE. OLLUCO. MELLOCO
IN BRINE

Chapter 6 - Nutritional Value and Variability

Introduction

The nutritional value of Lepidium meyenii, Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus has sporadically been reported in general treatments of these crops. Bukasov (1930) provided limited data for all but Lepidium meyenii. The material he analysed was most likely from Colombia although the origin was not indicated. Proximate anaylsis ("proximate" is nutritional term for general analysis, see Table X) data from Peru for all but Lepidium meyenii have been published by Cortés (1977; 1984), Lescano Rivero, (1984) and Collazos (1975). The data presented by these first two authors does not indicate the number of varieties analyzed or the method of analysis. The last citation is from the Peruvian Ministry of Health, and it includes data on vitamins and minerals, the only information on this nutritional aspect published to date. One other report by Rea (1984b) discusses the nutritional value of one high protein variety of Tropaeolum tuberosum and it is described below.

Prior to this research (eg. King & Gershoff, 1987) there have been no reports of the essential amino acid quality of the protein of any of the four species studied. Aside from the above mentioned citations no other nutritional information is available. By contrast an entire book has recently been published (Woolfe, 1987) on the nutritional qualities of Solanum tuberosum.

Methods

Data on each of the four species is presented separately on a fresh wet weight basis (FWB) and dry weight basis (DWB) along with collection location, and number of replicates. All of the analyses reported in this chapter were conducted by one commercial laboratory (Hazelton Biomedical Laboratories, Madison, Wisconsin). The methods of analysis are presented in Appendix II. The variation encountered in samples from Colombia, Mexico, New Zealand and Peru is fully reported, and the role of these tubers in the diet of Andean people is discussed in the following section. Due to the expense involved in each analysis, limited numbers of each species were analysed.

Lepidium meyenii

Limited data on the proximate nutritional composition has been reported by the Institute of Nutrition in Lima, Peru, as follows: protein 15.83%, moisture 13.52% and fat 1.06 % 100/g edible portion (FWB) (E. Zuniga, pers. comm.). Table X presents the proximate composition of two samples of Lepidium meyenii collected on November 12, 1981 in the village of Carahuamayo near the Shore of Lake Junín, in central Peru. Table XI presents the results of an essential amino acid analysis (EAAA) of two samples of Lepidium meyenii. The essential amino acids present are compared to the FAO/WHO provisional amino acid scoring pattern (Food and Agriculture Organization of the United Nations/World Health Organization, 1973). The FAO/WHO scoring pattern provides an estimate of the mg of each of the essential amino acids which would be expected in a gram of protein of 100% biological value. The score of the most limiting amino acid is an estimate of the total utilization of the protein if it was the sole source of dietary protein.

The proximate and EAAA were performed on July 17, 1987, more then 5.5 years after the harvest. The dried hypocotyls, stored in the United States at room temperature, were tested for edibility by a group of North American volunteers 2.5 years later and found to be edible to pleasant. The results of the proximate analysis in Table X show that Lepidium meyenii is of high caloric value and contains a significant quantity of protein. The amino acid profile indicates that the limiting amino acids in the 5.5 year old samples are leucine, lysine and tryptophan. The general quality of the other essential amino acids of the tubers was fair to poor with one very high value for methionine and cystine in sample 2.

These results suggest that Lepidium meyenii should be tested for its nutritional value in a fresh state. The possible deterioration of the essential amino acids may be a factor in the overall protein quality of the crop after long periods of storage. There has been very little relevant comparative research on the effect of time on change in the amino acid quality in Solanum tuberosum. In most cases the effects of storage have been studied in fresh Solanum tuberosum over periods of less then one year. There is a fluctuation of some essential amino acid levels, intially a decrease followed by an increase, induced by the metabolic changes associated with sprouting (Woolfe, 1987). The same source concluded that the situation requires further investigation (Woolfe, 1987).

Table X

Proximate Composition of Lepidium meyenii

Component (%) 100/g	(FWB) Sample 1	2	(DWB) 1	2
Protein	9.4	9.1	10.3	10.13
Moisture	9.0	10.2	--	--
Fat	0.9	0.8	0.98	0.89
Ash	4.6	4.4	5.0	4.8
Crude Fiber	6.3	7.7	6.9	8.5
Carbohydrates	69.8	67.8	76.7	75.0
Calories/100 g	325.0	315.0	357.0	351.0

Table XI

Analysis of Essential Amino Acids in Lepidium meyenii

Amino Acid Component	(mg/g) Sample 1	2	FAO/WHO Amino Acid Scoring Pattern	% of Scoring pattern 1	2
Isoleucine	24.8	24.1	40	62	62
Leucine	39.75	40.5	70	56	57
Lysine	30.8	31.6	55	56	57
Methionine + Cystine	59.1	19.8	35	168	56
Phenylalanine + Tyrosine	42.2	39.7	60	70	66
Threonine	28.4	29.2	40	71	73
Tryptophan	4.9	3.8	10	49	38
Valine	34.9	34.2	50	69	68

Oxalis tuberosa

Oxalis tubers were collected from Mexico, Colombia, Peru and New Zealand. The collection localities in Mexico are presented in Chapter 7. In Colombia, tubers were collected in the southern department of Nariño on August 22-30, 1984, and July 2-8, 1985. Material was collected in the frontier regions of Ipiales and Pasto. In these areas market collections were made because many of the vendors were also farmers, and I obtained the source and local name directly from the producer. Tuber specimens preserved in alcohol (#549-552) were made and deposited at NY. Four samples from Colombia were submitted for proximate analysis and one for EAAA. Two other samples were collected in the largest wholesale market in Lima, Peru on September 3, 1984. These two samples were reported by the vender to have originated in the province of La Libertad, in northern Peru. Preserved tubers specimens of these were also made (#553-554) and deposited at NY. These two Peruvian samples were submitted for proximate analysis and one was also submitted for EAAA.

The tubers from New Zealand were purchased in a wholesale market on March 15, 1987, in Auckland, New Zealand, by Dr. G. Samuels (NYBG). The company selling two varieties of tubers was Turners and Growers Ltd. These tubers were reported to be grown in the Manawata area near Palmerston. Tuber specimens of these were preserved in alcohol (#738-739) and deposited at NY. A total of four samples was submitted for proximate and EAAA from New Zealand.

The proximate composition data from the Andes, Mexico and New Zealand in Tables XII, XIII & XIV, show that the there is a high degree of variation among the three regions in the overall protein, carbohydrate and caloric value of the tubers. The protein level (FWB) of the maximum Andean Oxalis tuber in table XII is 6.5 times greater than the minimum Andean value for protein in Table XIII. The comparison in Table XV of the minimum and maximum values of Oxalis tubers (DWB) from all three geographic areas where it is cultivated demonstrates that the highest protein value is present in sample 4 of Table XIV from New Zealand.

The mean level of crude fiber in the Mexican Oxalis tubers was 20% (DWB) and for the Andean and New Zealand tubers, 4% and 5.5% respectively. This level of variation warrants further investigation into the dietary value of this fiber. The caloric value of the Mexican Oxalis tubers was also lower then the Andean and New Zealand samples.

The proximate nutritional data from the three areas of cultivation demonstrate a high variability within this species. The proximate nutritional data reveals that of the three areas where Oxalis tubers are now cultivated, Mexican samples have the lowest (FWB) values. The highest values are from New Zealand, and the greatest variation is present in the Andean region. The cultivation of New Zealand tubers should be examined to determine what environmental factors have contributed to the large range in protein and calorie values. Tubers from New Zealand, free of diseases, should be introduced to the Andean and Mexican regions for growth trials.

Table XII

Proximate Composition of
Oxalis tuberosa from Colombia and Peru

Component (%) 100/g	(FWB)			(DWB)		
Sample	1	2	3	1	2	3
Protein	0.6	0.8	0.9	3.0	3.2	4.0
Moisture	80.2	75.6	77.8	-	-	-
Fat	0.1	0.3	0.3	0.5	0.4	1.3
Ash	0.7	0.4	0.4	3.5	1.6	1.8
Crude Fiber	0.8	0.8	0.8	4.0	3.2	3.6
Carbohydrates	17.6	22.1	19.8	88.8	90.5	89.1
Calories/100 g	73.7	94.3	85.5	372.0	386.4	385.7

Component (%) 100/g	(FWB)			(DWB)		
	4	5	6	4	5	6
Protein	1.1	1.2	1.3	4.8	5.5	8.4
Moisture	77.4	78.4	84.6	-	-	-
Fat	0.1	0.4	0.3	0.4	0.9	0.6
Ash	0.5	0.4	0.3	2.2	1.8	1.9
Crude Fiber	0.9	0.9	0.8	3.9	4.1	5.1
Carbohydrates	20.0	18.9	12.9	88.4	87.5	83.7
Calories/100 g	85.3	82.2	57.7	377.4	380.5	374.6

Table XIII

Proximate Composition of
Oxalis tuberosa from Mexico

Composition (%) 100/g	(FWB)				(DWB)			
Sample	1	2	3	4	1	2	3	4
Protein	0.2	0.2	0.5	0.6	4.7	4.4	4.0	4.7
Moisture	95.8	95.5	87.8	87.4	-	-	-	-
Fat	<0.1	<0.1	0.2	0.1	-	-	1.6	1.5
Ash	0.4	0.5	0.6	0.7	9.5	11.1	4.9	5.5
Crude Fiber	0.9	0.8	1.4	0.7	21.4	17.7	1.4	9.5
Carbohydrates	2.7	3.0	9.5	10.0	64.0	66.6	5.3	79.3
Calories/100 g	11.6	12.8	41.8	43.3	276.0	284.0	326.0	343.6

TABLE XIV

Proximate Composition of
Oxalis tuberosa from New Zealand

Component (%) 100/g	(FWB)				(DWB)			
Sample	1	2	3	4	1	2	3	4
Protein	1.1	1.3	1.3	1.4	8.0	8.1	9.2	9.3
Moisture	86.3	84.0	86.0	85.1	-	-	-	-
Fat	0.7	0.6	0.6	0.6	2.9	3.7	4.2	4.0
Ash	0.7	0.8	0.9	0.8	5.1	5.0	6.4	5.3
Crude Fiber	0.7	0.7	0.6	0.7	5.1	4.3	4.2	4.6
Carbohydrates	10.8	12.6	10.6	11.4	78.8	78.7	75.7	76.5
Calories/100 g	51.2	61.0	53.0	56.6	373.7	381.2	378.5	379.8

Table XV

Nutritional Variability in the Proximate Composition of Andean, Mexican and New Zealand *Oxalis tuberosa**

Component (%) 100/g	Andean (DWB)		Mexican (DWB)		New Zealand (DWB)	
	Min.*	Max.	Min.	Max.	Min.	Max.
Protein	3.0	8.4	4.0	4.7	8.0	9.3
Moisture (FWB)	80.2	84.6	87.8	87.4	86.3	85.1
Fat	0.5	0.6	1.6	1.5	2.9	4.0
Ash	3.5	1.9	4.9	5.5	5.1	5.3
Crude Fiber	4.0	5.1	11.4	9.5	4.2	4.6
Carbohydrates	88.8	83.7	75.3	79.3	78.7	76.5
Calories/100g	372.0	374.6	326.0	343.6	378.5	379.8

*Andean data from King & Gershoff (1987). Max-Min of protein-calories

Essential Amino Acids

Tables XVI and XVII present EAAA of fresh Oxalis tubers from Colombia and New Zealand. The same EAAA for Mexican Oxalis tubers was conducted but due to laboratory error the results are not reliable. Table XVI suggests that the limiting essential amino acid in sample 1 is valine, while the limiting amino acids in sample 2 are tryptophan, phenyalanine and tyrosine. In both of these samples the levels of lysine and threonine exceed 100% of the FAO/WHO scoring pattern. Woolfe (1987) has reported that lysine is often a limiting amino acid in white wheat flour and Oryza (milled rice), which are both part of highland diets. The limiting amino acids in the diets of 34%, 56% and 9% families of rural highland Peru are respectively lysine, the sulphur amino acids methionine + cystine and threonine (Ferroni, 1980). The levels of all of these amino acids was fair to good in the Oxalis tubers examined.

The results of EAAA from Oxalis tubers from New Zealand demonstrate that the limiting amino acids in samples 1 and 2 are leucine, lysine, methionine + cystine and tryptophan. The data on tryptophan is likely to be unreliable due to the method of analysis by the laboratory. The Oxalis tubers from Colombia were also initially reported less than 0.10 in tryptohpan but were re-submitted for a more sensitive analysis. The reported tryptophan levels were much higher, and the levels of the other essential amino acids remained constant with a low degree of change. The New Zealand Oxalis tubers are, compared to the Colombian samples, poor in essential amino acid quality.

TABLE XVI

Analysis of Essential Amino Acids in
Oxalis tuberosa from Colombia and Peru

Amino Acid Component Sample	(mg/g) 1	 2	FAO/WHO Amino Acid Scoring Pattern	% of scoring pattern 1	 2
Isoleucine	46.00	36.36	40	115	79
Leucine	60.00	53.63	70	85	76
Lysine	57.00	59.08	55	103	108
Methionine + Cystine	34.00	25.45	35	97	72
Phenyalanine + Tyrosine	57.00	31.81	60	95	53
Threonine	47.00	45.45	40	117	113
Tryptophan	08.00	05.50	10	80	54
Valine	26.00	48.17	50	52	96

TABLE XVII

Analysis of Essential Amino Acids in *Oxalis tuberosa* from New Zealand

Amino Acid Component	(mg/g) Sample 1	(mg/g) Sample 2	FAO/WHO Amino Acid Scoring Pattern	% of Scoring pattern 1	% of Scoring pattern 2
Isoleucine	32.84	29.99	40	82	74
Leucine	34.98	36.36	70	49	51
Lysine	19.92	30.90	55	36	56
Methionine + Cystine	22.13	23.63	35	63	67
Phenylalanine + Tyrosine	54.97	58.17	60	96	91
Threonine	32.84	42.73	40	82	106
Tryptophan	<0.10	<0.10	10	00	00
Valine	43.55	43.63	50	87	87

Tropaeolum tuberosum

The tubers submitted for proximate and EAAA analyis presented in Tables XVIII & XIX are from Colombia, with the exception of sample 6, which is from Bolivia. The Colombian samples were collected the week of June 1, 1984 in fields in Vereda Cruzero, the department of Boyacá and in the market in the city of Tunja, Colombia. Herbarium specimens (Appendix I) and preserved tuber specimens were made (#843-846) and are deposited at NY. Sample number 6 is from Italalaque, Department of La Paz, Bolivia.

The proximate composition reported in Table XVIII suggests that there is less protein variation (DWB) among these cultivars than was present in the Oxalis tubers. Single classification ANOVA shows that the means (DWB) for protein levels are heterogenous ($F = 14.8$. $P<.01$ for 2,11 degrees of freedom) among the tubers of Tropaeolum (12.6), Oxalis (4.82) and Lepidium meyenii (10.22). The mean carbohydrate and caloric value (FWB) of Tropaeolum is also lower than both those values of Lepidium meyenii and Oxalis tubers. The crude fiber content is similar to the levels present (DWB) in the Andean Oxalis tubers.

Essential Amino Acids

The EAAA presented in Table XIX suggest that the quality of the protein in samples 1 and 2 is low; only three of the amino acids are 74% or more of the FAO/WHO standard. In sample 3 from Bolivia, the quality is higher with the limiting amino acids being leucine, threonine and tryptophan. Compared to the EAAA data for Lepidium meyenii and Oxalis tubers Tropaeolum tuber samples 1 and 2 contain low quality protein.

Table XVIII

Proximate Composition of
Tropaeolum tuberosum from Colombia & Bolivia*

Component % 100/g		(FWB)			(DWB)	
Samples	1	2	3	1	2	3
Protein	1.2	1.3	1.5	15.7	12.7	6.9
Moisture	92.4	89.8	78.3	-	-	-
Fat	<0.1	0.2	0.1	-	1.9	0.4
Ash	0.5	0.5	0.9	6.5	4.9	4.1
Crude Fiber	0.6	0.8	1.9	7.8	7.8	8.7
Carbohydrates	5.3	7.4	17.3	69.7	72.5	79.7
Calories 100/g	26.0	36.6	76.1	342.1	358.8	350.6

Component % 100/g		(FWB)			(DWB)	
	4	5	6*	4	5	6
Protein	1.6	1.9	-	14.9	13.6	11.8
Moisture	89.3	86.1	-	-	-	-
Fat	0.2	<0.1	-	1.8	-	0.5
Ash	0.2	0.4	-	1.8	2.8	4.7
Crude Fiber	0.8	0.9	-	7.4	6.4	3.9
Carbohydrates	7.9	10.7	-	73.8	76.9	78.9
Calories/100 g	39.8	50.4	-	371.9	362.5	357.0

* Sample 6 dried prior to analysis, no (FWB) data availible.

TABLE XIX

Analysis of Essential Amino Acids in
Tropaeolum tuberosum from Colombia & Bolivia

Amino Acid Component	(mg/g)			FAO/WHO Amino Acid Scoring Pattern	& of Scoring Pattern		
Sample	1	2	3*		1	2	3
Isoleucine	25.28	37.29	28.08	40	54	80	70
Leucine	35.28	43.29	46.53	70	50	61	66
Lysine	35.28	41.24	39.78	55	64	74	70
Methionine + Cystine	12.93	15.31	27.90	35	36	43	79
Phenylalanin + Tyrosine	37.04	14.65	49.41	60	61	24	82
Threonine	22.34	24.68	23.69	40	55	61	59
Tryptophan	05.32	05.32	6.66	10	53	53	66
Valine	25.8	46.64	40.59	50	51	93	81

* Sample is are the results of analysis of a tuber produced from sexual seed (Rea, 1984b).

Ullucus tuberosus

The samples submitted for proximate and EAAA in Tables XX and XXI were collected in Northern and Southern Colombia. Three samples were collected in the market of Tunja, department of Boyacá on June 3, 1987. The fourth sample was collected in the market in Pasto, Colombia, on August 30, 1984.

The data in Table XX suggest that the protein levels in Ullucus are higher (DWB) than tubers of Oxalis, Tropaeolum and Lepidium meyenii. Ullucus tubers are also less variable in protein levels than the Oxalis and Tropaeolum tubers. The mean calorie and carbohydrate values (DWB) are lower than those of Andean Oxalis tubers and only slightly higher then those of Tropaeolum. The mean crude fiber content (FWB) is similar in all of the Andean tuber samples except Lepidium meyenii, which is higher.

Essential Amino Acids

The EAAA data presented in Table XXI shows that the limiting essential amino acid in sample 1 is valine which is 75% of the FAO/WHO standard. In sample 2, the limiting essential amino acids are isoleucine, leucine, threonine and valine with the lowest value being 57% of the FAO/WHO standard. These data suggest that the EAAA of Ullucus tubers is comparable to the EAAA data of Andean Oxalis tubers and that they are superior in protein quality to Tropaeolum tubers and Lepidium meyenii. The quality of the Ullucus tuber protein is fair to good.

Table XX

Proximate Composition of
Ullucus tuberosus from Colombia

Component (%) 100/g	(FWB)				(DWB)			
Sample	1	2	3	4	1	2	3	4
Protein	1.5	2.0	2.2	2.2	10.8	12.9	15.7	15.4
Moisture	86.2	84.6	86.0	85.8	-	-	-	-
Fat	0.2	0.1	0.2	0.1	1.4	0.6	1.4	0.7
Ash	0.4	0.8	0.6	0.7	2.8	5.1	4.2	4.9
Crude Fiber	0.5	0.9	0.7	0.7	3.6	5.8	5.0	4.9
Carbohydrates	11.2	11.6	10.3	10.5	72.4	75.3	73.5	73.9
Calories/100 g	52.6	55.3	51.8	51.7	381.1	359.0	370.0	364.0

Table XXI

Analysis of Essential Amino Acids
in *Ullucus tuberosus* from Colombia

Amino Acid Component	(mg/g)		FAO/WHO Amino Acid scoring pattern	% of scoring pattern	
Sample	1	2		1	2
Isoleucine	48.46	34.95	40	121	69
Leucine	57.69	41.76	70	82	58
Lysine	55.38	41.40	55	100	74
Methionine + Cystine	34.00	25.45	35	97	72
Phenyalanine + Tyrosine	69.99	49.94	60	116	81
Threonine	30.76	23.60	40	77	57
Tryptophan	10.76	07.71	10	107	77
Valine	37.69	33.59	50	75	67

Comparative Nutritional Values With Other Crops

The data in Table XXII present a nutritional (FWB) comparison of the four species under study in this research with other roots, tubers and grains. Lepidium meyenii is superior in protein content to all of these crops except Triticum aestivum (wheat). The caloric value of Lepidium meyenii is also superior to all of these crops except Triticum aestivum and Oryza sativa (milled rice). The other fresh tuber crops have much lower protein and calorie values than dried Lepidium meyenii.

The mean Andean protein value of Oxalis tubers is inferior in protein content to all of the other crops presented. In calorie and carbohydrate values, Oxalis tubers are similar to Solanum tuberosum (potato) Oxalis tubers do show lower values for ash and crude fiber than Solanum tuberosum.

The mean Andean protein value of Tropaeolum tubers is nearly the same as the protein value of Ipomoea batatas (sweet potato), superior to the protein levels in Manihot esculenta (cassava) and inferior to all of the other crops presented except Oxalis tubers. The caloric and carbohydrate value of Tropaeolum tubers is inferior to all of the other crops presented. The values for ash and crude fiber content are inferior to all the other crops except tubers of Oxalis and Ullucus.

The mean protein value of Ullucus tubers is nearly equal to the levels reported for Solanum tuberosum and superior to the levels present in Ipomoea batatas and Manihot esculenta. The caloric and carbohydrate value of Ullucus tubers is inferior to all the crops except Tropaeolum tubers. The ash and crude fiber values for Ullucus are lower than the other crops with exception of tubers of Tropaeolum and Ullucus.

The above data are presented to compare the general proximate nutritional value of the species under investigation with major world food crops. The information should, however, be examined within the limits of general food tables. The values presented for each of the crops from this research are generated from a limited data set and within that data a high degree of variability has been encountered. The data on the other food crops does not provide information concerning the diversity of cultivars known in terms of nutritional value. The information on the major world food crops does not account for the great diversity of processing and preparation methods that affect their nutritional value. The protein value of cooked white rice drops from 6.8 g. to 2.3 g, close to the protein value in Ullucus tuberosus and the protein value of Triticum aestivum grain white bread drops from 13.3 to 8.7, less than the protein value of Lepidium meyenii (Woolfe, 1987). A detailed examination of this topic with specific reference to Solanum tuberosum is discussed by Woolfe (1987). Table XXII and Table XXIII should be examined with the above described data constraints in mind.

Table XXII

Comparative Proximate Nutritional Values for Andean
Lepidium meyenii, _Oxalis tuberosa_, _Tropaeolum tuberosum_
_Ullucus tuberosus_* and Other Major Crops*.
(per 100 g fresh weight edible portion)

Species	Protein (g)	Moisture (%)	Fat (g)	Ash (g)	Crude Fiber (g)	Carbo-hydrate (g)	Calo-ries (kcal)
_Lepidium meyenii_*	9.2	9.6	0.8	4.5	7.0	68.7	320.0
Oxalis tuberosa	0.9	79.0	0.2	0.4	0.8	18.5	79.7
Tropaeolum tuberosum	1.5	87.0	0.1	0.5	0.8	9.7	45.7
Ullucus tuberosus	1.9	85.6	0.1	0.6	0.7	10.9	52.5
Solanum tuberosum (Potato)	2.1	78.0	0.1	1.0	2.1	18.5	80.0
Ipomoea batatas (Sweet potato)	1.4	70.2	0.4	0.8	2.5	27.4	116.0
Manihot esculenta (Cassava)	1.1	62.6	0.3	0.9	5.2	35.2	145.0
Dioscorea spp. (Yam)	2.2	72.0	0.2	1.0	4.1	24.2	72.0
Zea mays (Corn, mature)	4.1	63.5	1.3	0.8	1.0	30.3	129.0
Oryza sativa (Rice, milled)	6.8	12.0	0.5	0.6	2.4	80.2	364.0
Triticum spp. (Wheat, hard)	13.3	12.3	2.0	1.7	12.1	70.9	332.0

* The data presented for these four species are mean values from Colombia, Peru and Bolivia.
* All values for other crops are from (Woolfe, 1987).
* The material of _Lepidium meyenii_ analyzed was "dry" when submitted.

Comparative Micronutrient Content

Analysis of the mineral and vitamin content of the four species investigated was not undertaken as part of this study. The data presented in Table XXIII for these species are from the Peruvian Ministry of Health (Collazos et al., 1975). The data on the mineral and vitamin content of other major crops are from all one source (Woolfe, 1987).

Among the Oxalis, Tropaeolum and Ullucus tubers (no data for Lepidium meyenii) the highest level of calcium (Ca) is present in Oxalis tubers and this amount is more then double the amount present in Solanum tuberosum. Oxalis tubers also contain more calcium then Zea mays and Oryza sativa but less then the remaining major crops. The ability of the body to absorb Ca is in part dependent upon adequate intake of vitamin D. Research on the dietary intake of Ca and vitamin D among highland people of Peru has indicated that Ca deficiency is not a major problem (Ferroni, 1980). It is relevant to note that 10-15% of dietary calcium in highland Peru comes from tubers, (Ferroni, 1980).

The levels of phosphorus (P) in the three species listed are similar. The highest level is 36 mg in Oxalis tuberosa is below the lowest value of the other crops listed as 41 mg for Manihot esculenta. Solanum tuberosum is considered a good source of P at a level of 50 mg, and the lowest of the three species investigated Ullucus tuberosus is cited as containing 28 mg.

The levels of iron (Fe) in the three species investigated are within 0.6 mg. of each other. The lowest level of 1.0 mg in Tropaeolum tubers is 0.2 mg higher than the 0.8 mg figure cited for Solanum tuberosum. The levels of iron in the other major crops listed are, with the high and low exceptions of Triticum spp. and Dioscorea spp., within 0.6 mg of the values cited for Oxalis, Tropaeolum and Ullucus tubers. There is evidence that high dietary intake of ascorbic acid promotes the absorption of Fe (Ferroni, 1980), and the ascorbic acid levels presented below for these tubers is high. The incidence of Fe deficiency in the Andean region is considered low, indicating that enough Fe is consumed in the diet.

The data in Table XIII show that the level of thiamin in Tropaeolum tubers is the same as Solanum tuberosum. All of the crops except Zea mays and Triticum spp. are within 0.06 mg of each other in thiamin content. Solanum tuberosum at a value of 0.10 mg is considered a good source of thiamin (Woolfe, 1987). In the highland region of Peru, Ferroni (1980) calculated that 35% of the thiamin in the diet comes from roots and tubers. It has also been reported that when overall food intake in highland Peru is adequate, thiamin deficiency is not a health problem.

The highest level of riboflavin content in Table XXIII is for Oxalis tubers, with a value of 0.13 mg. Tropaeolum tubers and Triticum spp. both contain 0.12 mg and Ullucus tubers at a value of 0.03 mg is similar to the 0.04 mg level in Solanum tuberosum. The other roots and tubers on the table are similar to the riboflavin level found in Solanum tuberosum. In highland Peru 38% of the riboflavin in the diet is from tubers (Ferroni, 1980).

In Table XXIII the level of niacin in Oxalis, Tropaeolum and Ullucus tubers is 3 to 7 times lower then the niacin content in Solanum tuberosum. The value of 0.67 mg for Tropaeolum tubers is close to the values for Ipomoea batatas, Manihot esculenta and Dioscorea spp., while the grains have niacin levels above the Solanum tuberosum level. In the highland region of Peru 41% of the niacin in the diet is from roots and tubers (Ferroni, 1980). Woolfe (1987) has reported that in cooked potatoes only 23% of the niacin is in a form available to the body which suggests that the level of available niacin in the three tubers investigated may be less than the values in Table XIII.

The ascorbic acid content of 77.5 mg in Tropaeolum tubers is twice as high as the nearest value of 36 mg for Manihot esculenta. Oxalis tubers at a level of 38.4 mg contain nearly twice as much ascorbic acid as Solanum tuberosum, which contains 20 mg. Solanum tubers are considered high in ascorbic acid and important sources for ascorbic acid in Great Britan and Australia (Woolfe, 1987). Ullucus tubers with a value 11.5 mg are the lowest of the three species investigated but they are superior to the level in Dioscorea spp. and the grains. Ascorbic acid in Solanum tubers can be destroyed by a variety of storage and processing procedures, but Ferroni (1980) has reported that methods utilized by Peruvian Andean people reduces the potential loss of ascorbic acid. In the mountainous regions of Peru, 75% of the ascorbic acid in the diet comes from root and tuber crops. Ascorbic acid deficiency has not been considered a nutritional problem of the Peruvian Andes (Ferroni, 1980).

Table XXIII

Comparative Content of Minerals and Vitamins in
Lepidium meyenii, Oxalis tuberosa, Tropaeolum tuberosum,
Ullucus tuberosus and other Major Food Crops
(per 100 g fresh weight edible portion)

Species	Ca (mg)	P (mg)	Fe (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Ascorbic acid (mg)
Lepidium meyenii*	ND	ND	ND	ND	ND	ND	ND
Oxalis tuberosa	22	36	1.6	0.05	0.13	0.34	38.4
Tropaeolum tuberosum	12	29	1.0	0.10	0.12	0.67	77.5
Ullucus tuberosus	03	28	1.1	0.05	0.03	0.20	11.5
Solanum tuberosum (Potato)	09	50	0.8	0.10	0.04	1.5	20.0
Ipomoea batatas (Sweet Potato)	33	46	1.1	0.11	0.05	0.7	26.0
Manihot esculenta (Cassava)	38	41	1.0	0.06	0.04	0.6	36.0
Dioscorea spp. (Yam)	25	53	0.9	0.10	0.03	0.5	09.0
Zea mays (Corn, mature)	05	128	1.1	0.18	0.08	1.9	09.0
Oryza sativa (Rice, milled)	20	115	1.1	0.08	0.04	1.8	00.0
Triticum spp. (Wheat, hard)	44	359	3.9	0.52	0.12	4.4	00.0

* No data for Lepidium meyenii.

Role of the Tubers In Andean Diets and Health

The nutritional contribution of Lepidium meyenii, Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus varies from between countries and regions within these countries. To gain a reasonable understanding of the overall nutritional status of rural Andean people would require a separate dissertation. There are however several factors that should be pointed out regarding the role of these tubers in the health status of Andean people.

One useful index of the protein quality of food is the net dietary protein calories percentage (NDpCal%). It has been estimated that an NDpCal% score of 5 or more supplies sufficient protein for growth if energy requirements are adequate (Ferroni, 1980). The NDpCal% of breast milk is approximately 8 and Solanum tubers and Triticum spp. (wheat) have a NDpCal% of 6 (Woolfe, 1987). It would seem reasonable that Lepidium meyenii, Oxalis, Tropaeolum, and Ullucus tubers would, when compared with the proximate nutritional value of Solanum tubers, have a NDpCal% of at least 5 or more.

The critical dietary variable is often not protein but energy in the form of calories. When calorie intake is deficient, a part of dietary protein is metabolized as energy. Micronutrient deficiencies are also often associated with deficient caloric intake (Ferroni, 1980). In 1973 the Ministry of Agriculture in Peru conducted a combined dietary and anthropometric survey of the nutritional status of rural Andean communities called the Encuesta National de Consumo de Alimentos (ENCA). The ENCA survey concluded that 37% of all highland households are "at risk" for calorie malnutrition and that another 16%

were below the recommended FAO/WHO minimum levels (Ferroni, 1980). In 1983, a United States Agency for International Development (USAID) sponsored health survey reported that in the region of Puno, Peru 70% of the population have some degree of of malnutrition, mostly of the third degree (Delgado, et al., 1983).

In the Peruvian Andes it has been estimated that 5-10% of the cultivated land is planted with Lepidium meyenii, Oxalis, Tropaeolum and Ullucus in any given year (Tapia, 1983). The peak period of consumption of these crops is, as would be expected, during and just after the harvest season for a total period of 3 months (Ferroni, 1980). During this time roots and tuber supply from 1200-1600 calories per capita per day (Ferroni, 1980). In some areas these tubers are planted on a scale similar to Solanum tubers. Data from the southern Andean community of Amaru has shown that in one year 2300 kilograms/per family were produced compared to 2120 kilograms/per family of Oxalis, Tropaeolum and Ullucus (Mateo & Tapia, 1987).

The above information concerning the nutritional value of these crops suggests that these crops are an an important component of the general subsistence strategy of Andean peoples. The factors that cause inadequate food intake are many but it has been suggested that an increased land base and more individual family farm production of endemic Andean grains, roots and tubers would likely improve the health of highland people (Ferrroni, 1980). The increased production and consumption of crops under investigation in this study would increase the protein-calorie intake of highland Andean people.

Chapter 7 - Secondary Compounds, Health and Andean Ethnomedicine

All of the species investigated are known to contain secondary compounds and, with the exception of Oxalis tuberosa, each has been used for medicinal purposes. Table XXIV present the secondary compounds reported for the four species and a synopsis of their uses. Andean people have domesticated several food crops that contain varying levels of secondary compounds, including the glycoalkaloid containing potato, Solanum ajanhuiri Juz. et Buk. There is strong evidence that crop domestication has involved active manipulation of levels of secondary metabolites by humans (Rindos, 1980, Johns, 1985; Davis & Bye, 1982). The process of chemical selection in the four species discussed here has been examined (Johns, 1986b) and is not repeated here. New and fundamental data are included to provide a complete report on existing and potential uses of these food crops.

Lepidium meyenii

Lepidium meyenii shows fertility-enhancing effects (Pulgar Vidal, 1946; León, 1964b; Johns; 1981, King, 1987). It is has been established that fertility rates of humans are lower at high altitudes (Clegg, 1978), and León (1964b) cites the early Spanish chronicles of Peru, frequently referring to the low reproductive rate of their cattle, chickens, and sheep at high altitudes. León also reports that the Spanish were advised by native Andeans to feed Lepidium meyenii to their animals, which they did with positive effects.

As part of this research farmers and vendors in the region of Lake Junín, were interviewed about the fertility-enhancing effects of Lepidium meyenii. All six of the people interviewed expressed the belief that Lepidium meyenii does increase fertility. Lepidium meyenii is sold to treat swollen ovaries in Lima, Peru (King, 1986). One study (Chacón, 1961) was cited by León (1964b) as supportive evidence for the fertility -enhancing effects of Lepidium meyenii.

Recent research has shown that both Lepidium meyenii and Tropaeolum tuberosum are characterized by the aromatic glucosinolates (mustard oils) listed in table XIV (Johns, 1981). The presence of alkaloids in Lepidium meyenii has also been noted, but the types of alkaloids have not yet been identified (F. Stermitz, pers. comm.) There are several medicinal beliefs associated with Tropaeolum tuberosum, one of which suggests that Tropaeolum tubers have anti-aphrodiasiac properties for males and positive fertility enhancing effects on females (Johns et al., 1982). The main chemical difference between these two species is the presence of benzyl isothiocyanate in Lepidium meyenii. The cultural and biological distinctions between these two species have been examined within the context of chemical ecology and crop domestication (Johns, 1981, 1986b, Johns et al., 1982) This laboratory resarch suggested that there is a biological basis for the belief in Andean ethnomedicine that plants containing isothiocyanates affect the reproductive process. Further experimentation on the potential-fertility enhancing effects of Lepidium meyenii needs to be conducted.

Oxalis tuberosa

Oxalic acid (ethanedioc acid) is present in many plant foods and is well known from the plants in the genera Oxalis (Oxalidaceae), Rumex (Polygonaceae), Spinacia (Chenopodiaceae) and Portulaca (Portulacaceae). It occurs in the cell sap of plants as the potassium or calcium salt and can also be a product of the metabolism of several molds (Hodgkinson, 1977). As discussed in chapter 2, Oxalis tuberosa is frequently cited as containing varying levels of oxalic acid. Varieties that are reputed to contain high levels are considered bitter and are processed to remove the bitterness, as described in chapter 3. The level of oxalic acid in Oxalis tubers has not previously been analyzed. The data in table XXV presents the results of analysis of varieties of Oxalis tuberosa from Bolivia, Mexico and New Zealand. The samples from Mexico and New Zealand were collected from the same localities as samples analyzed for their nutritional value. The samples from Bolivia were collected in the markets of La Paz,on October 24, 1987.

The data in table XXV show that Oxalis tubers do contain varying levels of oxalic acid in the Andes and New Zealand. The maximum level of 488 ppm of Bolivian tuber samples was 40 times higher than the minimum level of 12 ppm. The samples from New Zealand show lower variation with a mean level twice as high as the Andean mean. The one sample analyzed from Mexico contained a low level compared to the mean of the samples from the Andes and New Zealand.

The data in Table XXVI compare the level of oxalic acid in Oxalis tubers to other food crops. The maximum values of oxalic acid in potatoes and maize were 2.5 and 5 times lower than the mean levels in Bolivian and New Zealand Oxalis tubers. The highest levels of oxalic acid in the Bolivian and New Zealand Oxalis tubers were 7 times lower than the lowest level found in spinach, a food high with a high oxalic acid.

The results in tables XXV reveal that Bolivian Oxalis tubers show a high degree of variation of oxalic acid levels. Oxalic acid is soluble in water (1 gm/7mls Hodgkinson, 1977), which suggests that the making of freeze-dried Oxalis tuberosa "caya", which normally involves soaking the tubers, could reduce the level of oxalic acid. Andean people may be able to distinguish tubers with high levels of oxalic acid but this will require taste perception tests, similar to those conducted by Johns (1985).

High levels of oxalic acid can be toxic to humans and livestock and have been associated with the formation of upper urinary tract stones (Hodgkinson, 1977). Oxalic acid has also been shown to interfere with assimilation of calcium, but is considered a nutritional factor only in diets high in oxalic acid and low in calcium sources. In the Andean region calcium intake is not considered deficient. The highest levels of oxalic acid in tubers in the Andes, Mexico and New Zealand are far below foods like spinach that contain high oxalate levels. In the Andean region the process of freeze-drying tubers may further reduce the levels of oxalic acid. The level of oxalic acid in Oxalis tuberosa does vary but the amount is unlikely to represent a health problem unless the diet was composed soley of Oxalis tuberosa.

Tropaeolum tuberosum

The medicinal uses of Tropaeolum tubers have been recorded by numerous researchers and are summarized in table XXIV. In the market of Pasto, Colombia, Tropaeolum tubers were encountered only in the section where plant medicines were sold. Vendors called these tubers "majua" and stated they were used to treat chest and kidney ailments (King, pers. obser.) A similar use of the tubers for these problems has been recorded in Colombia by García Barriga (1975), by Soukop (1970) in Peru, by Hodge (1946) in Ecuador and by Oblitas Poblete (1969) in Bolivia.

The use of the tubers by the Incas to diminish sexual appetite of troops during military campaigns was recorded by Cobo (1956) and Garcilaso de la Vega (1960). Johns et al. (1982) have reviewed the comments of modern scientists who have cited a continued belief in the effects on human reproduction associated with the consumption of Tropaeolum tubers. In central Peru, men do not eat Tropaeolum tubers because they believe they will cause impotence and hence reduce their ability to produce children (Vasquez Varela, 1952). In Bolivia the tubers are believed to induce menstruation and in the Cuzco region of Peru they are used as emmenagogues (Oblitas Poblete, 1969; Herrera, 1940). The different effects suggested for men and women appear contradictory but it has been reported by Johns et al. (1982) that a compound that affects the estrogenic hormones in females would, in general, have an opposite effect on the male hormone androgen.

Pharmacological studies of the reported uses of Tropaeolum tubers have been conducted by Johns et al. (1982). Research conducted with rats supports the beliefs that this food can act as an anti-reproductive agent. The same study did not verify the emmenagogic or fertility-enhancing effects associated with Tropaeolum tubers. The known biological effects of isothiocyanates do support the diuretic and anti-biotic effects attributed to Tropaeolum tubers (Johns et al. 1982).

In fieldwork conducted as part of this research the majority of tuber varieties were not considered as medicine but used only as food. The medicinal activity attributed to some varieties of Tropaeolum tubers is a fascinating area of ethnomedicine that deserves further attention.

Ullucus tuberosus

There are few references in the literature to Ullucus tuberosus being used as medicine. The presence of saponins (Table XXIV) in Ullucus tuberosus has been reported by Hegnauer (1964) and Johns (unpublished results). Brücher (1967) has suggested that the cultivated Ullucus tuberosus has been selected for reduced bitterness, a common taste associated with saponins. The tubers of the cultivated and wild subspecies have not been termed "bitter" by informants during the course of this research. The level of saponins present is likely to be low but saponin levels were not measured.

Patiño (1963) cited Cobo (1956) as a source for the medicinal use of Ullucus tuberosus to ease childbirth and treat traumatic internal injuries. Saponins are not known to be employed for either of these purposes, and the medicinal beliefs associated with Ullucus tuberosus are likely related to other unknown compounds in the tubers.

Both cultivated and wild Ullucus tuberosus both contain mucilage. This may account for the limited medicinal association of Ullucus tubers with easing childbirth, the mucilage being viewed as an internal lubricant. Such an association could well have developed as a type of doctrine of signatures.

Table XXIV

Secondary Compounds and Medicinal Utilization of the Four Species

Species	Compound(s)	Use in Andean Ethnomedicine
Lepidium meyenii	benzyl & p-methoxybenzl isothiocyanate (Johns, 1981)	Increase fertility, reduce swollen ovaries (León, 1964b; King, (1986)
Oxalis tuberosa	oxalic acid (King, unpublished)	No use reported
Tropaeolum tuberosum subsp. tuberosum	p-methoxybenzl isothiocyanate (Johns & Towers, 1981)	Male anti-aphrodisiac, female fertility increase, diuretic, anti-biotic, treat kidney ailments, lung & chest problems, (Johns et al., 1982; García Barriga, 1975;) White, 1975).
Tropaeolum tuberosum subsp. silvestre	benzyl, 2-propyl & 2-butyl iosthiocyanates (Johns & Towers, 1981)	No use reported
Ullucus tuberosus subsp. tuberosus	Saponins (Hegnauer, 1964)	Facilitate birth, treat internal injuries. (Patiño, 1963).
Ullucus tuberosus subsp. aborigineus	Saponins (Hegnauer, 1964)	No use reported

Table XXV

Oxalic Acid Content of _Oxalis tuberosa_
From Bolivia, Mexico & New Zealand

Country of Origin	Oxalic acid per sample (ppm)							Mean
Bolivia	12	37	50	261	488	-	-	170
New Zealand	203	242	316	390	488	495	513	378
Mexico	79	-	-	-	-	-	-	79

Table XXVI

Comparative Oxalis Acid Content
of _Oxalis tuberosa_ & other Foods

Species	Level of Oxalic Acid Content (mg/100 g fresh material)	
Oxalis tuberosa Bolivia	1.2 - 48.8	(n = 5)
Oxalis tuberosa New Zealand	20.3 - 51.3	(n = 7)
Oxalis tuberosa Mexico	7.9	(n = 1)
_Solanum tuberosum_* (Potato)	2.3 - 7.1	
Spinacia sp. (Spinach, boiled)	356.0 - 780.0	
Zea mays (maize, fresh)	7.1	
Triticum aestivum (bread, white)	4.9 - 13.8	

*This and following values from Hodgkinson (1977).

Chapter 8 - Oxalis tuberosa in The Transverse Neovolcanic Axis of Mexico

Introduction and Methods

A survey of the Mexican Transverse Neovolcanic Axis was undertaken in collaboration with a Hélio Bastien, a Mexican agronomist. Numerous farm sites were visited and farmers interviewed. The data in table XXVI records the localities where voucher specimen and tubers for nutritional analysis were collected. Fresh tuber material was also collected and sent to the Hazelton Biomedical Laboratories in Madison, Wisconsin, for nutritional analysis. Areas to be surveyed were selected on the basis of information provided by regional field agronomists, market vendors and the agricultural knowledge of our Mexican team. A total of 16 farms were surveyed in three states of Central Mexico: Veracruz, Michoacan and México. Oxalis tuberosa was found in cultivation in fourteen of these farms. To discover the extent of tuber diversity in these areas a color photograph of the variation of Andean Oxalis tuberosa was used as a comparative tool for discussion. This technique proved very useful as many informants were highly interested in the diversity present in the Andes.

Oxalis tuberosa in Mexico

Martinez (1936) does not include Oxalis tuberosa in his book on useful plants of Mexico but he does mention it as being an edible tuber from Peru, in his catalog of common and scientific names of Mexican plants (1937). Bukasov (1930) was first to note the presence of Oxalis tuberosa in Mexico and he pointed out the morphological

Table XXVII

Herbarium Voucher & Tuber
Specimen Collection Data

Collection #	Elevation m	Date D/M	Locality	Material collected	Institution deposited
K-682	2760	8/9/86	Approx. 19°32′ North and 97°08′ West. Tembladeras, Veracruz.	HBV-tubers for Lab.	NY, MEXU & CHAPA.
K-683	2500	10/9/86	Approx. 19°58′ North and 97°20′ West. Xometla, Veracruz.	HBV-tubers for lab.	NY, MEXU & CHAPA.
K-684	2500	10/9/86	Approx. 19°58′ North and 97°20′ West. Xometla, Vercruz.	HBV-tubers for lab.	NY, MEXU & CHAPA.
K&B-687	2400	18/9/86	Approx. 19°40′ North and 101°40′ West. San Gregorio, Michoacán.	HBV-tubers for lab.	NY, MEXU & CHAPA.
K&B-689	2850	21/9/86	Approx. 19°38′ North and 100°41′ West. La Garnica, Michoacán.	HBV-tubers for lab.	NY, MEXU & CHAPA.
K-690	3300	25/9/86	Approx. 19°35′ North and 99°58′ West. Ojo de Aqua, Mexico.	HBV-tubers for lab.	NY, MEXU & CHAPA.

distinctions between the Andean and Mexican Oxalis tuberosa. Subsequent research on Oxalis tuberosa from Mexico and six Andean countries has revealed that the differences noted by Bukasov reflected more the limited variability he observed rather than regional morphological distinctions (Cárdenas, 1958). Bukasov provided no data on the importance of Oxalis tuberosa in Mexican agriculture. León (1958) reported Oxalis tuberosa being introduced to Mexico and Williams (1978) incorrectly identified Oxalis tuberosa in Mexico as Tropaeolum tuberosum, because of tuber similarity. This mistaken identification was based on living tuber specimens as these two species are in different families and are quite distinct. No further research on the cultural and agricultural importance of Oxalis tuberosa in Mexico is available.

Mexican Distribution of Oxalis tuberosa

We encountered Oxalis tuberosa (Fig. 29) throughout the Mexican Transverse Neovolcanic Axis between the elevations of 2400-3300 m The highest density of cultivation was encountered in the vicinity of Toluca at an elevation of 2500-2800 m, where fields of up to one half hectare were not uncommon.

The field research indicates (Fig. 30) that this cultivated species is a common minor crop throughout the Tranverse Neovolcanic Axis. We found no specimen of this cultigen in the collections of the UNAM herbarium (MEXU). This is not unusual as most major herbaria contain very few cultivated plants (Prance, 1987). The herbarium at the Colegio de Postgraduados in Chapingo (CHAPA) did include one specimen, collected by Efraim Hernandez-X. near Chapingo.

Fig. 29. Variation of _Oxalis tuberosa_ collected in one field, color red to pink. Tembladeras, Veracruz, 2700 m (_King & Bastien 682_).

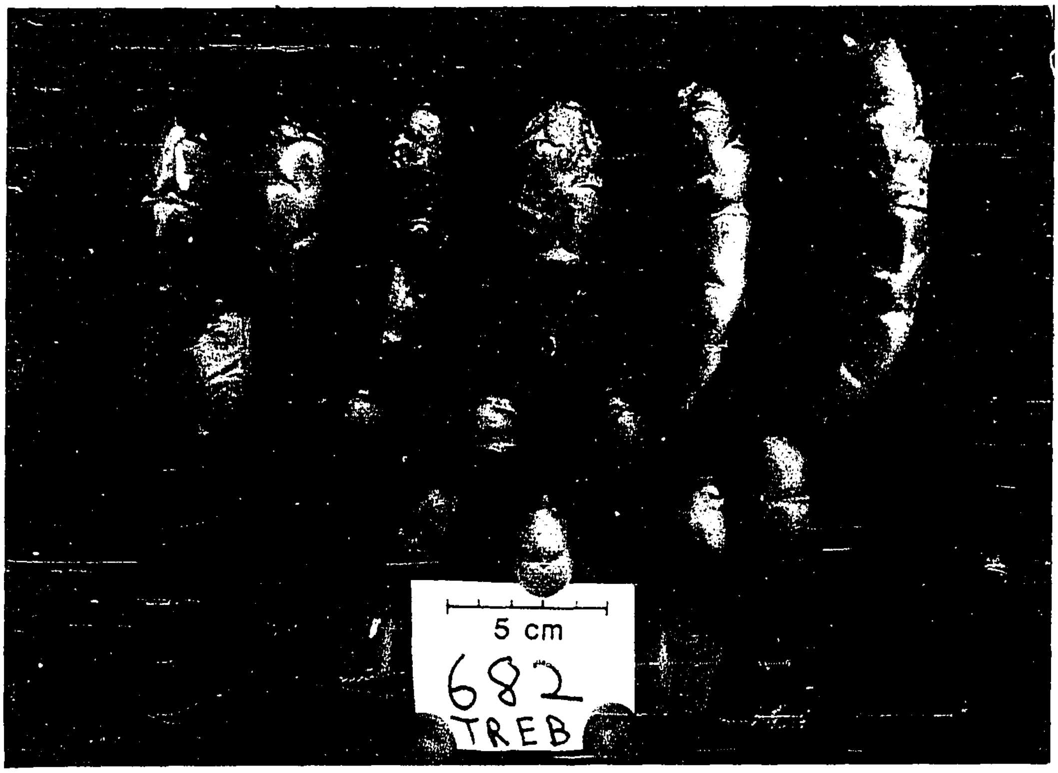
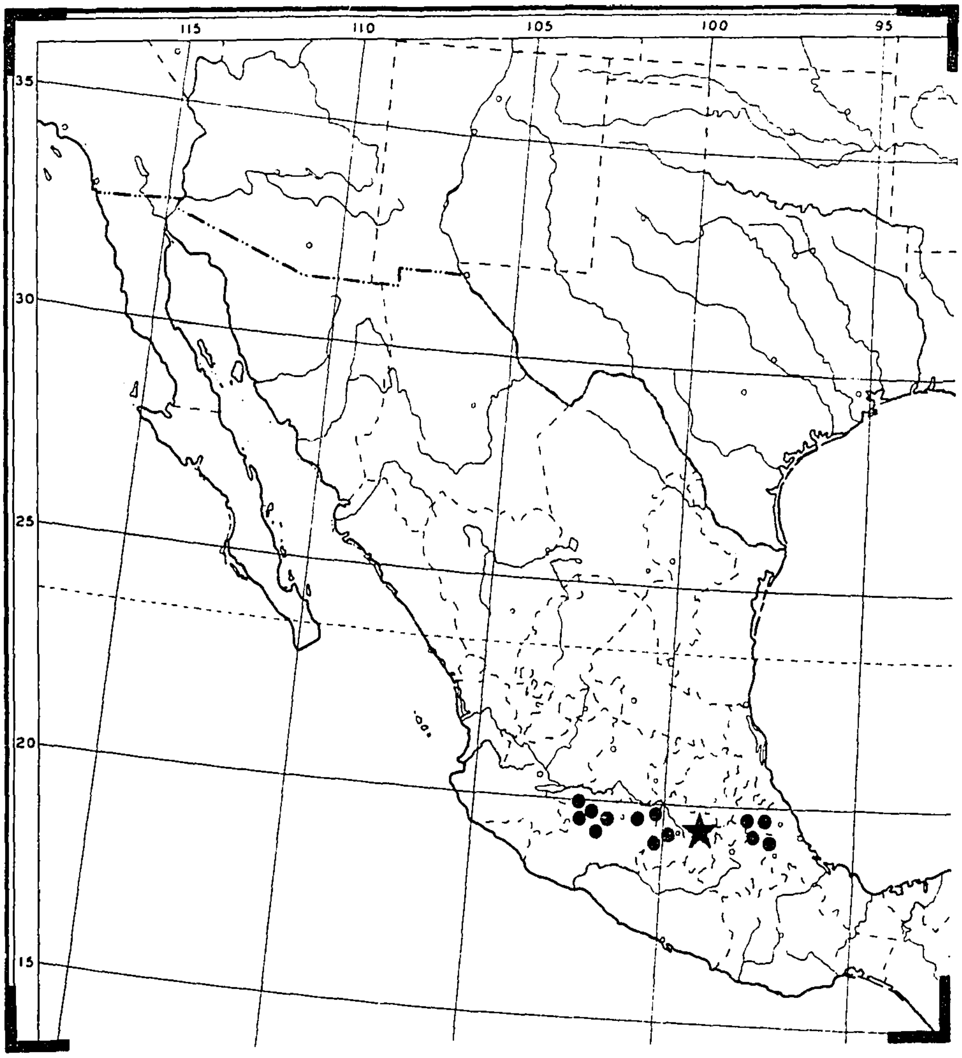

5 cm
682
TREB

Fig. 30. Map of study regions where Oxalis tuberosa was encountered in the transverse neovolcanic axis of Mexico.


115
110
105
100
95
35
30
25
20
15

Botanists working in the northern and southern highland regions of Mexico have not reported seeing Oxalis tuberosa in cultivation or in markets (M. Nee and D. Stevens, pers. comm.). It should be possible, however to cultivate Oxalis tuberosa in areas above 2000 m which have enough moisture to support its development. Further investigations in other highland regions needs to be carried out.

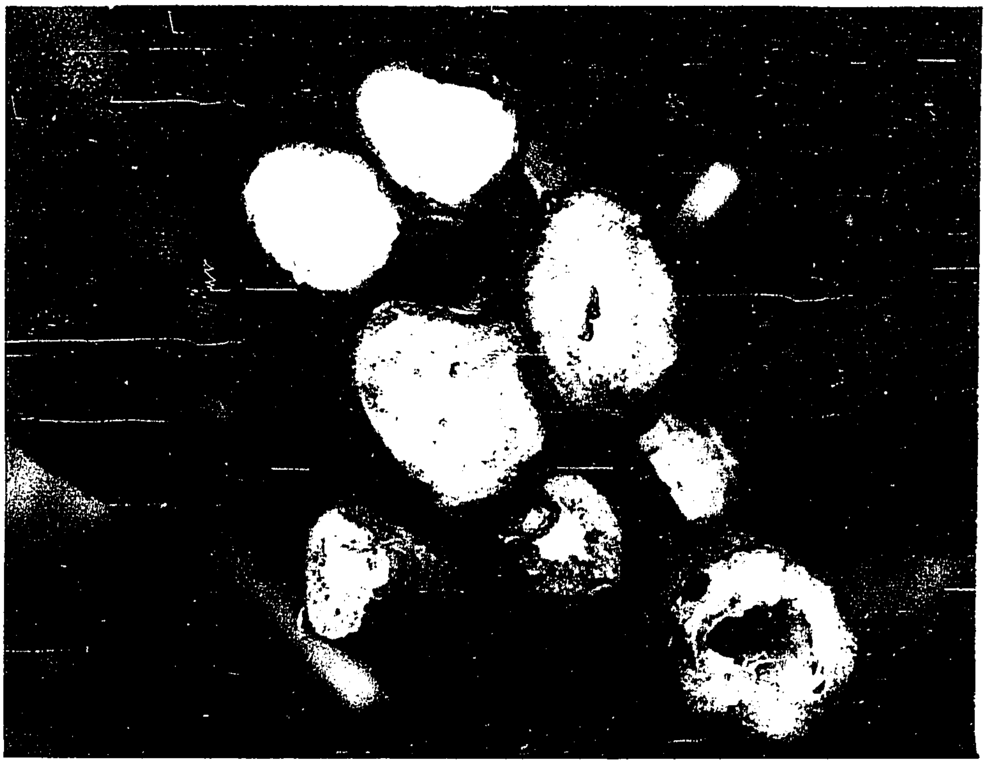
Cultivar Diversity

The cultivar diversity of Oxalis tuberosa in Mexico appears to be low, especially when compared to the variation present in the Andes. In the present study we encountered two cultivars based on tuber yield, taste, texture and subtle color differences in the phloem.

In the village of Xometla, Veracruz at 2500 m farmers recognized two types of tubers: yellow and white. The color difference was only present in the phloem of the tuber and not in the epidermis, which in both varieties was red. When these two varieties are viewed in cross section side by side it is possible to note a slight color difference (Fig 31).

The distinction between the cultivars was explained as follows by a farmer. The yellow variety produces better yields than the white variety and the tubers are larger, in both length and width. The white variety was also said to be more "ágria" (sour) than the yellow and was therefore not as desirable as the latter. These two varieties reportedly could be distinguished by the farmers on the basis of the aerial portion of the plant. Herbarium vouchers of the two varieties are not easily distinguishable (King 683, 684).

Fig. 31. Two varieties of Oxalis tuberosa recognized by farmers of Xometla, Veracruz 2500 m. Cross-sectional view of yellow variety top tuber (King 683) and bottom four tubers white variety (King 684). The color distinction refers to the phloem tissue, the epidermis of both varieties was red.



There were reports from other informants of tubers in the above mentioned yellow and white colors. Two informants in the cities of Orizaba and Toluca reported that plants were infrequently harvested with yellow and white tubers, intermixed with red tubers, all as part of one individual plant. As this research was conducted two months prior to the harvest season these accounts will require verification.

A third informant also mentioned that the red tubers are at times placed in the sun for five to seven days and that they then turn white. This is according to our informant, to sweeten the tubers. This practice also has been observed in the Andean region, where it is also reported to sweeten the taste of the tubers (Cortés, 1977).

In the other regions of Mexico, where Oxalis tuberosa is cultivated, only the one red variety was mentioned. While further fieldwork is needed during the harvest season, it does appear that there is limited diversity of cultivars of Oxalis tuberosa in Mexico, especially when compared to the Andean zone.

Soils and Vegetation

The soils of the Transverse Neovolcanic Axis have been termed andosol and volcanic (Ugent, 1968). The soils are generally dark brown to black, slightly acidic, and are considered fertile (Ugent, 1968). It has been reported that the pH in potato field soils in the region of the Nevado de Toluca range from 5.0-5.7 (Ugent, 1968). Ugent also reported that the pH in the Pinus and Abies forest soils were less acidic, ranging from 5.8-6.0. The natural vegetation of the highland regions where *Oxalis tuberosa* is cultivated consists of forest stands of *Pinus* and *Abies* combined with grassland dominated by *Festuca*, *Muhlenbergia*, *Stipa* and *Agrostis*.

Ecogeographic Limits of The Crops

We encountered *Oxalis tuberosa* under cultivation between 19° 20′ and 20° 30′ North and 96°50′ and 102°18′ West. Our research suggests however, that *Oxalis tuberosa* is likely to be encountered throughout the Tranverse Neovolcanic Axis at elevations of 2000 m and above. The lowest limit for succesful cultivation found in this study was 2400 m in the village of San Gregorio, Michoacan. Researchers at the Instituto Nacional de Investigaciones sobre Recursos Bióticos (INIREB) in Jalapa, Veracruz have tried unsuccessfully to cultivate *Oxalis tuberosa* as part of their collection of useful plants at their Francisco Javier Clavijero Botanical Garden at an elevation of 1300 m. Plants grown from tubers outdoors attained a height of 300 mm, then wilted and died, primarily due to the heat.

The upper limit of cultivation for *Oxalis tuberosa* observed was 3300 m. In the villages of Conejo, Veracruz and Raices, Mexico, potatoes were the main crop, but three to nine plants of *Oxalis tuberosa* were planted at the edge of several potato fields. Local farmers told us that *Oxalis tuberosa* did not grow or yield well at this elevation and that in villages at lower elevations we would encounter many people growing it. The temperature at these elevations was more severe, with frosts and snow occurring occasionally. It is likely that the clones of _Oxalis_ _tuberosa_, cultivated in Mexico, represent a variety that are not well adapted to freezing temperatures, and that the northern latitude lengthens the cultivation cycle, increasing the exposure to seasonal low temperatures.

Agricultural Cycle of _Oxalis_ _Tuberosa_

Oxalis tubers are planted from February to March, and harvested from October to December. The maturation time ranges from seven to nine months; plantings above elevations of 3000 m take up to eleven months to mature. In August, six months after planting, we encountered plants with numerous stolons that were in the process of forming tubers (Fig. 32).

In Mexico, _Oxalis_ _tuberosa_ is propagated vegetatively, as it is in the Andes, from tubers selected from the previous year's harvest. In the region of Toluca several small tubers, 20-40 mm in diameter are placed in each hole 50-100 mm deep. These small tubers are known as "el ripio", which means the waste or unusable portion. Seed tubers are selected not for their large size, but because they are leftovers, unsuitable for consumption, but just as useful for propagation. Farmers reported that _Oxalis_ _tuberosa_ does not produce fruit.

Cultivation Systems

In this investigation we observed ten distinct variations of interplanting _Oxalis_ _tuberosa_, each utilizing a specific mixture or configuration of crops. The full list presented in Table XXVII

Fig. 32. Stolons of Oxalis tuberosa forming tubers, six months after planting. San Gregorio, Michoacán 2670 m (King & Bastien 687).

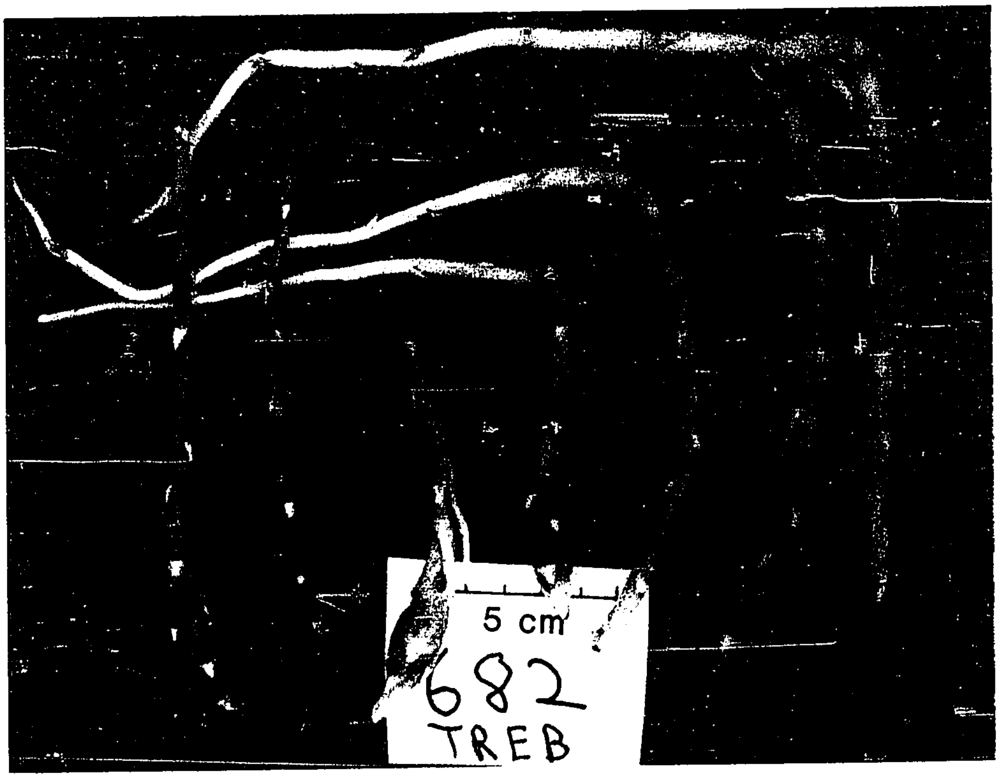

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Table XXVIII

Interplanting Systems of
Oxalis tuberosa in Mexico

Location	Elevation M	Mode	Other Plants
Los Raices, Mexico	3300	5-10 O. tuberosa plants at the end of each row of potatoes.	Solanum tuberosum
Oje de Aqua, Mexico	3300	Mostly O. tuberosa with other food plants at low density.	Pisum sativum, Avena sativa Triticum, aestivum.
La Garnica, Michoacan	2850	O. tuberosa in rows with cucurbit vines trailing around.	Cucurbita ficifolia
San Gregario, Michoacan	2400	O. tuberosa between rows of miaze.	Zea mays
San Gregario, Michoacan	2580	O. tuberosa in same row as maize, spaced between corn.	Zea mays
El Conejo, North slopes of Cofre de Perote, Veracruz	2800	O. tuberosa planted in dooryard garden with herbs.	Medicinal and culinary herbs
Tembladeras, Veracruz	2755	O. tuberosa mixed i low density dooryard garden.	Vicia faba
Tembladeras, Veracruz	2760	high density monocrop.	none
Xometla, Veracruz	2500	O. tuberosa planted in same hole as maize.	Zea mays
Xometla, Veracruz	2580	O. tubersoa mixed with ornamental, maize.	ornamentals Zea mays

describes these variations observed at fourteen farm or house garden sites. One of the most unusual methods involved planting Oxalis tubers with maize in the same hole. The two plants grow together, maize rapidly overtopping Oxalis tuberosa (Fig. 31 & 32). Farmers utilizing this system explained that the maize plant protects Oxalis tuberosa from damage due to periodic hail storms. In this system the Oxalis tubers are harvested before the maize is fully mature. To my knowledge Andean tubers are never planted in this in this manner.

Crop spacing varies according to the method employed, each farmer applying his own experience and expertise to planting. One 7 by 15 m plot was densely planted, with almost indistinguishable rows. This dense planting of Oxalis tubers contrasted sharply with the well spaced rows of potatoes growing in the area. This densely planted site was, however, the exception among the ten methods observed. The average spacing between plants was 150-400 mm. and the average distance between rows was 900-1000 mm. The largest plot we observed was one-half hectare. Yields reported by a Mexican farmer for a one quarter hectare plot varied from 500 to 1000 kg.

Inputs, Insects, and Diseases

None of the farmers interviewed used fertilizer on their plots of Oxalis tuberosa. They did report using manure and fertilizer on their other crops, most of which were grown for their cash value. The low market price of Oxalis tuberosa was one of the reasons cited for not applying fertilizer.

Fig. 33. Oxalis tuberosa and Zea mays sown in the same hole; the corn is protecting Oxalis tuberosa from hail damage. Xometla, Veracruz 2550 m.

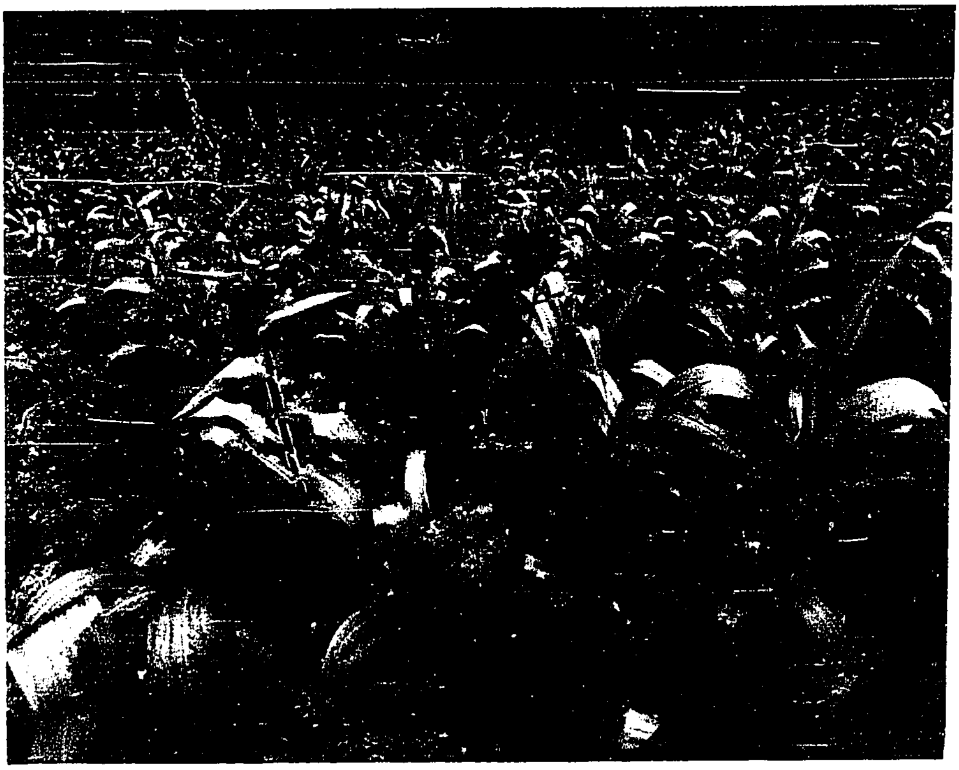


Fig. 34. Field of Oxalis tuberosa interplanted with Zea mays as in figure 33. Xometla, Veracruz.

Insect predation was not reported to be a problem for Oxalis tuberosa. None of the plants we examined showed indications of insect attack. No farmers reported using insecticide on their plants. Screening of the Mexican Oxalis tuberosa for the presence of viruses found among the Andean varieties has not yet been undertaken. Research on the viral status of Mexican Oxalis tuberosa is important in view of experiments by Brunt and co-workers (Brunt et al., 1982a, 1982b; Atkey & Brunt 1982) that indicates that virus-free plants may show dramatic yield increases.

Fasciation of Oxalis tuberosus stems was common in six of the fourteen sites investigated (Fig. 35) (King 684). We were unable to observe tubers of these plants. Mexican farmers reported that fasciated Oxalis tuberosa plants produced as well as the non-fasciated plants and that this anomaly was not considered detrimental.

Utilization, Market Value and Cultural Acceptance

In many areas of its cultivation in Mexico Oxalis tuberosa was regarded to be more like a "fruit" than a "vegetable". In the markets it is often sold in the fruit section, not in the area where tubers, such as potatoes are sold. It is commonly eaten raw with a small amount of salt, lemon and powdered chili pepper (Capsicum). Oxalis tuberosa is also used to make preserves, and in some instances is combined with roots of Pachyrhizus erosus, (jícama, Leguminosae) and fruits such as apples, peaches or pears. A second type of preserve is also prepared using vinegar, cucumbers and onions. It was also reported to be used in a pork stew, fried in a manner similar to fried potatoes.

Fig. 35. Stem of fasciated Oxalis tuberosa, six months after planting. Numerous plants observed in this condition. Tembladeras, Veracruz, 2760.

In Mexico the tubers are sold in the markets from November to February. The price is always less than potatoes by twenty to fifty percent. The price ranged from seventy to one hundred pesos per Kg. ($ US 0.10 to 0.30 $) in August, 1986. Several farmers reported that they planted only a small amount to eat and sell because there was not enough demand for it at the markets. One farmer, near the village of Tancitaro, Michoacan reported that twenty years ago he planted a hectare but that its popularity and cash value has declined since that time. In the markets of Orizaba and Patzcuaro, Oxalis tubers are sold both inside the market by middle men and outside on the street by the producers themselves.

In the market in Toluca several vendors carried Oxalis tuberosa when it was in season. They claimed there was a large demand for it during the Christmas season. These vendors and some farmers reported the tubers to be used in piñatas at festivals, suggesting a possible cultural role of Oxalis tuberosa.

Comparative Nutritional Value

Fresh tuber material was submitted for nutritional analysis to the same independent laboratory reported in Chapter 5. Results are presented in Table XXVIII and compared with pooled data from cultivars of Andean Oxalis tubers (King & Gershoff, 1987). Table XXVIII presents the approximate nutritional composition of four samples of Oxalis tuberosa from three distinct localities in Mexico. The percent protein value shows a range from 4 - 4.7 %, which is 50 % lower than the maximum value of 8.4 % for Andean cultivars. The Mexican Oxalis tuberosa also shows a much lower degree of nutritional variation in protein content compared to the protein variation present in the Andean cultivars.

Other apparent distinctions between the Mexican and Andean proximate analyses are higher ash content in Mexico and a higher percentage of crude fiber. The crude fiber in Mexican samples had a maximum of 21.5 % compared to the Andean maximum of 5.1 %. The carbohydrate value of the Mexican samples is also slightly lower than the Andean Oxalis tuberosa.

Origin and Introduction to Mexico

It is beleived that Oxalis tuberosa is a post-Conquest introduction to Mexico. One Andean tuber specialist has stated that a red variety was introduced to Mexico during the colonial period but provided no supporting data or references (León, 1958). The Spanish did send orders to their ships requesting that they bring plants from the Old World to the New world and in the sixteenth century missionaries also sent plants and animals to the New World (Crosby, 1972). It is probable that numerous plant species were transported between South American ports and the Mexican ports of Acapulco and Veracruz. Our hypothesis, based on the combined evidence presented below, is that Oxalis tuberosa was introduced during the post-Conquest period.

TABLE XXIX

Nutritional variability of
Andean and Mexican *Oxalis tuberosa*

Component (%) 100 /g	Andes		Mexico			
	Min.	Max.	1	2	3	4
Protein	3.0	8.4	4.0	4.4	4.7	4.7
Moisture	80.2	84.6	87.8	95.5	95.8	87.4
Fat	0.5	0.6	1.6	<0.1	<0.1	1.5
Ash	1.9	3.5	4.9	11.1	9.5	5.5
Crude fiber	4.0	5.1	11.4	17.7	21.4	9.5
Carbohydrates	80.2	84.6	75.3	66.6	64.0	79.3
Calories/100 g	368.7	364.0	326.0	284.0	276.0	343.0

All values are presented on a dry weight basis, except moisture, which presented as fresh weight basis.
Andean data from King & Gershoff (1987).

One of the most important sources for evaluating the history and antiquity of Mexican food, medicinal, and useful plants is the beautifully illustrated Florentine Codex (Sahagun, 1979). This classic work was produced shortly after the arrival of the Europeans in Mexico. It is an important reference for students and scholars of Mexican natural history. We found no mention of any type of root crop similar to Oxalis tuberosa; the same lack of data was also noted by Dr. Hernandez-X. There is also no evidence of a plant that matches Oxalis tuberosa in the De La Cruz - Badiano Aztec Herbal (Gates, 1939), a chronicle of Mexican plant resources written in 1552.

A second major factor that points toward a post-Conquest introduction is the low diversity of cultivars encountered in Mexico. In the Andes more then 600 germplasm accessions have been collected in Peru and Bolivia (Tapia, 1984). There is also a large germplasm collection of 91 germplasm accessions of Oxalis tuberosa in Ecuador (Tola Cevallos et al., 1987). A number of these germplasm collections are likely to be duplicates but there is a tremendous documented diversity compared to the Mexican Oxalis tuberosa. The nutritional variability of Oxalis tuberosa in Mexico is also limited. As was indicated above, Andean landraces exhibit a much greater nutritional variability than the Mexican samples.

A third factor suggesting the recent introduction of Oxalis tuberosa is the number of different local vernacular names associated with the same variety. The following names were used by farmers and vendors to identify the Mexican plants: "papa extranjera", (foreign potato), "papa colorado" (colored or red potato), "papa zanahoria" (carrot potato), "papa roja" (red potato), "papa yuca" (manioc potato) "papa castillana" (Spanish potato), and "papa chirivia" (not translated potato). All of these names were applied to the red variety which we encountered and each of the names refers to Oxalis tuberosa as a type of potato. Only in the village of Xometla, Veracruz, was a distinction made between a yellow and white type. By contrast in Andean Peru, Oxalis tuberosa is known as "oca" and cultivars bear distinct Quechua or Spanish names used to describe the characteristics of each cultivar (Rea & Morales, 1980). If Oxalis tuberosa had been cultivated in Mexico for several centuries before the arrival of the Spanish it is likely that indigenous and/or regional names, not based on the Spanish word "papa" (potato), would now still be used. We encountered no such names, only those listed above.

One final, important part of this question involves the literature on the origin, cultivation and diversity of potato cultivars in Mexico. Ugent (1968) cited the same Transverse Neovolcanic Axis as being the dominant region of potato cultivation in the late 1960's. In this area he documented 22 distinct potato cultivars and examined the question of the history of the potato in Mexico.

Based on taxonomic, linguistic and historical data he concluded that there is little or no evidence to support potato cultivation prior to the Spanish conquest. Given that a fairly large diversity of potato varieties is present today and that they were introduced after the Spanish entered Mexico, it seems unlikely that Oxalis tuberosa could have preceded the potato and still exhibit such a low degree of cultivar variation.

Germplasm Status of Oxalis tuberosa

There is no collection of Mexican Oxalis tuberosa germplasm in Mexico. Germplasm material from our field research has been sent to an *in vitro* tissue culture germplasm collection of Andean tubers at the University of San Marcos, in Lima, Peru. Farmers of Mexico who cultivate Oxalis tuberosa are interested in receiving germplasm of the Andean varieties for experimentation. This interest has also been expressed by the researchers at the Colegio de Postgraduados at Chapingo. The request for Andean Oxalis tuberosa germplasm for experimentation in Mexico has been forwarded to the germplasm banks in Peru.

Extensive collection of Mexican Oxalis tuberosa during the harvest season would perhaps discover, as yet unrecognized, varieties and/or increase the range in which they are presently known to occur. The maintenance of these collections in Mexico would be the next logical step towards systematically evaluating the diversity of Oxalis tuberosa from distinct geographic areas.

Implications for International Agriculture

Before we examine the significance of *Oxalis tuberosa* in world agriculture it is useful to mention the current role of a better known tuber crop of Andean origin. The potato is now a major world food crop under cultivation in 130 countries with a world production of 290 million tons annually (International Potato Center, 1984). This production figure ranks potatoes fourth in volume after wheat, maize and rice. To understand why, up to now, only the potato has become a major crop of world importance while other nutritious tuber crops from the Andean region have not, is outside the scope of this thesis. What is important to take into account is that the potato was unknown outside of the Andes only 400 years ago.

The fact that *Oxalis tuberosa* is a widespread minor crop in the central highlands of Mexico demonstrates that it is adaptable to mountainous environments outside of the Andes. As was mentioned earlier, *Oxalis tuberosa* has been cultivated as a minor crop for the past 20 years in New Zealand. Small scale growers are also beginning to experiment with it on the northwestern coast of the United States (Vietmeyer, pers. comm.)

Currently the agricultural research and development priorities of the International Potato Center in Lima, Peru do not include projects focusing on *Oxalis tuberosa* or other Andean tuber crops. The development of this crop will continue for the present, only through the interest and efforts of individuals and agronomic research programs interested in new crops.

Conclusion

Oxalis tuberosa is a widespread minor crop in the Central Volcanic Cordillera of Mexico. There appears to be very few cultivars present in the the region. *Oxalis tuberosa* has been integrated into a number of distinct cultivation systems and is especially well suited to elevations between 2400 and 3000 m. It is utilized in a variety of dishes and preparations and is of fair to good nutritional value but amino acid analyses still need to be performed. It is probable that *Oxalis tuberosa* was introduced through Spanish trade networks from South America during the past 200 to 300 years. Finally, researchers are encouraging the cultivation and utilization of *Oxalis tuberosa* in other areas of the world. If given research and development priority, this crop could serve ultimately to expand the food base that supports the global community.

Chapter 9 - Germplasm Conservation and Agricultural Research Priorities

Collections of The Diversity of Andean Tuber Crops

There have been several germplasm collecting expeditions in Ecuador, Peru, and Bolivia. Germplasm of all four of the species is now being stored and evaluated in germplasm banks in Ecuador and Peru. Table XVI lists the numbers of collections for each species. There have been germplasm collecting expeditions in Bolivia but these collections have not survived (M. Holle pers. comm.). Duplicates of a portion of these Bolivian collections were sent to Peru and are being maintained.

The Ecuadorian germplasm collection is being evaluated at the Santa Catalina research station. The largest number of germplasm accessions is in Peru. There are a total of 5 Peruvian germplasm banks that contain Andean tuber germplasm, located in Cajamarca, Huancayo, Ayacucho, Cuzco and Puno.

Lepidium meyenii is the least well represented of the four species, with only 4 collections in Ayacucho. Germplasm collection of this species is now being conducted J. Rea (pers. Comm.). *Oxalis tuberosa* is the most well represented of the crops, with 1205 accessions being maintained in 6 germplasm banks in Ecuador and Peru. The next largest in number of collections is *Ullucus tuberosus*, followed by *Tropaeolum tuberosum*.

In Peru there is also a collection of *Oxalis tuberosa*, *Tropaeolum tuberosum* and *Ullucus tuberosus* at the University of San Marcos laboratory of genetic resources and biotecnology. This duplicate

Table XXX

Germplasm Collections of The Four Species*

Species	Ecuador	Peru	Total
Lepidium meyenii	0	4	4
Oxalis tuberosa	55	1050	1205
Tropaeolum tuberosum	43	233	276
Ullucus tuberosus	96	255	351

*Ecuador data from (INAIP/CIRF, 1985). Peru data from (Tapia & Mateo, in press).

collection from Peruvian germplasm banks is preserved in vitro. One of the primary aims of this research group is to eliminate viruses from varieties of the three species. The Viral free germplasm would then be released to farmers and the expected increased vigor of the plants would raise the productivity of the crop (Estrada, in press).

The large number of germplasm accessions of Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosus are likley to contain tubers that are genetic duplicates of other accessions. Research on the biochemical differentiation of potato cultivars has proved successful in eliminating duplicate material in potato germplasm collections. Stegemann et al. (1985) utilized polyacrylamide electrophoresis to classify potato tuber proteins. Stegemann and co-workers showed that 80% of the of the 12,000 germplasm collections of Andean potato cultivars were genetic duplicates. This dramatically reduced the number of accessions that needed to be maintained for breeding programs. A similar approach is being developed for application to the large number of germplasm accessions of Oxalis tuberosa (Stegemman et al. 1988). This type of work is important because it reduces the number of accessions that must be maintained in germplasm banks.

There is, however, a high degree intraspecific diversity within Oxalis tuberosa, Tropaeolum tuberosum and Ullucus tuberosa and agronomic characterization of these varieties is being conducted at germplasm banks. Analysis of the diversity of each species is task that will involve numerous scientists and several years. If adequate resources are allocated conservation efforts, crop breeders will have a wide degree of variation to grow and improve.

Andean Tubers and Agricultural Research Priorities

As mentioned, the International Board of Plant Genetic Resources (IBPGR) has supported the collection of Andean crops, including Oxalis tuberosa, Ullucus tuberosus, Tropaeolum tuberosum and Lepidium meyenii. Recently, however, in 1987 the IBPGR has declared that these Andean tuber crops are not a high priorty for germplasm collecting at this time (IBPGR pers. comm.). A Scientist (D. Horton pers. comm.) at the International Potato Center (CIP) in Lima has also stated that these endemic tuber crops are not part of their research mandate as determined by the Consultative Group on International Agriculture (CGIAR). The reasons that these important minor food crops of the Andean region are receiving research attention of the international agricultural research community are related to the origins of this research system.

While there has been much criticism of the policies and achievements of International Agricultural Research Centers (IARCs) and the Green Revolution that these centers facilitated (Chambers, 1983; Pacey & Payne, 1985; Richards, 1985), the work of the centers has dramatically increased the productivity of the major world food staples. The initial meetings focusing on agricultural development at Bellagio, Italy in 1969 included officials from the Food and Agriculture Organization of the United Nations (FAO), UNDP, World Bank, the Inter-American Bank, Asian Development Bank, Ford and Rockefeller Foundations, representatives of aid organizations from the United States, Canada and Sweden (Baum, 1986).

This distinguished group met with the intention of investigating the ways world food production could be increased through global cooperation utilizing, in part, the highly successful model of crop-specific research centers supported by Ford and Rockefeller Foundations that were developing high yielding varieties of wheat and rice.

From 1969 to the present the emphasis has been on the major crop plants, on which that the majority of the Earths population depends for food. It is not surprising that the emphasis of these IARCs still reflects the priorities of their international donors, priorities that do not include the diversity of the minor crops that also contribute to the basic food needs of millions of people.

In the early 1970's, the yields of improved varieties of maize wheat and rice continued to increase to a point where a few developing nations such as India, Mexico and the Philippines became self-sufficient in grain production (Doyle, 1985). This important achievement was, however, dependent in part on expensive imported fertilizers, the cost of which was in turn dependent upon petroleum prices. When the energy crisis in 1973 raised the price of oil, the cost of nitrogen fertilizers also increased. The nations that had adopted the Green Revolution agriculture were forced to pay more in order to keep their food production stable. The burden of this increased cost was heaviest upon the small farmer, the person who the world leaders at the the first Bellagio conference in Italy viewed as one of the important beneficiaries of their global plan.

The effects of improved varieties on the diversity of regional cultivars of minor crops has been the subject of many papers on crop genetic resources (Frankel, 1974; Harlan, 1975; Ochoa, 1975, and Oldfield, 1984). These reports conclude that genetic erosion of traditional cultivars is the result of the adopting experimentally improved crop cultivars. These traditional crops, including Andean tubers, have been selected over centuries for their adaptation to environments that often will not support large scale temperate agriculture or the improved high yielding varieties developed for large scale mechanized cultivation.

The goals of the international agricultural research community do in fact include subsistence farmers, and recent work has been aimed at tailoring major crops for environmental limitations, such as arid lands, low fertility soils and short growing seasons (Baum, 1986). The intent of this section is not to point out the problems of the IARCs but rather to outline complementary research priorties and the actions that are necessary if these priorities are to be implemented.

If we accept that a significant number of people in the developing world are engaged in subsistence farming in mountainous environments, then it is reasonable to suggest that international agricultural research priorities should include research aimed at improving the welfare of these people. One method of achieving this goal without creating external economic dependence is to work on improving the regional crop varieties that are already integral parts of the existing agricultural complex.

The antiquity of the crops domesticated in the Andes suggests that the Andean tuber crops, among others, would be excellent candidates for agricultural research aimed at improving yield, disease resistance, storage characteristics and cultivation techniques. In order to achieve this goal, crop scientists will need to work with as wide a diversity of genetic material as possible. This possibility will become increasingly difficult to carry out as the diversity of landraces of minor Andean crops is reduced (Plucknett *et al*., 1987).

Germplasm Conservation

The germplasm collections of the four Andean tuber taxa included in this study are subject to a number of the problems that affect most *ex situ* germplasm storage systems. *Ex situ* storage systems have several limitations that are especially critical in the case of vegetatively propagated crops and recalcitrant seeds. A few of the known dangers in single strategy *ex situ* germplasm conservation are pointed out in this chapter. This is followed by a description of common responses the proposal of *in situ* germplasm conservation and the position of the IBPGR on *in situ* conservation. The reasons for developing *in situ* conservation systems and the current status of the few that have been created is then discussed. Recent North-South concerns regarding germplasm and farmers rights are then discussed in reference to *in situ* conservation strategies. In the final section a hypothetical system for implementing *in situ* preservation of Andean tubers is outlined as part of the applied recomendations of this research.

Limitations of *Ex Situ* Germplasm Storage

The conservation of germplasm in seed banks, often far from the source of origin of the collections, has become the major method of preserving crop genetic resources (Wilkes, 1983). This method is highly conducive to the needs of breeders since the material in these banks has been already grown and evaluated. The distinct characteristics of each collection and the seed material itself is usually easily obtained for research aimed at improving crops.

A number of the methods utilized for medium and long term storage require that germplasm be stored at low temperatures to extend the period of time between mandatory regeneration of the material. Selection for varieties that respond well to cold storage may not correspond with other desirable crop traits (Oldfield, 1984). Growing out and renewing germplasm material is usually expensive and requires trained personnel to assure that the material is properly handled and evaluated for acceptable viability rates and plant health. Some workers have also noted that unwanted changes can take place when plants are grown, out due to genetic drift, unintentional hybridization and new selection pressures that were not present in the cultivars, region of origin (Plucknett *et al*., 1987).

One of the other dangers, also pointed out by Plucknett and co-workers include the potential damage or complete loss of collections due to electrical failure, natural disaster and political instability. While many important collections of germplasm are conserved in at least two places, due to financial contraints others are not. One fire started by poor wiring caused a nearly complete loss of a Brazilian Lima bean collection (Plucknett *et al*., 1987).

An entire collection of Bolivian germplasm of *Oxalis tuberosa*, *Ullucus tuberosus* and *Tropaeolum tuberosum* was also destroyed (M. Holle pers. comm.). A portion of this collection is duplicated in Puno, Cuzco and Ayacucho, Peru but much of it must be recollected if it still exists. Germplasm maintained in such artificial environments is also removed from the natural selection pressures that generated it, and this eliminates the possibility of genetic interaction with related wild crop relatives. Finally, as Brush (1986) has pointed out, crop plant germplasm has been selected for cultural, social and economic factors as well as for biological characteristics. This type of information is difficult or impossible to convey on present passport data forms, yet it often greatly increases the value of the germplasm. These types of problems reveal the need to develop a series of complementary *in situ* germplasm sites created in collaboration with the curators of *ex situ* germplasm banks.

In Situ Germplasm Maintainance

The establishment of *in situ* germplasm banks is at present a theoretical subject. It has been noted that the concept is important to implement (FAO, 1985), but few international agencies have been willing to provide the support necessary to create *in situ* conservation sites.

Several other criticisms of _in situ_ conservation have been analyzed by Oldfield and Alcorn (1987). They discussed the oft-cited socioeconomic problems associated with _in situ_ conservation. Critics of _in situ_ conservation maintain that it is contradictory for national policy makers to promote the preservation of traditional cultivars when there are usually other political pressures to adopt improved crop varieties and associated fertilizers and inputs. The preservation of crop germplasm as part of traditional agricultural systems may also be viewed as an attempt to keep indigenous groups and small rural farmers in a state of agricultural suspended animation. It has also been suggested that the necessary financial subsidies that would be payed to farmers would be prohibitive (Frankel, 1974).

The IBPGR and _In Situ_ Conservation

The position of the IBPGR on _in situ_ conservation is complex, and it reflects the mandates of the donor organizations that support it. To begin with, the ability of the IBPGR to focus its resources on the question minor crops is limited. The IBPGR has stated that: "with the budget running currently at about 4 million dollars per year, we are unlikely to be able to expand to cover minor species... and, one of the paradoxes of work at the regional level is that many minor species assume great importance and the board with its small budget and staff has to limit its support to such crops" (Williams, 1983). This position is understandable given the global drive to collect, conserve and evaluate the major cultivated food staples.

In July 1984 the IBPGR convened a task force for two days in Washington, D.C., to help develop a policy for the use of ecological and geographical data in exploration and employment of in situ methods for conservation of germplasm (IBPGR, 1985). The reason for this meeting was based in part on the board's emphasis on the importance of wild relatives as genetic resources. As a result most of the recommendations of the task force reflected its perception of the principles, methods, goals and priorities for conserving the gene pools of wild crop relatives based on scientific study using the tools of ecogeographic surveying and in situ conservation.

One of the first objectives for in situ conservation is "to maintain self-perpetuating populations in natural ecosystems. For crop germplasm, in situ methods will therefore be employed largely for wild species." Further: "The interventions required to protect the survival of landraces in agricultural landscapes would be too extensive to be considered" (IBPGR, 1985). It was added, however, that model "evolution gardens" might be considered under special circumstances.

The conclusions of the group were affected to some extent by the composition of its members, and their views did not reflect a fundamental diversity of philosophy from which to approach the issue. The effect of such lack of diversity has been described by Doyle (1985): "In many policy-making and scientific proceedings in Washington and other places, it is increasingly a handful of industrial and scientific representatives cut from a very similar cloth who set and establish the tone and content for much of officialdom that eventually influences legislation and government action. In the course of these various studies and scientific proceedings, consumers, farmers, and environmental interests are not equally represented nor are their views usually accorded the same weight as scientists or industry representatives."

The statement of the special task force on ecogeographic surveying and in situ conservation does reflect the larger mission of the IBPGR as mandated by the CGIAR. The in situ conservation of minor crop landraces was considered unfeasible and the group offered some suggestions concerning the limititations of in situ conservation. In effect a policy precedent was set when the IBPGR stated that it is not feasible to consider the in situ conservation of landraces. It is now up other organizations and individuals to create innovative approaches to the challenge of preserving the diversity of landraces in situ.

Rationale for In Situ Conservation of Crops

Prior to discussing the advantages and benefits of in situ conservation, it is important to note that such methods should be created in collaboration with existing ex situ germplasm banks and that these should be complementary to one another.

The most powerful reasons for establishing systems that conserve traditional farming systems involve the ongoing evolutionary interaction of humans, crops, wild relatives, pests and pathogens (Oldfield & Alcorn, 1987). The continued manipulation of crop plants in the natural environment is similar to a field laboratory where new experiments are constantly being tested. The continued maintenance of crops that demonstrate resistance to diseases and insects are highly valuable to regional farmers and plant breeders. Farmers often integrate the production of livestock into their agricultural systems and the value of the crops selected for such systems is often site specific (Altieri & Merrick, 1987).

Many cultivars are well adapted to specific local ecogeographic conditions, such as varieties of Andean tubers that thrive at high altitudes, and these characteristics are important to people that live in such environments. The cultural practices that are associated with traditional subsistence farming also create differential selection pressures that contribute to a constant biological interaction between farmer, crop and environment. The traditional crop exchange network of farmers is another mechanism that facilitates a continual flow of genetic material, a flow that is reduced if material is only preserved in *ex situ* banks.

The importance of the interaction of crops, weeds and wild relatives was pointed out by the IBPGR task force on ecogeographic surveying and *in situ* conservation (IBPGR, 1985). By encouraging the maintenance of cultivars *in situ*, this important evolutionary relationship will not be lost. One recent approach to the *in situ* conservation of the wild relatives of maize has been implemented by one of the CIAGR centers in Mexico. The International Maize and Wheat Improvement Center (CIMMYT) has established an *in situ* monitoring system of wild populations of the teosinte and *Tripsacum* species found in Mexico and Guatemala. In this project, CIMMYT scientists will make yearly visits to monitor wild populations of the these wild relatives of maize (Wilkes & Taba, 1986). This is an experimental approach that will seek to observe the status of wild relatives of a crop of major world importance. This method is not costly, but it is not a project that is able to incorporate regional farmers into a long term conservation strategy. Projects that include humans as part of the natural landscape are important if both wild relatives and landraces of minor crops are to survive.

The goals of international aid organizations that work to promote integrated rural agricultural development projects can be enhanced by including *in situ* conservation projects for local indigenous minor crops. This serves multiple functions for agricultural communities and keeps a sample of any germplasm collected in a specific area in the hands of interested farmers. *In situ* conservation systems can serve as focal point for the community and act as a teaching tool, so that farming practices and associated cultivars can be passed on to the next generation of farmers.

Increasing the involvement of local farmers also serves to increase the awareness of regional food producers about the importance of their agricultural achievements. This awareness can also be useful for farmers as they work with regional agricultural extension agents who are supposed to promote improved varieties of major crop plants. The idea of communities taking an active role in the conservation of their regional genetic resources is being incorporated at an international level in several ways. One of the developments in this area is the community seed bank kit, which describes in simple language why and how people in agricultural communities should and can preserve their own regional genetic resources (Rural Advancement Fund International, 1985). There are several existing in-situ conservation approaches, each working with different sizes of area and each with positive and negative features.

Examples of In situ Conservation Programs

The largest and most comprehensive attempt to initiate in situ conservation efforts was that of UNESCO'S Man and the Biosphere Programme (MAB), which initiated an international network devoted to the conservation of genetic resources within long inhabited human landscapes (Oldfield & Alcorn, 1987). The MAB program works at integrating rural development with wilderness conservation, and humans are always an integral component. The in situ conservation of cultivars landraces and wild relatives has been only recently added to the MAB biosphere reserve system, and each geographic area requires a distinct approach tailored in part to the development needs of the people inhabiting that area. A reserve of the Kuna Indians of Panama is likely to become one of the MAB biosphere reserves, and it will serve as an excellent model of in situ conservation integrated with the development needs of native people.

In Ecuador a similar project is being developed with the Siona-Secoya, a group that has been collaborating with the national government, the U. S. based groups Cultural Survival and the World Wildlife Fund. In this case conservation is directly linked to establishing a natural preserve that will both meet the future needs of this group and protect the natural environment from unnecessary destruction. Both of these serve as examples of the integrated approaches to *in situ* conservation that need to be established for both crop landraces and their wild relatives.

The methodological approach of involving farmers directly in the process of the preservation of germplasm is not new or untested. In the United States, the Native Seeds/Search, based in Tucson Arizona, is working with native amerindian farmers and encouraging them to grow traditional crop cultivars. The organization also works to involve older farmers, so that they can pass on the traditional information associated with cultivation of these crops (Nabhan, 1985).

Other organizations like the Seed Savers Network have enlisted interested food producers across the United States in a large informal network of people who are growing and exchanging landraces of cultivated crops which would might have been otherwise lost due to lack of interest by most seed companies (Whealy, 1987). These two methods of conserving landraces of crop germplasm all involve people as active participants and function in a complementary way to established *ex situ* germplasm banks. *In situ* conservation systems that involve people serve another very important function, especially in developing nations.

International Germplasm Issues

The current international debate over the rights of multi-national seed companies and traditional farmers has created both legal and ethical conflicts that have powerful repercussions for individuals and organizations interested in the conservation of the Earth's crop genetic resources.

The 23rd FAO conference, held in Rome, marked the 40th anniversary of the FAO, and genetic resources was one of the key issues under discussion. At the previous FAO conference, an intense debate over germplasm issues led to the passage of two resolutions that called for the establishment of the International Undertaking on Plant Genetic Resources and the Commision on Plant Genetic Diversity. At the 23rd FAO conference representatives from 156 countries discussed the variable needs and perspectives of both developed and developing countries. Numerous concerns were raised regarding the current status of germplasm collecting activities and directions as expressed by the IBPGR. Many developing nations called for a global system of "seed" genebanks, which were to be controlled by the FAO. These countries also asked for additional training opportunities for germplasm curators and plant breeders. The proposed global system called upon the international donor community for the necessary financial support. Many of the developed countries opposed this idea, saying that the new fund was unnecessary and unlikely to find support (Witt, 1985). Much of the concern expressed by developed countries is fueled by the belief that international seed companies are using developing country genetic resources as the base for the development of their improved varieties, which are then sold at a profit back to developing nations. It has been agreed, however, that one of the major problems in this issue is the lack of information about existing gene banks, and about freedom of access and ownership of material. One of the major concerns of the developing nations involves the disposition of germplasm material. To date, 25% of all the material collected has gone to the United States, roughly five times the quantity that has been received by other developed nations. The overall balance of the conservation centers is weighted heavily to the industrialized nations. This may be logical in terms of storage facilities and political stability, but it engenders problems when developing nations experience difficulties in obtaining germplasm from other countries. There have also has been examples of confusion in the subsequent release of unimproved germplasm. The International Genetic Resources Program (IGRP, 1986) has reported that both Chile and Bolivia had experienced difficulty in obtaining disease resistant strains of Phaseolus from IVRO in Holland.

The response to this type of problem may increasingly reflect the policy of the governments of Brazil and Ethiopia. Ethiopia expressed their position at the 23rd FAO meeting saying "we fail to understand why plant genetic resources should be any different from other resources. It is the sovereign right of any country to use its genetic resources as it sees fit, and anybody who wants to acquire them should agree upon a mode of acquisition with the proprietor." If this attitude becomes widespread it could adversely affect the work of the CGIAR centers and plant scientists around the world. The issues raised at the 23rd FAO conference indicate the importance of establishing in-situ crop germplasm strategies that emphasize both in situ and ex situ crop germplasm strategies that can serve both local and international food security concerns.

During the second session of the 1987 meeting of the Commission on Plant Genetic Resources at the FAO, 61 of the 84 member states discussed the rights of both farmers and plant breeders. At this meeting the Commission agreed to ask the Director General to establish an international fund for the conservation and utilization of plant genetic resources (RAFI, 1987). The fund would initially be contributed to by both governmental and non-governmental organizations on a voluntary basis. The idea was also discussed that a more formal funding arrangement could be established that would involve the taxation of the international seed industry, involving the small percentage of the retail price of seed and related planting material. One of the most significant developments of the meeting was the attempt to recognize farmer's rights as equal to the rights of plant breeders. The recent meetings at the FAO also suggested the urgency of creating _in situ_ regional conservation strategies that will serve the needs of farmers who may not at this time be benefiting from the existing global programs of germplasm conservation. By agreeing to support such national _in situ_ conservation systems with an international genetic resources fund, the perceived distribution imbalance would be, in part, addressed.

New models and experiments for creating such regional germplasm conservation systems need to be created and tested. Such models will be difficult to generate and test if international agricultural experts do not adopt a more innovative attitude to the challenges of conserving the diversity of crop plant germplasm.

A Model For The In Situ Germplasm Conservation of Andean Tubers

In order to bring this discussion of crop germplasm back into the focus of this research, a plan for the experimental in situ conservation of Andean tubers is presented. The emphasis of this model is to create an in situ germplasm conservation system that both compliments existing ex situ sites and one that serves both the consumers of national agricultural production and the producers.

One of the critical prerequisites for instituting local in situ conservation strategies involves understanding the evolution of national agricultural programs, especially those that have focused on the crops that have been domesticated in the region. The situation of the Andean crops is complex, and each country has its own distinct crop domestication history. It can be said that the Andean countries have, in the past 24 years, made considerable advances in investigating and promoting the products of their agricultural heritage. In the case of traditional Andean crops, other than the potato and the international agricultural research center devoted to it, their have been continual innovative that seek to maximize the food self sufficiency of Andean countries.

The research conducted to date on Andean crops has been supported by several international donor organizations. In Peru, one result is a widespread network of Andean crop research centers based in several national universities and coordinated by the Programa Nacional de Sistemas Andinos de Producción Agropecuaria (PISA) in Lima (Fries and Tapia, 1986). The numbers of germplasm collections and their status has been presented above, and this data suggest the degree of national involvement and commitment to these crops. The model for creating *in situ* conservation sites for Andean tuber germplasm would be integrated with this agricultural research network and the rural development programs operating in the different regions of the country. The range of diversity of minor Andean tubers is still incompletely known, but there are numerous plant scientists that have extensive experience working with these crops. It is this established system, Andean scientists and one other critical group of experts, the farmers, that form the core of this proposed *in situ* conservation strategy.

The model in part is very similar to the working method developed by social scientists at the International Potato Center, and it has been called the farmer-back-to-farmer model (Rhoades, 1982). In the case of *in situ* conservation for Andean tubers, the farmers in the region of each national university would be the keys to establishing sites. Criteria for selecting specific ecogeographic regions and farmers in them would be determined in part through the personal knowledge of the plant scientists and the range of diversity that has been collected for the *ex situ* germplasm banks. A range of altitude, moisture and temperature would be sought for at least four highland regions of Peru. Within each of these regions, four farmers would be selected to cultivate and maintain the diversity of three to four of these crops.

A critical aspect of the model would involve the selection of the individual farmers, which should be based on previously observed personal interest in these crops and their reliability. These individuals would work closely with the crop scientist, initially exchanging ideas on the intent and feasibility of the project. After this phase a maintenance plan, with farmer-originated ideas incorporated, would be created. No farmer would be involved unless he or she saw a direct benefit to their household and community.

The individual farmers would receive a financial subsidy that might ordinarily be obtained through off farm labor, often pursued outside of the demands of the yearly agricultural cycle. A system of tuber exchange would also be implemented, following idealy the mechanism of traditional food crop exchange. The varieties to be cultivated could be selected through a combination of the following methods: 1) The farmer himself would be asked to name the varieties of Ullucus tuberosus, Oxalis tuberosa and Tropaeolum tuberosum with which he was familiar. 2) A selection of these would be placed under his care for one season, with a mid growing season and post-harvest inventory visit made by the collaborating scientist. 3) Landraces for planting could also be brought from the nearest germplasm bank, in some cases introducing the farmer to new varieties or poorly known varieties. 4) An additional tactic would be to solicit information from the women of the village about varieties with which they were familiar.

The method of cultivation would be left up to the participating farmer, and these methods would be recorded by the collaborating scientists, along with any verbal explanation for planting systems. Harvest and subsequent post-harvest storage method would be documented. Any techniques learned by the collaborating scientist from other farmers or fellow scientists could be passed on to the participating farmers. The same farmer could participate for several agricultural seasons, and the varieties could be exchanged with other regions as mutually determined between the farmer and the scientist. In the course of the experiment, the entire community could be introduced to the idea behind crop germplasm conservation and the responsible farmers rotated if so desired.

In the course of the cultivation, problems that the farmers were experiencing with these crops would be recorded, and would then be relayed to the agricultural scientists at the regional universities for potential research projects. Varieties that exhibited desirable characteristics, such as disease resistance, high yield or resistance to unusual weather conditions, would also be noted and this data added to the crop's passport data.

After two or three agricultural cycles farmers from several distinct ecogeographic areas could be brought together for discussion with the regional university agronomists to evaluate the utility of the program to the farmer, his community and to the universities goal of maintaining the diversity of the landraces in complimentary in-situ and ex-situ systems. The work of Peru's University of San Marcos tissue culture laboratory could also be integrated with the system. As viral-free cultivars were ready for distribution, the regional agronomist and his farmer counterpart would receive and evaluate the material. This mechanism could also operate in the reverse: as the farmer noted decreasing yields of highly desirable varieties, he could request that they be checked for known viruses and then, if detected they could be "cleaned" and returned to him. This particular service is one that is often performed by the IARC's for varieties of the major crops.

The cost of the model described above would likely be perceived initially as prohibitive, especially considering that there are several other important minor crops in the Andean region that would merit similar conservation schemes. Criticism of the high cost would have to be carefully examined before being accepted. The actual cost necessary for each farmer would not be especially high, particularly if a portion of the harvested material were available for consumption by the family. Even the cost of the agronomists' time and expenses would not be prohibitive if countries such as Peru were entitled to a portion of the international fund recommended to the Director-General of the FAO. The issue of cost, viewed on an international expenditure basis, would in fact be reasonable, especially if the per diem paid for an international expert from a developed country is matched against the outlay for a farmer, an agronomist and their minimal expenses for one year. A normal government per diem for an international expert to stay in Lima, Peru for consulting purposes is usually at least one-hundred dollars per day. The cost of one expert consultant for 14 days, not including fees, would easily fund three sets of farmers and collaborating agronomists on a part-time basis for one year. The system would, by definition, be an extension of existing research facilities and crop mandates. If the above figure is close to the reality, it would appear to be easily as valuable as the services of an expert from outside the country and probably over the long term a more useful expenditure from the perspective of the country in question.

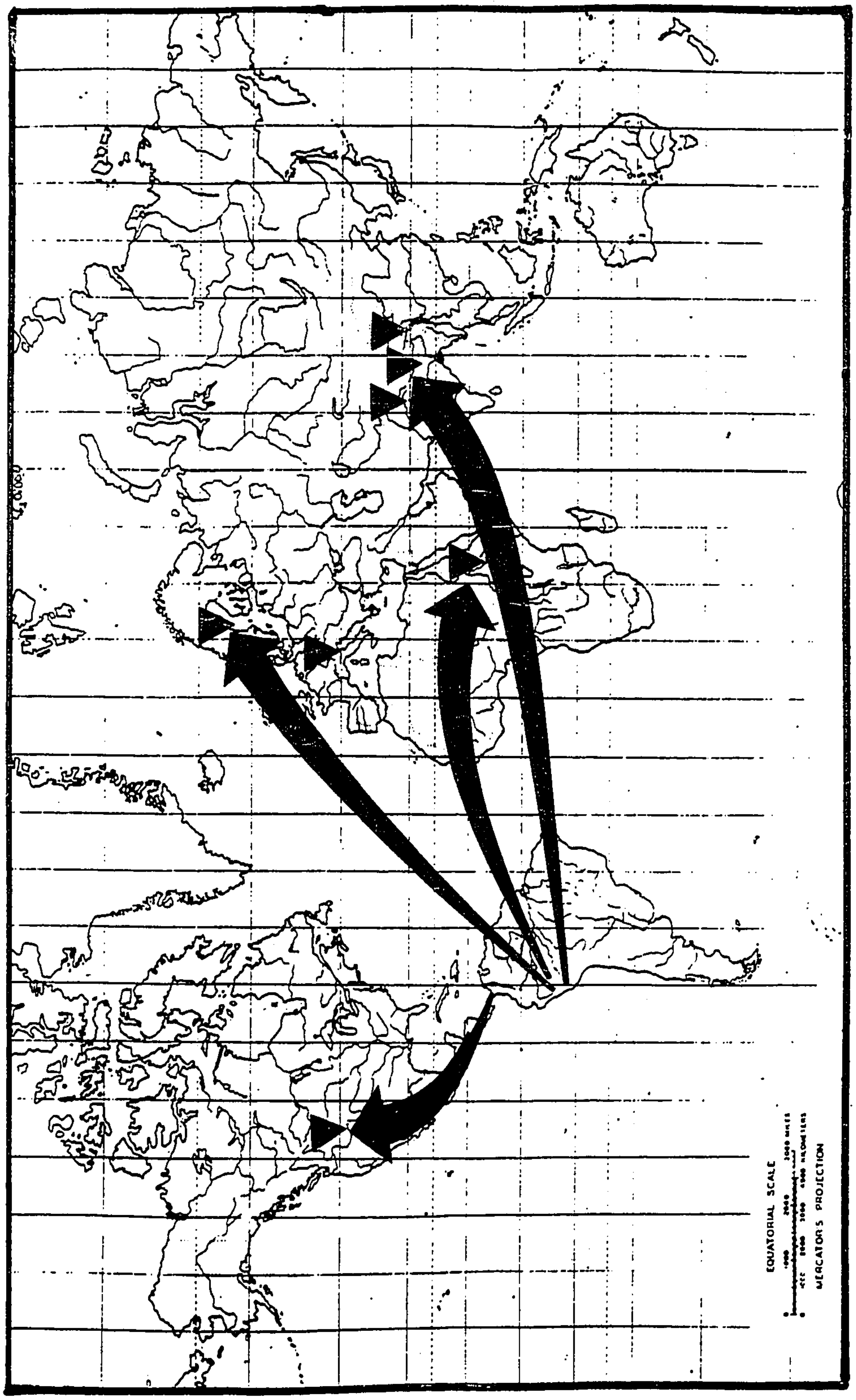
Discussion

In evaluating the above outlined in-situ conservation it is important to remember that it is an experimental design and that it will surely require modifications over time. Neither the model nor the Andean farmers exist as static components. Farmers have been and are always conducting their own small scale experiments and change is a vital part of their ability to adapt to fluctuating environmental, cultural and economic conditions; the same applies to creating *in situ* germplasm methods for landraces of Andean tubers. Regular monitoring and system adjustment will be a necessary component of the strategy.

The *in situ* conservation strategy described above would address several of the germplasm conservation areas that are not currently addressed by maintenance of germplasm in *ex situ* storage banks. This system would allow for the ongoing human selection of minor crop plants and directly involve farmers in the process. The method would also likely improve the international communities' concerns about single strategy germplasm conservation and the apparent imbalance in the location of germplasm storage facilities (IGRP, 1985). This issue of access is a major concern of the IBPGR, but it is important to recognize that the mandate of the IBPGR mostly reflects the aims of the CGIAR and the donor organizations that support it. Developing nations with an extensive diversity of landraces of minor crops have partially distinct national priorities. Both goals should be encouraged by the national governments and the international donor community.

The ultimate fate of the diversity of landraces of Oxalis tuberosa, Ullucus tuberosus, Tropaeolum tuberosum, Lepidium meyenii and other Andean crops, will likely be determined by the outcome of discussions now taking place at the FAO and in numerous countries that are the guardians of these genetic resources. Because these crops are part of our global agricultural heritage, it is hoped that the organizations currently influencing the creation of in situ germplasm conservation systems will encourage the increased experimentation and adoption of germplasm management that involves regional farmers and agronomists of many nations. A wide diversity of these crops would then be available for utilization in the other mountainous countries (Fig. 36) of the world, such as the United States, Kenya, Nepal, Tibet, Bhutan, India and China.

Fig. 36 Regions of the world suitable for the exchange of mountainous crop genetic resources.


EQUATORIAL SCALE
MERCATOR'S PROJECTION

Appendix I

Collection Localities of Herbarium Vouchers (HBV), Tubers Submitted for Nutritional Analysis (TSA) And Tubers Preserved in Alcohol (TPA).

Mexico *Oxalis tuberosa*

Coll. #	Date D/M	Locality	Material Collected	Institution Deposited
K682	8/6/86	Tembladeras, Veracruz	HBV, TSA	HBV to NY, MEXU, CHAPA
K683	10/6/86	Xometla, Veracruz	HBV, TSA	" "
K684	10/9/86	Xometla, Veracruz	HBV, TSA	" "
K687	18/9/86	San Gregorio, Michoacan	HBV, TSA	" "
K689	21/9/86	La Garnica, Michoacan	HBV, TSA	" "
K690	25/9/86	Ojo de Aqua, Mexico	HBV, TSA	" "

Colombia

Oxalis tuberosa (OT), *Tropaeolum tuberosum* (TT) and *Ullucus tuberosus* (UT)

Coll. #	Date D/M	Locality	Material Collected	Institution Deposited
K531 TT	4/6/84	Verada Cruzero, Boyaca	HBV	HBV NY, MEDL
K532 OT	5/6/84	Verada Cruzero, Boyaca	HBV, TSA	HBV NY, MEDL
K533 TT	8/6/84	Tunja Market, Boyaca	TSA	-
K534 TT	8/6/84	Tunja Market, Boyaca	TSA	-
K535 TT	8/6/84	Tunja Market, Boyaca	TSA	-
K536 TT	8/6/84	Tunja Market, Boyaca	TSA	-
K537 TT	8/6/84	Tunja Market, Boyaca	TSA	-
K538 UT	8/6/84	Tunja Market, Boyaca	TSA	-
K539 UT	8/6/84	Tunja Market, Boyaca	TSA	-
K540 UT	8/6/84	Tunja Market, Boyaca	TSA	-

Colombia Collections Cont.

K549 OT	22/8/85	Pasto Market, Nariño	TSA, TPA	TPA to NY
K550 OT	22/8/85	Pasto Market, Nariño	TSA, TPA	" "
K551 OT	22/8/85	Pasto Market, Nariño	TSA, TPA	" "
K552 OT	22/8/85	Ipiales Market, Nariño	TPA	" "
K553 OT	22/8/85	Ipiales Market, Nariñ	TPA	" "
K554a OT	22/8/85	Ipiales Market, Nariño	TPA	" "
K555a UT	23/8/85	Ipiales Market, Nariño	TSA, TPA	" "

Peru OT, TT, UT and <u>Lepidium meyenii</u> LM.

Coll. #	Date D/M	Locality	Material Collected	Institution Deposited
K530 LM	12/11/81	Carahuamayo, Pasco	TSA, TPA	TPA to NY
K556 OT	9/3/85	Lima Wholesale Market	TSA	-

Peru Collections Continued

K557 UT	9/3/85	Lima Wholesale Market	TSA	-
K153 OT	4/2/82	Chinchero, Cuzco	HBV	HBV to F
K154 OT	4/2/82	Chinchero, Cuzco	HBV	" "
K155 TT	4/2/82	Chinchero, Cuzco	HBV	" "
K156 UT	4/2/82	Chinchero, Cuzco	HBV	" "
K157 UT	4/2/82	Chincehro, Cuzco	HBV	" "
K158 UT	4/2/82	Chinchero, Cuzco	HBV	" "
K211 UT	5/2/82	Chinchero, Cuzco	HBV	" "
K231 OT	9/2/82	Chinchero, Cuzco	HBV	" "
K232 TT	9/2/82	Chinchero, Cuzco	HBV	" "
K233 UT	9/2/82	Chinchero, Cuzco	HBV	HBV to NY, F
K234 UT	9/2/82	Chinchero, Cuzco	HBV	HBV to F

Peru Collections Continued

K235	UT	9/2/82	Chinchero, Cuzco	HBV	HBV to F
K236	UT	9/2/82	Chinchero, Cuzco	HBV	" "
K276	TT	12/2/82	Chinchero, Cuzco	HBV	" "
K277	OT	12/2/82	Chinchero, Cuzco	HBV	" "

Bolivia Collections Oxalis tuberosa

Coll. #	Date D/M	Locality	Material Collected	Institution Deposited
K800 OT	28/10/87	La Paz, Market	TSA	-
K801 OT	28/10/87	La Paz, Market	TSA	-
K802 OT	28/10/87	La Paz, Market	TSA	-
K803 OT	28/10/87	La Paz, Market	TSA	-
K804 OT	28/10/87	La Paz, Market	TSA	-

New Zealand Collections *Oxalis tuberosa*

Coll. #	Date D/M	Locality	Material Collected	Institution Deposited
K738a OT	15/3/87	Auckland Wholesale Market	TSA	-
K738b OT	15/3/87	Auckland Wholesale Market	TSA	-
K739a OT	15/3/87	Auckland Wholesale Market	TSA	-
K739b OT	15/3/87	Auckland Wholesale Market	TSA	-
K740 OT	15/3/87	Auckland Wholesale Market	TSA	-
K741 OT	15/3/87	Auckland Wholesale Market	TSA	-

Appendix II

Methods Used By Hazelton Biochemical Laboratories for Biochemical Analysis of Tubers.

Promixate Analysis Methods

Protein (N x 6.25)

Official Methods of Analysis (1984) 14th edition, methods 2.057, AOAC, Arlington Virginia.

Moistrure, 100 degree vac oven

Official Methods of Analysis (1984) 14th edition, methods 16.259, AOAC, Arlington Virgina.

Fat

Official Methods of Analysis (1984) 14th edition, methods 7.063, AOAC, Arlington, Virgina.

Ash

Official Methods of Analysis (1984) 14th edition, method 14.006, AOAC.,

Arlington, Virginia.

Crude Fiber

Official Methods of Analysis (1980) 13th edition, method 7.061-7.065, AOAC, Washington, D. C.

Appendix II cont.

Carbohydrates

Composition of Foods, Agriculture Handbook #8 Page 164, United States Department of Agriculture.

Calories

Composition of Foods, Agriculture Handbook #8 Pages 159-160, United States Department of Agriculture.

Amino Acid Analysis

Amino Acid Profile

Analytical Chemistry, Volume 30, Pages 1190-1206 (1958).

Performic Acid Hydrolysis

Journal of Biological Chemistry; Page 238, (1963).

Official Methods of Analysis 1st supplement, 14th edition (1985) method 43.A08-43.A13, VA.

Oxalic Acid

Official Methods of Analysis (1984) 14th Edition, methods 32.044-32.047, 32.049, AOAC, Arlington VA.

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