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Andean roots and tubers:

Research priorities for a neglected food resource

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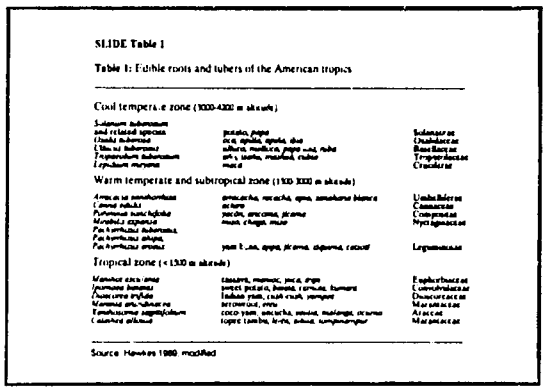


SLIDE Table 1

Table 1: Edible roots and tubers of the American tropics

Cool temperate zone (1000-4000 m altitude)

Warm temperate and subtropical zone (1500-3000 m altitude)

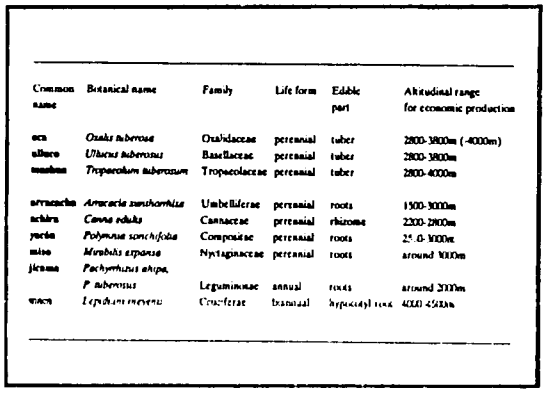
Tropical zone (< 1500 m altitude)

Source: Hawkes 1989, modified

SLIDE 1—Table Edible roots and tubers of the American tropics

There are approximately 25 species of edible roots and tubers that were domesticated in America: they include such worldwide crops as the potato, sweetpotato, and cassava, which represent a greater range of root and tuber crops, in terms of taxonomic diversity and ecologic adaptation, than occurs anywhere else in the world.

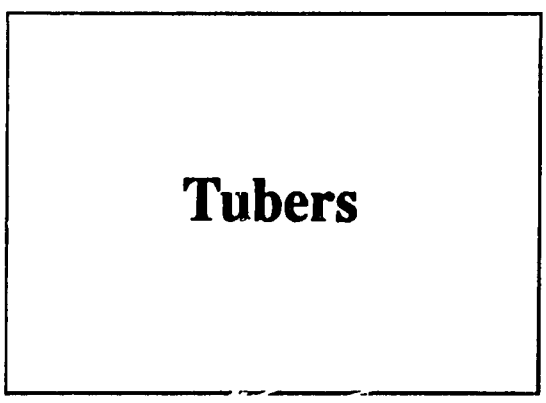
Which among these are Andean crops? There is a general notion that Andean crops are high-altitude crops of the cool-temperate zone above 3000 meters elevation. This is not correct. When speaking of Andean crops we must also include the many species, in particular root and fruit species, that have their origin in the warm-temperate and sub-tropical inter-Andean valleys.



Common name	Botanical name	Family	Life form	Edible part	Altitudinal range for economic production
oca	*Oxalis tuberosa*	Oxalidaceae	perennial	tuber	2800-3800m (-4000m)
ullucu	*Ullucus tuberosus*	Basellaceae	perennial	tuber	2800-3800m
mashua	*Tropaeolum tuberosum*	Tropaeolaceae	perennial	tuber	2800-4000m
arracacha	*Arracacia xanthorrhiza*	Umbelliferae	perennial	roots	1500-3000m
achira	*Canna edulis*	Cannaceae	perennial	rhizome	2200-2800m
yacón	*Polymnia sonchifolia*	Compositae	perennial	roots	2500-3000m
mizo	*Mirabilis expansa*	Nyctaginaceae	perennial	roots	around 3000m
jícama	*Pachyrhizus ahipa*, *P. tuberosus*	Leguminosae	annual	roots	around 2000m
maca	*Lepidium meyenii*	Cruciferae	biennial	hypocotyl root	4000-4500m

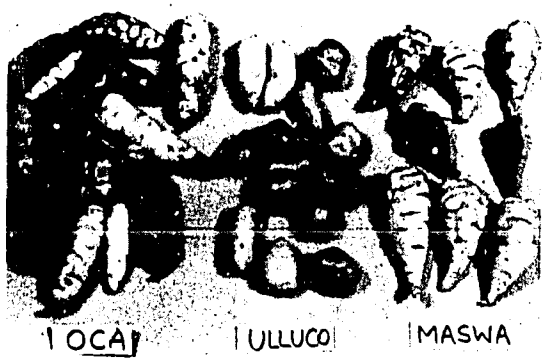
SLIDE 2—Table Andean roots and tubers

There are nine species with edible underground parts. Three are tubers and the remaining six are roots, root-derived structures or rhizomes. Each species belongs to a different family. With the exception of the seed propagated jícama and maca, they are vegetatively propagated perennials. The edible part generally serves as propagule.



SLIDE 3—Tubers

I will first deal with the three tuber species.



SLIDE 4—Oca-ulluco-mashua

Ulluco is easily recognized for its smooth surface and sometimes mottled skin pigmentation. Oca and mashua tubers are very similar and it takes some practice to differentiate them at a glance. Both have rather deep eyes, but the shape of mashua is tapered and it has most of its eyes towards the apex. If you are unsure, try them. Mashua has an acrid, water cress-like taste.

SLIDE 5—Oca, mashua, ulluco intercropped

In "traditional" farming systems all three species are grown intercropped, occasionally in association with potatoes, with which they share environmental requirements.

SLIDE 6—Farmer and child with phina (Cusco)

Tubers are of eminent economic and nutritional importance to subsistence farmers at high altitudes.

SLIDE 7—Hamlet in Cotopaxi (Ecuador)

The harsh climatic conditions at these altitudes permit the cultivation of only a limited range of staples, such as potatoes, barley, faba beans, and quinoa. Farmers are too poor to supply themselves with vegetables or fruits that can only be produced in distant valleys. Livestock is often unavailable. Andean tubers are thus a welcome addition to an otherwise extremely monotonous diet.

SLIDE 8—Map South-America

Andean tubers are cultivated almost everywhere in the Andes, from the mountains of Merida in Venezuela to the northern provinces of Argentina and Chile, at altitudes of between 3000 to 4000 meters, the area which is shaded in brown on this map.

SLIDE 9—Woman and child with Cusco scientist Pedro Cruz in Accha Alta, Peru (3900 m)

However, the production and consumption of Andean tubers is highest in areas with native populations. This is why most of the production is concentrated in the Central Andes north and south of Lake Titicaca and as far north as Northern Colombia, where Indian populations are still grow an amazing variety of tubers.

Ulluco

ulluco
(melloco, papalisa, ruba)

Ullucus tuberosus **Caldas**
(2n = 24, 36)
Basellaceae

SLIDE 10—Ulluco systematics

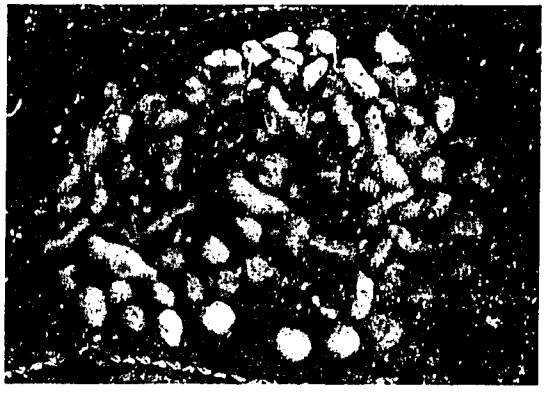
The botanical binomial for ulluco is *Ullucus tuberosus*. Ullucus is a monotypic genus of the Basellaceae, a family of about a dozen species. There are no other species of the Basellaceae closely related to ulluco. Cultivated ulluco is a diploid, but there are also triploid forms of ulluco. Other vernacular names of ulluco include *papalisa* or *lisas* in Southern Peru and Bolivia, *melloco* in Ecuador, and *ruba* in parts of Colombia.

SLIDE 11—Ulluco plants (Cusco, Peru)

This ulluco plant, here shown at an altitude of about 3500 m altitude has a prostrate growth habit.

SLIDE 12—Tuberizing plant (Cotopaxi, Ecuador, 3800 m altitude)

The onset of tuberization in ulluco starts only 4 to 5 months after planting, when the plant has formed abundant foliage. Tuber bulking takes about 2-3 months and varies within the plant. The result is a comparatively long crop duration of 7 to 9 months, which is much longer than most potato varieties require.

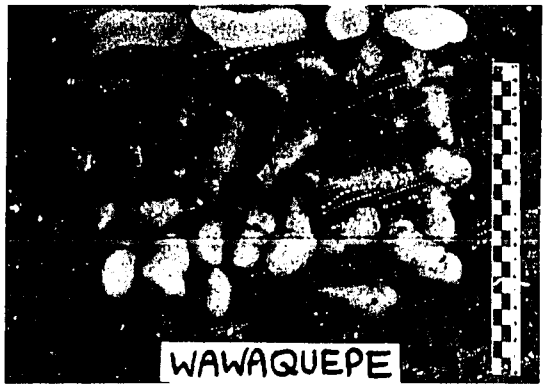


SLIDE 13—Ulluco variability in Cusco

There are white ullucos, red ullucos, and mottled ones, which are most likely chimera. But the most popular are the yellow ones ...

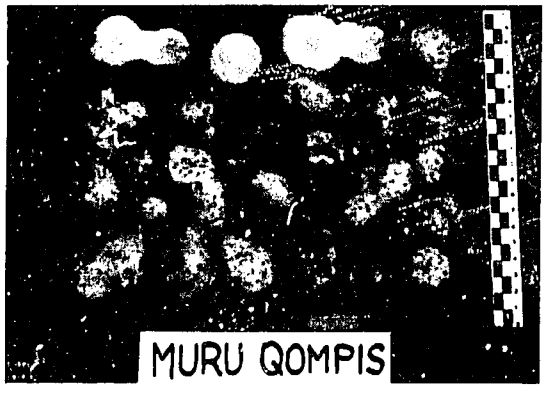
SLIDE 14—Ulluco variety *Wawaquepe*

... like this clone from Cusco, which is known as *Wawaquepe*. *Wawaquepe*, a Quechua word, means "carrying a child." Indeed, this clone is easily recognized for its tendency to form small tuberlets in the eyes of larger tubers, especially in light soils.



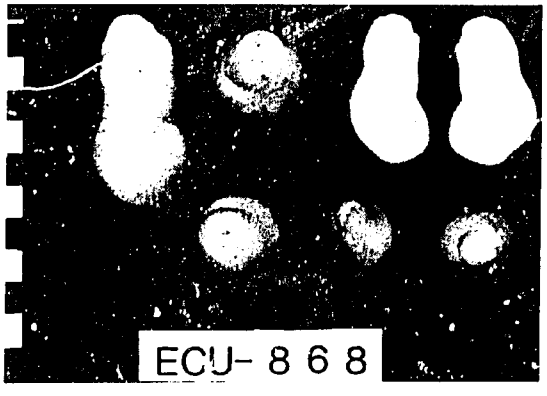
SLIDE 15—Ulluco variety *Wawaquepe*

Wawaquepe can be found in most rural markets in the Department of Cusco. It is a popular variety because it gives a strong yellow color to meals, just like another variety which in Cusco ...



SLIDE 16—Ulluco variety *Muru qompis* (Cusco)

... is called *muru qompis*. This variety is commercialized in most lowland and coastal towns in Peru.



SLIDE 17—Ulluco variety from Ecuador (INIAP No. ECU-868)

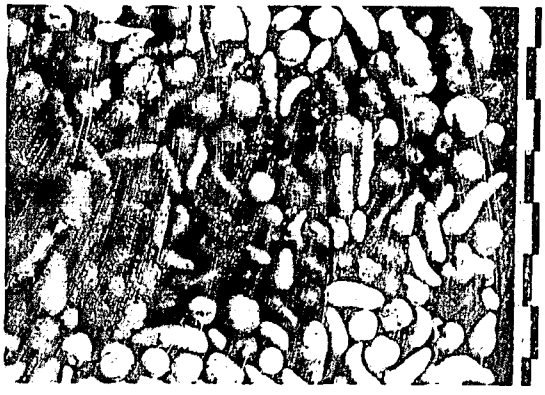
This is a widely grown morphotype of ulluco in Ecuador with red skin and white flesh. Such tubers are popular in that country, but rare in the Central Andes.

SLIDE 18—Ulluco flowering plant (Cusco)

Most ulluco clones flower profusely, but only seldom set seed. The reasons for this are not known. Ulluco pollen has been shown to be of satisfactory fertility and meiosis is regular. Ulluco was until very recently believed to be a sterile plant.

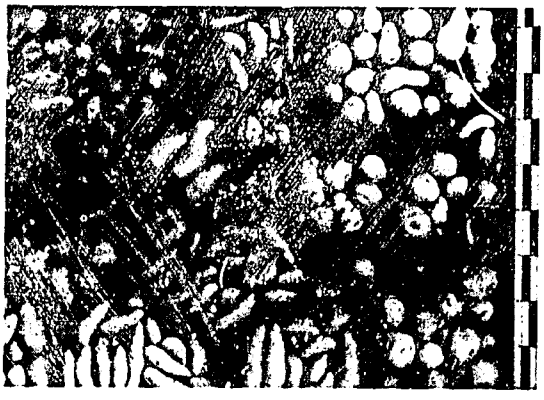
SLIDE 19—Sexual seed of ulluco

Research at Cusco University has shown that when such vegetative sinks are removed as growing shoots, stolons or tubers, the plant forms significantly more botanical seed. The same results can be achieved by giving the plant support so that it does not lie on the ground.



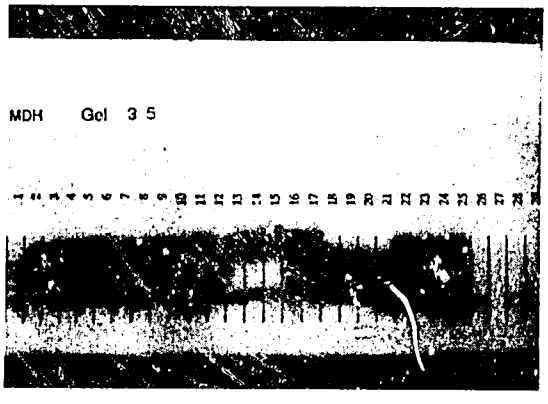
SLIDE 20—Ecuadorian ulluco collection (INIAP), unsorted

Morphological variation is discontinuous in ulluco: it comes in distinct shapes and colors. In markets ulluco is often displayed in mixtures of several clones, thus suggesting high diversity. Each tuber in this photograph represents one accession of a collection of 180 ullucos collected in Ecuador.



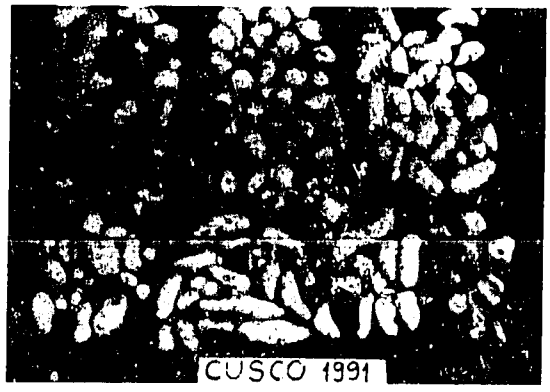
SLIDE 21—Ecuadorian ulluco collection (INIAP), sorted

If this material is sorted according to similarities, 15 clearly distinct groups or morphotypes emerge, most of which have red or no pigmentation. There is very little variation within each group.



SLIDE 22—Malate dehydrogenase in ulluco tuber material

Evidence for the high degree of clonal duplication comes from the electrophoretic patterns of five isozymes that were studied. This one is malate dehydrogenase. In this collection of 180 Ecuadorian ullucos, there are only 58 distinct genotypes. Some of the genotypes are highly replicated with as many as 25 accessions, others are unique or rare. The 10 most frequent genotypes account for almost 50% of the total number of accessions.



SLIDE 23—Cusco ulluco collection (CICA) sorted

Similar results are obtained with material from other parts of the Andes, as with this material from a collection in Cusco. Again, each tuber represents one accession. The classes that can be established are the same as for the Ecuadorian ullucos, however, they have a preponderance of yellow tubers, which are rare in Ecuador.

SLIDE 24—Ulluco in soup (utilization in the highlands)

Ulluco is mainly used in soups and in stews such as the popular dish "ulluco con charqui" in Peru. Most of you will know ulluco from the Lima markets and from occasional lunches in CIP's cafeteria. Ulluco has a somewhat earthy taste which is not entirely pleasant when one tries it the first couple of times. This certainly limits the acceptability of ulluco where it is introduced as a new vegetable. However, I find that ulluco is a very palatable food with an interesting taste and texture.

Nutritional variability of ulluco (*Ullucus tuberosus*)

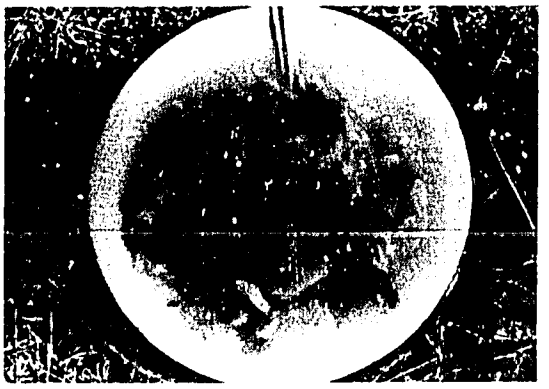
	MIN	AVG	MAX	n
[1]Dry matter content (%)	10.1	15.5	25.1	180
[1]Raw protein (% DM)	6.7	10.2	18.5	155
[2]Dry matter (%)	13.8		14.0	5
[2]Protein (% DM)	10.8		15.7	5
[2]Carbohydrates (% DM)	73.5		81.1	5
[2]Fat (% DM)	0.1		1.4	5
[2]Fiber (% DM)	3.6		5.0	5
[2]Calories/100 g	376		381	5

Source: [1]Hermann, unpublished data [2]King 1987

SLIDE 25—Nutritional variability of ulluco

There is very scarce information on the nutritional value of ulluco. My own data obtained from 150 accessions of the Ecuadorian collection suggest that there is considerable genetic variability regarding tuber protein content. On average, the samples contained 10% of raw protein on a dry weight basis. Given an average dry matter content of 15% in fresh ulluco tubers, these samples contain about 1.5% of protein. Average ulluco protein content would thus be in the lower range of variability of potato protein contents. These data are confirmed by the results of King (1987). Amino acid scores of the same author have shown that ulluco protein is of a fairly good quality.

Incidentally, there is a popular belief in the Peruvian Andes that ulluco is an aphrodisiac. If rural people become aware of a couple in marital crisis, they will go and present them with a few ullucos in order to help them restore marital harmony.



SLIDE 26—Use of ulluco leaves in soups

Ulluco leaves are succulent and tender, in taste and texture very similar to the closely related Malabar spinach, *Basella alba*, which is a widely grown leaf vegetable in the lowland tropics of Asia and Africa. I have observed in rural areas in Cusco that a few ulluco leaves are always added when a soup of ulluco tubers is being prepared. This is a salutary habit which should be encouraged. Green leaves are known to contain high levels of protein, calcium, and carotene, and a spoonful of cooked leaves can provide a considerable part of a child's daily requirements of essential nutrients.

SLIDE 27—Cusco women chopping ulluco

An undesirable but harmless constituent of ulluco is mucilage. This is most likely a polysaccharide which is present in all plant parts and probably confers some drought or frost resistance. High levels of mucilage are found in wild ulluco and small-sized varieties. There seems to be a positive relation between altitude and mucilage content.

In order to remove mucilage, ulluco is chopped into small bits, ...

SLIDE 28—Cusco woman with young girl washing ulluco

... and then washed up to 5 times.

SLIDE 29—Ulluco in Palmira market (Cauca Valley, Colombia)

Of the 3 tuber species, only ulluco is traded in substantial quantities and transported over long distances to supply the lowlands, where the crop cannot be grown, such as here in Palmira in the hot Cauca Valley in Colombia. Ulluco has a reasonably long shelf life in tropical environments. On the other hand, oca and mashua are easily bruised and are very perishable under warm-humid conditions.

SLIDE 30—Palmira market close-up

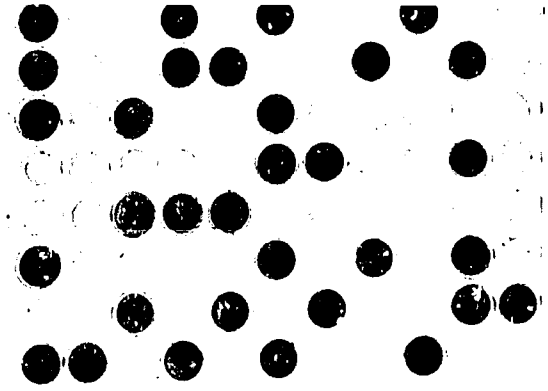
The fact that ulluco can be obtained in almost every urban market, both in the coastal and in the Amazonian lowlands, testifies to its popularity. It is clearly the most important species of the three tubers, rivalling, and perhaps exceeding, the sweetpotato in economic importance in the Andean countries.

SLIDE 31—Ulluco plant showing virus symptoms (Courtesy C. Arbizu)

Ulluco is a robust plant and I am not aware of any serious pest or disease that affects it. I have seen tubers damaged by molluscs and diptera larvae, but apparently this does not lead to severe damage or crop failures. This plant shows virus symptoms.

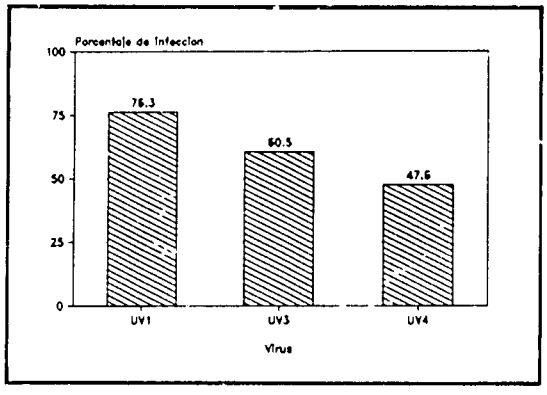
SLIDE 32—Four viruses under the electron microscope (Courtesy J. Toledo)

In epidemiological studies it has been found that ulluco is not a host for potato viruses, but it has some specific viruses. So far, 4 ulluco viruses have been identified ...



SLIDE 33 —Elisa virus tests (CIP) (Courtesy J. Toledo)

... and CIP's virology department has produced antisera for virus detection.



SLIDE 34—Graph showing virus infestation of ulluco (Courtesy J. Toledo)

Much of the existing virus work on ulluco at CIP has been done by Judith Toledo from San Marcos University under the supervision of Upali Jayasinghe, and her survey of about 200 ulluco accessions from Peru has shown that most of the material is infested with one or more viruses.

Oca

oca
(apilla, ibia)

Oxalis tuberosa **Molina**
(2n = 58, 64, 66)
Oxalidaceae

SLIDE 35—Oca systematics

Oca, also called *apilla* by Aymara speakers, and known as *ibia* in Colombia, is a perennial herb of the genus *Oxalis*, which is widespread in South America but taxonomically poorly known. Despite the high number of *Oxalis* species in the Andes, there appear to be no wild tuber-bearing species closely related to the cultigen, as in the case of the potatoes. Not even the somatic chromosome number of oca is known with any certainty, which illustrates the scant knowledge that we have of the biology of this and other Andean crops.

SLIDE 36—Oca Wari vessel (Ayacucho, Peru) (Courtesy C. Arbizu)

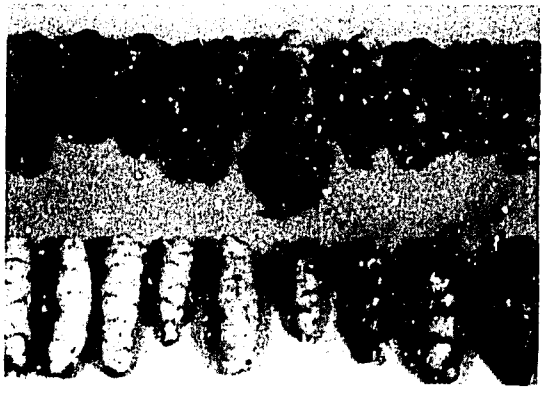
There is evidence from historic accounts that oca was a major Andean staple in pre-Colombian times second only in importance to the potato. The plant is depicted here on a Wari ceramic vessel from Peru.

SLIDE 37—Oca plant (Ecuador)

Oca has about the same ecologic requirements as non-bitter potatoes. It seems to be somewhat hardier than ulluco as it reaches higher elevations (at Lake Titicaca up to 4100 m). However, oca is very susceptible to tuber deformations in heavy soils. Tuber size and yield may be depressed under such conditions.

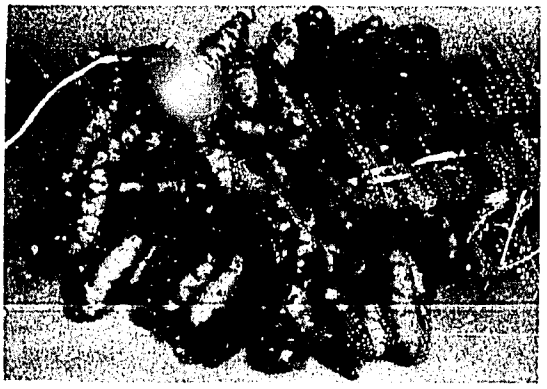
SLIDE 38—Oca flower (Courtesy C. Arbizu)

Although exclusively reproduced by tubers, oca has retained the ability to set sexual seed, however, at a reduced rate. It has an effective outbreeding mechanism. In order to obtain successful pollinations, plants of different flower morphs are required.



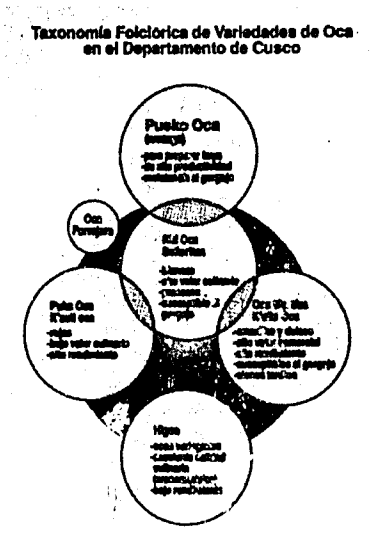
SLIDE 39—Selected ocas from Cusco

Morphological diversity in oca is much higher than in ulluco, in terms of tuber shape, pigmentation, eye number and distribution. Variation in oca, unlike that in ulluco, is continuous. For example, ocas can be arranged, as in this picture, in gradual transition from black over red, orange, yellow, and white morphotypes.



SLIDE 40—Oca collection from Cusco

This is a core sample of the oca collection of the Centro de Investigaciones de Cultivos Andinos (CICA) of the University of Cusco. This collection comprises some 600 accessions from the department of Cusco. In cooperation with Pedro Cruz of the University of Cusco, we grouped this material into about 100 morphologically distinct classes. Allowing for some genetic diversity within each morphological class, which will be revealed by isozyme analysis, the number of distinct clones for Cusco easily reaches 200. Taking into account the fact that the department of Cusco comprises only a small part of the Andes, the total number of oca clones in the Andes may be far beyond that number.



SLIDE 41—Folk taxonomy of Oca in Cusco

We also attempted to work on a folkloric taxonomy of the oca varieties in Cusco. Farmers have certain concepts of oca varieties. Their classification systems are, of course, not natural ones, but they provide meaningful information on the agronomy and utilization of oca, which complement technical descriptions. This knowledge is now rapidly being lost.

SLIDE 42—Close-up of an oca variety from Cusco

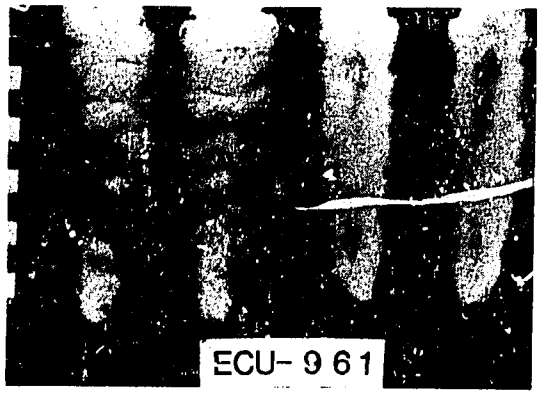
The beauty of certain ocas is an interesting example of esthetic selection ...

SLIDE 43—Oca close-up (variety group *higos*)

... which has also been described for other New World crops such as *Phaseolus* beans.

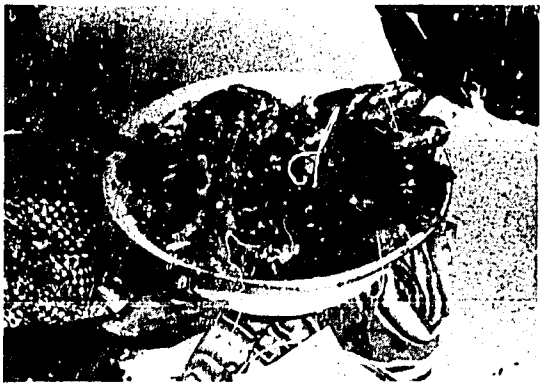
SLIDE 44—Close-up *chocclo higos*

This oca is called in Quechua "*chocclo higos*." *Chocclo* because it resembles a maize cob, *higos* (figs) because it belongs to a highly appreciated group of ocas with excellent culinary quality. Unfortunately, clones of the higos group have comparatively low yields and they are rarely offered in markets.



SLIDE 45—Oca variety from Ecuador (INIAP No. ECU-961)

White and yellow ocas are the most common commercial forms and dominate also in regions where oca diversity is low, such as in the Northern Andes. Ocas of this morphotype have been introduced to New Zealand and are now grown on a commercial scale.



SLIDE 46—Baked oca and sweetpotato in a Bolivian market

Oca is mainly eaten baked or cooked. It requires at least twice as much cooking time as potatoes, which is a serious drawback in the Andes where people are desperately short of fuel. Ocas of good eating quality have a starchy texture very similar to the potato, but unlike the potato, they lack a specific flavor. However, some ocas have a slightly sweet taste, especially after they have been exposed to sunlight for a few days.

Nutritional variability of oca (*Oxalis tuberosa*) (King 1987).

	MIN	MAX
Dry matter (%)	15.6	19.8
Protein (% DM)	3.0	8.4
Carbohydrates (% DM)	83.0	88.8
Fat (% DM)	0.5	0.6
Fiber (% DM)	4.0	5.1
Calories/100 g	369	374

SLIDE 47--Nutritional variability of oca

The dry matter content of oca is comparable to that of the potato, but the protein levels are very low. Most of the dry matter is starch and experiments in Cusco have shown that it can replace, to some extent, wheat flour in the preparation of bread.

Oca also contains strongly varying levels of oxalic acid. Ocas with low oxalate contents are generally referred to as sweet ocas, "ocas dulces," and those with high levels, not quite correctly, as "ocas amargas" or bitter ocas. They leave a slightly unpleasant sensation on the tongue. Oxalates are leached out during cooking and probably broken down to some extent during solarization, which is commonly carried out for most clones. Research must be done to determine whether or not residual oxalate concentrations are a health hazard.

SLIDE 48—Umakaya (Lake Titicaca, Bolivia)

Another way of removing oxalate is by preparing of kaya from certain ocas. This is a processed product similar to chuño, which can be stored for several years without losing its nutritional value.

SLIDE 49—Oca spread over the ground (Bolivia)

To prepare kaya, ocas are exposed to low night temperatures. When frost has killed all of the tuber tissue, ...

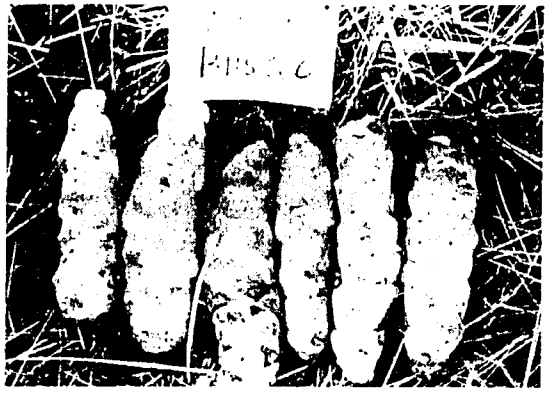
SLIDE 50—Campesino treading frozen oca (Bolivia)

... moisture, and thus soluble oxalates, are squeezed out of the tubers and they are dried in the sunlight.

It is interesting that, despite the biting cold at altitudes around 4000 meters, farmers always take off their shoes to have the right feeling for this work.

SLIDE 51—Cusco scientist Pedro Cruz with pond

To leach out extremely high levels of oxalic acid, oca tubers may also be placed in ponds for several weeks before they are freeze-dried. The dried product is called *okaya* or *umakaya.*

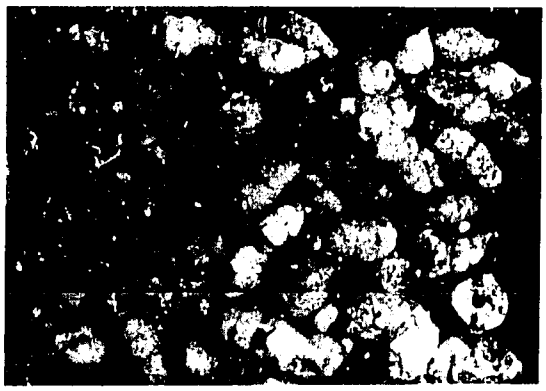


SLIDE 52—Oca variety *Yurac pusqo* (Cusco, Peru)

Germplasm of bitter oca like this variety from Cusco is rapidly disappearing in the Andes, although it offers some resistance to the oca weevil ...

SLIDE 53—Oca tuber with weevil (Cusco, Peru)

... which may cause havoc to non-bitter ocas and can lead to crop failure.



SLIDE 54—Damaged oca (Cusco, Peru)

Farmers in the Andes are not accustomed to selecting healthy oca tubers as seed material. The problem of weevil infestation is thus perpetuated from one growing season to the other.

SLIDE 55—Children on mound of ocas (Cusco, Peru)

A common misperception is that oca is a poor yielder. Although this crop is never fertilized and is generally grown on plots of marginal soil quality, oca easily yields rich potato yields. Given adequate inputs, oca outyields potatoes 2 to 1.

SLIDE 56—Man with productive oca plant (Cusco, Peru)

Under experimental conditions, yields of oca are in the range of 35 to 55 tons per hectare, with single plant yields of up to 5 kg.

SLIDE 57—Phinas (Cusco)

Traditionally, oca is stored in phinas: these are heaps of oca covered with straw of the high altitude grass *Stipa ichu*. Oca, in much the same way as ulluco and mashua, shows a pronounced tuber dormancy which lasts from 2 to 4 months, depending on genotype and storage temperature.

SLIDE 58—Oca in the market in Cusco

A major proportion of oca is consumed on-farm. It is grown for domestic purposes with the surplus production going to highland markets. Typical retail prices for oca, like the prices for ulluco, are slightly below those for white potatoes ("papas blancas").

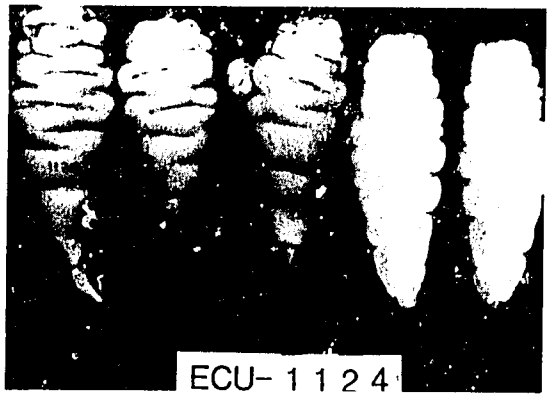
Mashua

mashua
(añu, isaño, cubio)

Tropaeolum tuberosum Ruíz & Pavón
(2n = 4x = 52)
Tropaeolaceae

SLIDE 59—Mashua systematics

Mashua in Ecuador and Northern Peru, *isañu* in Bolivia, and *cubio* in Colombia – these are all vernacular names for the tubers of *Tropaeolum tuberosum*, a tetraploid of the Tropaeolaceae.



SLIDE 60—Mashua variety from Ecuador (INIAP No. ECU 1141)

Mashua, here seen in a clone from Ecuador, almost seems to be tailored to the needs of resource-poor mountain people.

SLIDE 61—Mashua plants (Ecuador)

The plant thrives on marginal soils, rapidly develops high leaf area indices, and thus competes successfully with any weed. The harvest index, in other words, the proportion of dry matter allocated to the tubers, may be as high as 75%.

SLIDE 62—Pedro Cruz with two productive mashua plants (Cusco)

Yields of up to 70 tons per hectare have been recorded on experimental plots in Ecuador and Cusco. Clearly, such yields are near the upper limit of the biomass production achievable in unprotected conditions.

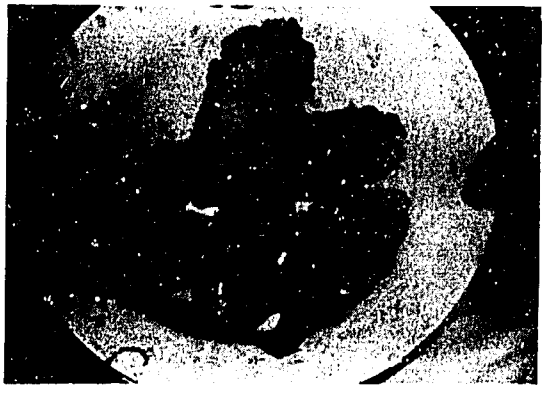
SLIDE 63—Boy in Boyacá (Colombia) with potatoes and mashua intercropped

High levels of isothiocyanates in mashua tubers may explain the virtual absence of pests and diseases in this crop. Isothiocyanates are known for their insecticidal and nematocidal properties. In Boyacá, Colombia, I have met farmers who plant mashua around potato fields, believing that this will repel potato pests.

SLIDE 64—Woman preparing watia (Cusco)

Despite the apparent agronomical value of mashua, its use is very limited. I cannot give a plausible explanation for this, but it seems to me that its strong flavor may be what has prevented it from becoming a major staple.

Mashua is commonly solarized for a few days, before it is baked for consumption, preferably in watias (improvised field ovens) as in this picture, taken in Cusco.



SLIDE 65—Plate with mashua prepared in watia

The taste of raw mashua is similar to watercress or horseradish. When baked it has a pleasant texture and an aromatic taste. I regard it as a delicacy, but I admit that when I first tried it, I found it rather unpleasant.

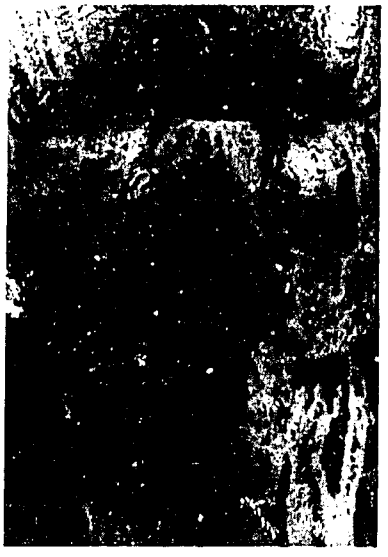
SLIDE 66—Child sitting on a heap of mashua tubers

There is bad news about mashua. It reputedly has a strong anti-aphrodisiac effect. Rural women in Cusco prepare concoctions from mashua and add it surreptitiously to their men's food. It is believed that this prevents them from becoming unfaithful, when they go to the valleys to work on tropical plantations. The Inca had a similar use for mashua. Garcilaso de la Vega, a chronicler from the early years of the Conquest, reports that the Incas gave mashua to their soldiers so as to make them forget their wives.

Such beliefs, despite the skepticism of this young man, may not be totally unsubstantiated. Preliminary trials have shown that male rats feeding on mashua show significantly decreased levels of testosterone.

SLIDE 67—Mashuas from Boyacá, Colombia

Mashua's diversity is generally limited, but an astoundingly high degree of morphological variation may still be found in Northern Colombia, far from the Central Andes, the supposed center of domestication. This sample was taken from a market in Tunja. Colombian mashua is predominantly primitive material which is not available further south. It might have been taken to Colombia in remote times and have persisted there, but it was probably replaced in the Central Andes by superior domesticates ...



SLIDE 68—Mashua variety *Yahuar wacaq* (Cusco)

... such as this popular variety, called *yahuar wacaq*, which means "crying blood."

Roots

SLIDE 69—Roots

So far I have dealt with the three tubers; I will now describe the roots.

Arracacha

arracacha
(racacha, zanahoria blanca)

Arracacia xanthorrhiza **Bancroft**
(2n = 20)
Umbelliferae

SLIDE 70—Arracacha systematics

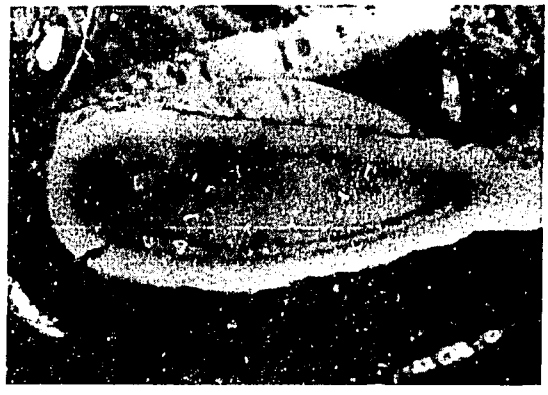
I start with arracacha, which I think is for many reasons a most remarkable crop and has great potential outside its present range. It is the only umbelliferous domesticate in the Americas. While all umbelliferous crops from the Old World are seed-propagated, arracacha is vegetatively propagated.

SLIDE 71—Arracacha plant

The plant can be grown in a wide range of environments, but its optimum environment is the rather humid inter-Andean valleys, at altitudes of between 1500 and 2500 meters. Major producing countries are Venezuela, Colombia, and Ecuador. In Peru and Bolivia, arracacha production is concentrated in a few regions, for example in Cajamarca, Huánuco, Cusco, Tacna, and in the Yungas of La Paz.

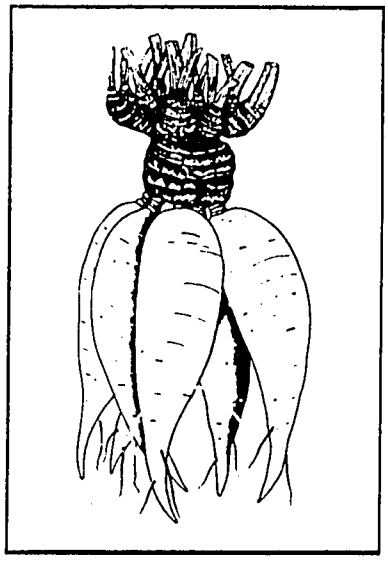
SLIDE 72—Arracacha roots

The economically valuable plant part is a starchy storage root which may be mistaken for Cassava by the unfamiliar observer. Most clones have white or yellow flesh ...



SLIDE 73—Purple arracacha roots

... but there are also purple varieties. The young stems can also be used in salads or as a cooked vegetable, and the leaves, which are still green at harvest, may be fed to livestock.



SLIDE 74—Arracacha plant architecture (source of drawing: J. León, 1964)

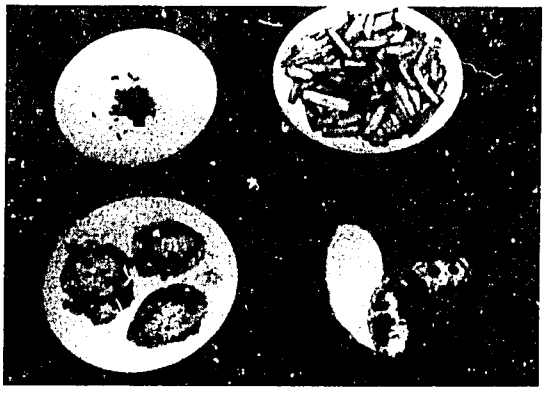
The storage roots, which cannot serve as propagation organs, are inserted on a stem-like rootstock. From this root-stock emerge, just at ground-level, cormel-like structures called "colinos" (in Spanish) which are used as propagules.

SLIDE 75—Heap of harvested arracacha roots with "colinos" (Yungas, Bolivia)

When harvested, the colinos are separated and prepared to serve as the next season's planting material.

SLIDE 76—Colinos (Boyacá, Colombia)

In this form they can be stored at ambient temperatures for a month or two.



SLIDE 77—Arracacha dishes

Most of the root dry matter is made up of starch of a very small granule size. The starch is therefore easily digested, and arracacha is a preferred food for infants and invalids.

The delicate flavor of cooked arracacha roots has been described by one enthusiast as a combination of "the tastes of celery, cabbage, and roasted chestnut." What is more, arracacha can be used in a number of ways both in sweet and salty preparations.

SLIDE 78—Virus in arracacha (Ecuador)

There are two major constraints to arracacha utilization. In the first place, it has a very reduced shelf life and must reach the consumer within a week after harvest. Research in Venezuela and Brazil has shown that the rapid postharvest deterioration of arracacha roots is associated with water loss, and when there is some protection against transpiration, the shelf life can be significantly enhanced.

Secondly, arracacha is very susceptible to viruses. Leaf yellowing due to virus mosaics is a common sight on commercial plantations.

Attempts to introduce arracacha in the US and Europe date back to the last century, but all ended in failure. The crop requires moderate temperatures over 8 to 10 months. It can withstand neither frost nor the excessive heat of summers at higher latitudes. Its ecological requirements are met only in the tropical highlands.

SLIDE 79—Map of arracacha production in Brazil

Arracacha was introduced to Southern Brazil towards the end of the last century, probably via the Caribbean and, over the last twenty years, its cultivation has been developed into a major horticultural operation in the states of Paraná, São Paulo, and Minas Gerais.

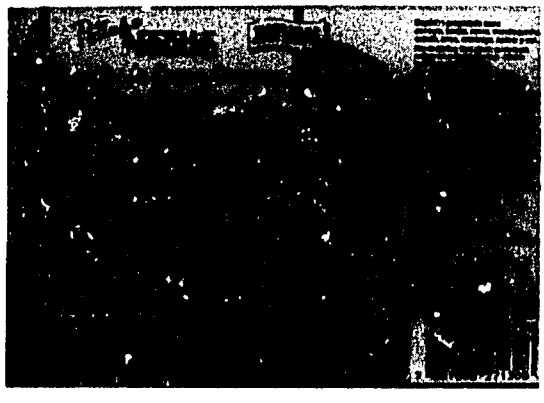
Arracacha (*mandioquinha-salsa*) in the Southern Plateau of Brazil

Cultivated area	ca. 4000 ha
Average area planted per farmer	< 0.5 ha
Latitude	20-25° S
Ecological requirements	600-1100 m altitude ca. 1000 mm rainfall sandy (marginal) soils
Yields (minimum inputs)	10 tons/ha
Retail prices (US$/kg, Sao Paulo, 1991)	mandioquinha-salsa $ 2.1 potato $ 0.7 sweet potato $ 0.3 pears (imported) $ 2.2

SLIDE 80—Production data of arracacha in Brazil

Known in Brazil as *mandioquinha-salsa* or *batata-baroa*, arracacha is now produced on approximately 4000 hectares on the Southern Plateau at elevations of between 600 and 1100 meters. Just as in the Andes, it is typically grown by small farmers with an average area of less than one hectare per farmer.

Resource-poor farmers like arracacha because it needs only a fraction of the inputs required for potato, and it produces high returns on labor investments. Retail prices for arracacha indicate that it is one of the most highly-prized vegetables in Brazil. In March 1991, arracacha was as expensive as imported pears, about 2 dollars per kg. The price of one kilogram of arracacha would buy 3 kg of potatoes and 7 kg of sweetpotatoes. Arracacha is a rare case of a high-value cash crop which can be grown by poor farmers.



SLIDE 81—Nestlé labels (Brazil)

Nestlé and other companies process arracacha roots into a number of baby food formulas. A major constraint to a wider utilization of arracacha in the processing industry is the lack of suitable and affordable raw material.

SLIDE 82—Man with Brazilian arracacha (São Paulo)

All Brazilian arracacha is derived from one yellow clone. It has rather small storage roots and its reduced shelf life and almost year-long crop-duration are considered severe limitations. There is wide consensus among Brazilian farmers and researchers that the top priority for arracacha research in Brazil is to broaden the genetic base of the crop and to find more suitable materials. Researchers from the agronomy institute in Campinas and at several universities involved in arracacha research, have expressed to me their interest in obtaining virus-free stocks of cultivated arracacha and wild species from the Andes.

SLIDE 83—Cusco scientist Pedro Cruz with wild *Arracacia* species from Peru

I think there might be a case for an international center to take the initiative in this research. Who better than CIP would be able to raise the funding needed for the collection and disease elimination of germplasm, such as this wild *Arracacia* species from the Ceja de Selva in Cusco. Even if there is currently no pressing need for an arracacha breeding program in the Andes, the national programs in these countries would benefit from the availability of cleaned-up materials and the wealth of information that would be gathered in the process.

Yacón

yacón
(jícama, aricoma)

Polymnia sonchifolia Poeppig & Endlei
Compositae

SLIDE 84—Yacón systematics

The yacón root comes from *Polymnia sonchifolia*, a member of the sunflower family.

SLIDE 85—Yacón plant

The plant is an ubiquitous constituent of backyard gardens in the warm-temperate Andean valleys. It can be found up to 3200 meters, but at such altitudes it is often damaged by frosts. Farmers always maintain a few plants but they pay little attention to them.

SLIDE 86—Yacón roots (Yungas, Bolivia)

Roots of good quality characteristically weigh about half a kilogram. Most of the dry matter content of 15-20% in the root consists of fructose and oligo-saccharides. Depending on the genotype, there are also varying concentrations of inulin, a polymer composed mainly of fructose. The human body has no enzyme to hydrolyze inulin, so it passes through the digestive tract unmetabolized. This could be an attractive marketing feature for dieters and diabetics. Japanese scientists are now considering developing this crop into an industrial source of fructose. As it yields very well, it may some day become the fructose counterpart of sugar beets.

SLIDE 87—Bolivian scientist David Morales eating yacón

The potential of yacón is largely overlooked in its native range. Thirsty farmers occasionally unearth a few roots to refresh themselves. Yacón roots are juicy and have a crisp texture. However, their taste is insipid. Yacón is sold in minor quantities along roads and on rural markets from Colombia to northern Argentina. Apparently, the plant does not require short days (<14 hours) to produce storage roots as it has been grown in latitudes as far north as Italy and Germany.

Achira

achira

Canna edulis **Ker-Gawler**
Cannaceae

SLIDE 88—Achira systematics

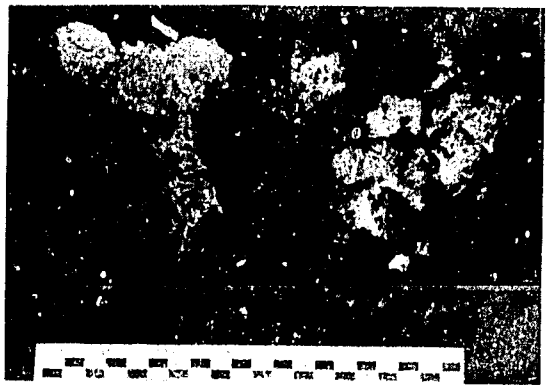
Another little-known species from the warm Andean valleys is achira. Its botanical name is *Canna edulis*. I am aware of only 3 international publications on achira.

SLIDE 89—Achira intercropped with yacón in Bolivia

Sometimes it is intercropped with yacón as in this irrigated valley near Lake Titicaca, Bolivia.

SLIDE 90—Achira rhizomes (Cusco market)

The economic plant part is a starchy rhizome which needs to be boiled at least 2 to 3 hours to be eaten. It is generally baked in earthen ovens and then shipped to markets. Achira is only available during certain periods. It is traditionally eaten during Corpus Christi.



SLIDE 91--Baked rhizomes (Cusco market)

I regard this as an inferior food because it looks unattractive and has a poor taste and texture. However, its starch granules are very large and settle quickly out of solution. Achira starch can thus be extracted with homemade equipment at little expense, and cottage industries have developed in some locations in the Andes. In the Magdalena valley this starch is processed into tasty cookies, which are highly prized and commercialized under the name achira.

I was unaware of achira production in Vietnam until CIP breeder Enrique Chujoy wrote me the following: "About 10,000 hectares are estimated to be grown with achira. Most is grown on hilly areas. I have observed plantations of one to two hectares in NW Vietnam; it is also grown in the mountainous areas of Central Vietnam. Achira is used for making noodles because of its high quality starch. In Hanoi, a premium price is paid for *Canna* noodles."

Maca

maca

Lepidium meyenii **Walpers**
(2n = 54, 6x?)
Cruciferae

SLIDE 92—Maca systematics

I would finally like to say a few words about maca, which is a very minor root species of the crucifer family, with no more than a total of 50 hectares under cultivation.

SLIDE 93—Juan Tello with maca plants

I have learnt much about maca from Juan Tello, a student from La Molina University with whom I have been collaborating during the last two years.

SLIDE 94—Maca field at 4400 m altitude (Junin, Peru)

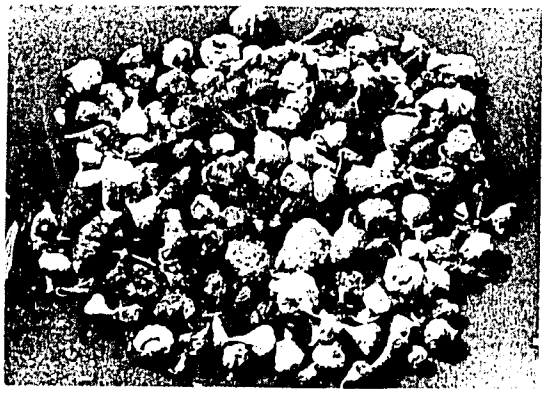
Maca is grown at the upper altitudinal limit for agriculture. There is no other crop plant, except bitter potatoes, which gives reliable yields at 4400 m elevation, as on this slope of Lake Junin not far below the snow line.

SLIDE 95—Young vegetative maca plants

Maca is biannual. It is propagated by sexual seed. In the first year the plant remains vegetative and yields ...

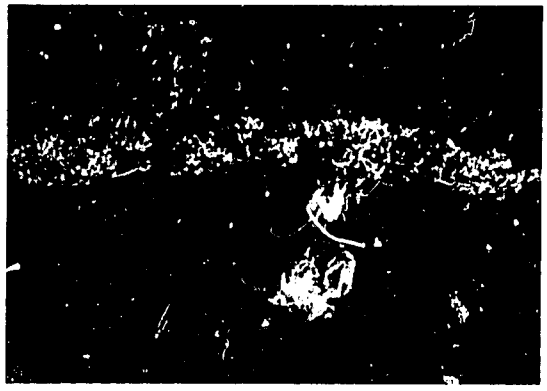
SLIDE 96—Maca variability in Junin, Peru

... a radish-like root. Some of the produce is eaten in watias, however most is ...



SLIDE 97—Dried maca from Junin

... air-dried. In this form it can be traded and stored for several years. A selected few of the fresh maca roots are retained after harvest and planted ...



SLIDE 98—Generative plant from Junin

... in the next season on protected plots to produce flowering plants and harvest sexual seed.

SLIDE 99—Maca-Cap bought in pharmacy in Lima, Peru (Courtesy C. Arbizu)

Also maca is said to possess fertility-enhancing properties. Highland people must have been aware of the reduced fertility rates of mankind and animals at high altitudes and have certainly searched for remedies.

Recently, there has been a renewed interest in maca, and at least two preparations of the ground root are available from pharmacies in Lima.

SLIDE 100—Label of maca medicine (Courtesy C. Arbizu)

One prescription says the following: "Excelente suplemento alimenticio, mejora la capacidad física y mental, vigoriza las funciones de los órganos de la reproducción e incrementa la potencia del sistema inmunitario." [An excellent supplemental food, improves physical and mental capabilities, strengthens the functions of the reproductive organs, and increases the powers of the immune system.] So far, so good.

Constraints

SLIDE 101—Constraints

You will have noticed that there is scarce information on Andean roots and tubers and the little that is available is often very speculative. Numerous national scientists have been working during the past 20 years on a number of problems and yet, we lack the most essential data on reproductive biology, ecological requirements, genetic diversity, and factors limiting a major utilization.

Research findings on Andean tubers are rarely published, or are only available from a widely scattered and only locally-available literature. For example, about 50 theses have been written since 1968 at the University of Cusco on a wide range of topics concerning oca. However, this information is not accessible to other researchers in the Andes and consequently many of the research efforts are being duplicated.

The lack of adequate information hampers the identification of research goals, and the need to generate more knowledge on Andean crops in itself is of high priority. Nevertheless, some promising research areas are evident. However marginal Andean crops may be in a global or even regional context, these are poor people's crops which provide food in marginal environments and allow rural people to diversify a monotonous diet. What is more, they are important generators of cash income. From a development-policy standpoint it would thus seem desirable to further a wider utilization of Andean roots and tubers. However, there is evidence that the importance of Andean tubers, with the possible exception of ulluco and arracacha, is steadily declining. What are the reasons for this and what can be done to halt this tendency?

Table 10-3 Farmers perceptions of the principal factors limiting production of Andean crops in the two communities of Cuzco Department Peru (% farmers reporting each factor)

	Quinoa[a]	Lupines[b]	Olluca[c]	Oca[c]	Mashua[c]
Low yield	61	22	11	16	17
Scarcity of good land	21	38	48	32	78
Climate problems	12	37	11	4	8
Scarcity of seed	7	-	4	8	17
Pests and diseases	-	-	15	20	-
Storage problems	-	-	6	4	8
Other problems	-	4	4	16	26
Total	100	100	100	100	100

[a] A cereal [b] A pulse [c] Root crops

Source Cuzco farm survey 1987

SLIDE 102—Farmers' perception of limiting factors

Data from Cusco, which I have taken from CIP's annual report of 1989 underline the rusticity of Andean tubers. In the perception of farmers, pests and diseases and other possible production constraints, are insignificant.

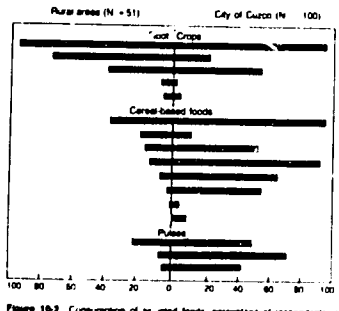


Figure 10-2 Consumption of selected foods: percentage of respondents reporting frequent consumption in the Department of Cuzco Peru

SLIDE 103—Percentage of frequent consumers

Data from the same survey suggest that the decline in Andean tuber production and use is related to the high consumption of cereal-based foods in urban centers. The causes for shifting dietary patterns are well established: subsidies for wheat in both wheat-producing and wheat-importing countries, as well as an increasing demand of urban dwellers for processed food, especially as their incomes rise.

To reverse this trend is certainly beyond the scope of research. I am skeptical whether improved production technologies can significantly increase the competitiveness of Andean tubers.

Research priorities

SLIDE 104—Priorities

Nonetheless, I would suggest that new ways of utilizing Andean roots and tubers should be identified. I have given several examples where this has already occurred: the elaboration of starch from oca and achira, processing of arracacha into baby food, yacón as a new source of fructose and dietary carbohydrates. If achira could become a preferred raw material in the manufacturing of noodles in Vietnam, could it not play the same role in its native country, Peru? New uses would almost certainly boost the demand for Andean crops and provide perspectives and employment to rural people.

Approximate number of germplasm accessions of Andean roots and tubers at national programmes (1990).

	COL	ECU	PER	BOL	ARG	CHL	Σ
ulluco	-	180	515	20	?		725
oca	-	90	1184	-	?	4	1274
mashua	-	70	259	-	?	-	329
arracacha	?	45	123	-	-	-	168
yacón	-	3	39	-	-	-	42
Σ	-	388	2120	30	-	-	2538

SLIDE 105—NARS holdings of Andean tubers

It is sad to think that much of the diversity of Andean crops is now being lost without its economic potential ever having been realized. Some national programs started germplasm collections many years ago, but much of their material has been lost and current holdings lack good geographic representation, are highly duplicated, and do not include wild species.

CIP has therefore started a special project in order to help consolidate efforts of the National Programs and to maintain under safe conditions core samples of Andean tuber germplasm. In my opinion CIP should avoid amassing large numbers of genetic materials.

Hypothetical structure of an ideal germplasm collection of Andean roots and tubers.

	VEN	COL	ECU	PER	BOL	ARG	CHL	Total
Ulluco	5	15	20	20	10	5	5	80
Oca	5	15	10	100	30	20	10	190
Mashua	5	15	10	30	30	10	5	105
Arracacha	20	20	20	20	20	-	-	100
Yacón	-	5	5	10	10	10	5	45
Achira	-	10	5	10	5	-	-	30
Maca	-	-	-	10	-	-	-	10
Total	35	80	70	200	105	45	25	560

SLIDE 106—Structure of an ideal germplasm collection of Andean roots and tubers

An ideal CIP collection might look like this: The total number of accessions for 6 species would be restricted to some 600 distinct clones to keep the collection at a manageable size, enabling proper characterization and virus elimination. The structure and final size would, of course, be subject to modifications as a deeper understanding of diversity in these species evolves. With the combined evidence from morphological, isozyme, and geographical data, those clones could be selected which encompass most of the existing diversity. The rationale behind this approach is to concentrate all research efforts on the most interesting materials from an economic and biological point of view. It is clear that to achieve this goal, initial efforts should focus on elimination of duplicates.

Whether this project will have an impact on the utilization of Andean roots and tubers will largely depend on how fast CIP can come up with a set of cleaned-up materials to be tested for their economic value. Virus work on ulluco, oca, and arracacha is under way in our virology department, and first attempts to clean ulluco germplasm are being carried out. I hope that we will be able to release the first virus-free clones two years from now.

Perspectives

SLIDE 107—Perspectives

I hope I was able to show that Andean roots and tubers are indeed a neglected resource and deserve more research attention.

The cultivation of arracacha in Brazil, of achira in Vietnam, and of oca in New Zealand, indicates a wider agricultural interest in Andean root crops than has been previously recognized. CIP's germplasm collection will be a formidable resource to support crop-introduction programs. We will inevitably experience failures and disappointments, but we may perhaps have a chance to see one or two of the so-called "minor" Andean crops evolve into major ones. We should not forget that many crop plants have made it from obscurity to celebrity. The potato is one of them. Thank you.

Acknowledgements

In the preparation of this seminar I have freely drawn on information and materials which numerous researchers from National Programs in the Andean countries have generously shared with me. I am particularly indebted to Dr. Carlos Arbizu (University Ayacucho, Peru), Ing. Pedro Cruz (Centro de Investigaciones de Cultivos Andinos, Cusco, Peru), Raúl Castillo (Instituto Nacional de Investigaciones Agropecuarias, Quito, Ecuador), Ing. Juan Tello (Universidad Nacional Agraria, La Molina, Peru) and Ing. David Morales (Instituto Boliviano de Tecnología Agropecuaria, La Paz, Bolivia).