Yacon

Smallanthus sonchifolius (Poepp. & Endl.) H. Robinson

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Contents

1 Introduction

The Andean region has been the cradle of a surprisingly wide range of edible tubers and roots. Most of them have been used by the Andean inhabitants as food energy, while two - ahipa *(Pachyrhizus ahipa)* and yacon *(Smallanthus sonchifolius)* -have been considered 'fruits'. That perception is particularly strong in the case of yacon, which despite its juiciness and sweet taste, has been recognized as a food of relatively low energy value since early times.

Some medicinal attributes may have increased the attractiveness of yacon to the ancient Andean people. However, its high productivity and other attractive agronomic traits could not counterbalance its low nutritive value. This likely led to diminished interest on the part of the old Andean agronomists, who presumably did not work on yacon as they did on potato *(Solanum tuberosum),* oca *(Oxalis tuberosa)* or ulluco *(Ullucus tuberosus).* Furthermore its reduced nutritive value may have contributed to the disappearance of yacon landraces in 'many areas at different historical stages, in times of crisis or famine. This process has probably accelerated significantly in the present century, owing to the profound political, social and cultural changes happening in the Andes. In recent decades, improved transport has increased the availability of fruits in the region, which may be competing with yacon in the local markets.

In modern times, the human view of yacon could be radically different from in the past. Certainly, calories are still limited and critical in many regions of the earth and the Andes themselves. In contrast, on a global scale, starch, glucose and fructose are comparatively common commodities, with relatively low prices, and are available to certain sectors of the human population in quantities well above their dietary requirements and even beyond their physiological tolerance. Under these conditions, yacon may provide the low calories and fiber necessary to survive the stress of sedentary lifestyles combined with overconsumption of carbohydrates and fats.

The productivity and other valuable agronomic traits of yacon strongly suggest that it is a species with a great potential. With limited testing and fine tuning, addition of conventional fertilizers to the clones developed by the old Andean agronomists has produced annual yields of up to 100 t/ha (fresh weight). It is easy to speculate on potential yields if modern breeding techniques, hybridization or genetic engineering were applied. But perhaps the challenge of the future will be not only to breed yacon into a very productive multipurpose crop and to satisfy several aspects of modern life requirements, but also to pay back to the descendants of the old Andean agronomists a fair share for their invention.

2 Vernacular names

The species has received common names in the dominant Andean languages, Aymara and Quechua (Cárdenas 1969). *Aricoma* and *aricuma,* the Aymara terms, are used in certain areas of Bolivia. *Llaqon, llacum, llacuma* or *yacumpi* are the Quechua words that evolved into 'yacon', perhaps after the Spanish conquest. In the Quechua language, *yacu* and *unu* are words meaning water, while *yakku* is an adjective meaning watery or insipid. 'Yacon', with subtle regional differences in the pronunciation of the 'y' and the 'c' or 'k', is commonly used from Peru to northwestern Argentina. Much less frequent is the term *ipio,* used by the Chiriguano groups in the lowlands of Southern Bolivia. In Ecuador, *jicama, chicama, shicama, jiquima* or *jiquimilla* are the common names of the species (Tittel 1986). These terms closely resemble and probably derive from *xicama,* the Mexican term applied to *Pachyrhizus erosus* and extended to the other members of the genus *Pachyrhizus.* This word was presumably introduced by the Spanish invaders, who began their Andean conquest in Ecuador after arriving from Central America. The term *arboloco,* used in Colombia, suggests very strongly a Spanish background. Yacon has also received names in other European languages, coined probably by researchers or growers: *poire de terre* (French) and yacon strawberry (English).

3 Taxonomy

3.1 The genus

Yacon and its relatives were originally placed in *Polymnia* (Compositae, Heliantheae, subtribe Melampodinae), a genus founded by Linnaeus in 1751. De Candolle (1836) produced the first comprehensive treatment of the group. Later, important contributions were made by Blake (1917, 1930). In the first modern revision of the genus, Wells (1967) maintained yacon and its relatives within *Polymnia.*

A different perspective was adopted by Robinson in a more recent study (1978). Robinson re-established the genus *Smallanthus,* proposed by Mackenzie in 1933.

Robinson separated the species previously considered within Polymnia by Wells into two genera — *Smallanthus* and *Polymnia* — keeping both within the subtribe Melampodinae. One North American species, most Central American species and all South American species were placed in *Smallanthus,* while a few North American species remained in *Polymnia.* According to Robinson, there are important differences separating *Polymnia* from *Smallanthus* (e.g. striation on the cypsela surface, presence of a whorl of outer involucral bracts, absence of glands on the anther appendages, lack of a particular feature in the lobes of the disk flower corollas). Some of those characters place *Polymnia* as the most isolated genus within the subtribe, while *Smallanthus* is closer to other genera in the group, such as *Melampodium* and *Espeletia,* than to true *Polymnia.* Robinson's point of view is formally sound, it has gained acceptance by the North American authors and it is being used in the North American herbaria. *Smallanthus* also has been adopted by Brako and Zarucchi (1993) in their catalogue of plants of Peru, and by Jørgensen and León (1997) in their catalogue of vascular plants of Ecuador.

It is important to point out that both Wells and Robinson principally, or perhaps only, studied herbarium specimens of the South American species. Moreover, herbarium material of these species is scarce, frequently poorly preserved and rarely includes underground organs, which in this case would be of particular interest. These limitations have certainly affected the work of Wells and Robinson. This fact may explain why Wells' key to the species is of limited value for identifying the South American taxa.

Smallanthus sensu Robinson includes at least 21 species, all American, ranging mostly through southern Mexico and Central America and the Andes. They are perennial herbs, less frequently shrubs or small trees and only rarely annuals.

3.2 The species

Smallanthus sonchifolius (Poepp. & Endl.) H. Robinson, Phytologia 39:51. 1978.
Synonyms: *Polymnia sonchifolia* Poepp. & Endl. Nov. Gen. Sp. Pl. 3:47. 1845.
Polymnia edulis Wedd., Ann. Sci. Nat. Bot. IV. 7:114:1857.

3.3 The other Smallanthus species

Smallanthus apus (Blake) H. Robinson
This is a poorly known Mexican species.

Smallanthus connatus (Spreng.) H. Robinson
An annual herb up to 2 m tall, widely distributed, present in southeastern Brazil, Paraguay, Uruguay and eastern Argentina to 35°S. It is the southernmost species, closely related to S. *macroscyphus.*

Smallanthus fruticosus (Benth.) H. Robinson
It is a shrub or tree to 12 m tall, distributed in southern Colombia, Ecuador and northern Peru.

Smallanthus glabratus (DC.) H. Robinson
A shrub or tree up to 8 m tall, closely related to *S. fruticosus* and placed by Wells together with *S. parviceps* and *S. microcephalus* within the *glabrata* complex. Its main area of distribution is the Peruvian mountains. It also has been reported in Ecuador and Chile.

Smallanthus jelksii (Hieron.) H. Robinson
A shrub or tree up to 8 m tall, described only for Peru, related to S. *pyramidalis,* both with characteristic small flower heads.

Smallanthus latisquamus (Blake) H. Robinson
Considered a synonym of *S. quichensis* by Wells (1965), *S. latisquamus* is treated as a separate species by Robinson (1978). Stems up to 3 m tall, present in Costa Rica.

Smallanthus lundellii H. Robinson
This species proposed by Robinson (1978) is a herb up to 1 m tall, related to *S. latisquamus* and *S. quichensis,* found in Guatemala.

Smallanthus macroscyphus (Baker ex. Martius) A. Grau, comb. nov.
A perennial herb up to 3 m tall, present in Bolivia and northwestern Argentina, where it is known as *yacon del campo* (wild yacon). It has a well-developed root system with storage roots that can reach 2-5 cm diameter. *Smallanthus macroscyphus* and *S. connatus* were treated as synonyms by Wells (1965) and Robinson (1978). On the contrary, Cabrera (1978) and Zardini (1991) consider them different species (Fig. la, b).

Smallanthus maculatus (Cav.) H. Robinson
A coarse herb up to 5 m tall. Several varieties of the species have been described for Mexico, Guatemala, Honduras, El Salvador, Nicaragua and Costa Rica.

Smallanthus macvaughii (Wells) H. Robinson
A herbaceous species up to 5 m tall, present in Mexico and related to *S. oaxacanus.*

Smallanthus meridensis (Steyerm.) H. Robinson
A herb with stems up to 3 m tall, distributed in Venezuela and Colombia.

Smallanthus microcephalus (Hieron.) H. Robinson
A shrub or small tree up to 8 m tall, found in Ecuador.

Smallanthus oaxacanus (Sch.Bip. ex Klatt) H. Robinson
A herb up to 2 m tall, distributed in Mexico, Guatemala and Honduras.

Smallanthus parviceps (Blake) H. Robinson
Another shrub or tree up to 8 m tall with stems of 15 cm diameter. It occurs in southern Peru and northern Bolivia.

Smallanthus pyramidalis (Triana) H. Robinson
A tree up to 12 m tall and 20 cm diameter at the base, distributed in Venezuela, Colombia and Ecuador.

Smallanthus quichensis (Coult.) H. Robinson
Closely related to *S. latisquamus* and present in the same region, Costa Rica and Guatemala.

Smallanthus riparius (H.B.K.) H. Robinson
A herb or shrub up to 4 m tall, with a very wide latitudinal range, from southern Mexico to northern Bolivia.

a b

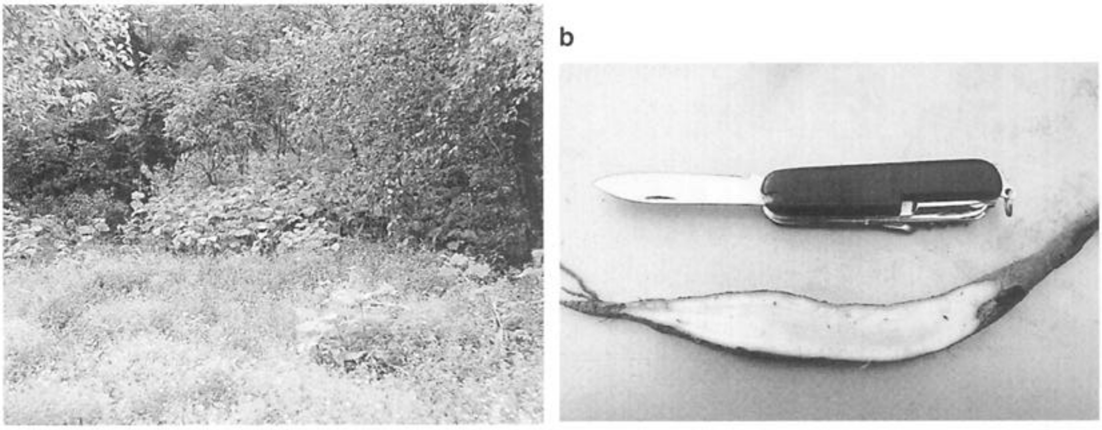


Fig. 1. Yacon del campo *(Smallanthus macroscyphus)* growing on a landslide at 1400 m asl in the cloud forest of Tucumán province, Argentina (a); storage root, detail (b).

Smallanthus siegesbeckius (DC.) H. Robinson
Described as an annual herb by Wells (1965). However, observations by Lizárraga and Grau (unpublished) on material responding to the description of *S. siegesbeckius* indicate that this species is perennial, up to 5 m tall, possessing a well-developed underground system, with many tuberous roots very similar to yacon, 20 cm long and 6 cm diameter or more (Fig. 2a, b). This species has been described for Peru, Bolivia, Brazil and Paraguay. It is possible, however, that the Brazilian and Paraguayan material actually belongs to a different species.

Smallanthus suffruticosus (Baker) H. Robinson
A shrub or herb up to 2 m tall adapted to the lowlands of Venezuelan Amazonia.

Smallanthus uvedalius (L.) Mackenzie
A perennial herb up to 3 m tall, distributed in the eastern United States of America from New York to Florida and Texas.

3.4 Relationships between species

No comprehensive taxonomic study has been carried out beyond Wells' perspective (1965) and Robinson's rearrangement (1978). Following, in part, Wells' guidelines it is possible to distinguish some species groups.

The best-studied group includes the North American-Mexican-Central American species. Owing to the availability of herbarium material this group was thoroughly analyzed by Wells, who recognized several varieties in some of the species. These species are herbs and some of them are related: *S. maculatus* is hard to distinguish from *S. uvedalius; S. macvaughii* is close to *S. oaxacanus; S. quichensis* is related to *S. latisquamus* and *S. lundellii.* While geographically distant from yacon, some of the Central American species may be taxonomically close to the 'yacon

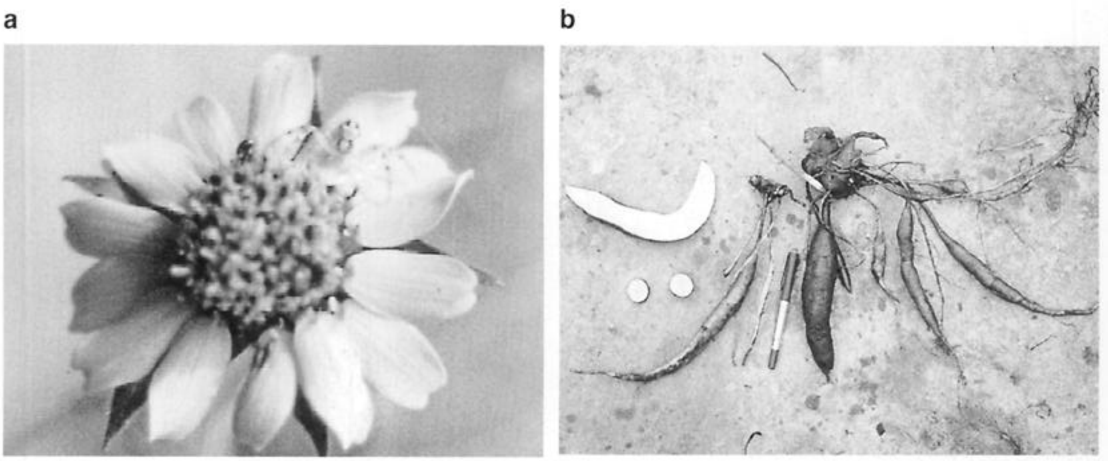


Fig. 2. *Smallanthus* cf. *siegesbeckius* collected by L. Lizárraga and A. Grau at 1900 m asl, Ahuabamba, Cusco region, Peru: flower (a), underground organs (b).

group' (see below). *Smallanthus riparius,* the only Central American species that extends to the Andean region, is indeed a member of that group.

Considering geographical distribution, growth habit and morphology of the aerial parts, six species appear to be close to *S. sonchifolius,* forming a sort of 'yacon group': *S. connatus, S. macroscyphus, S. riparius, S. meridensis, S. suffruticosus* and *S. siegesbeckius. Smallanthus riparius* is considered very close to *S. siegesbeckius* by Wells (1965), to the point that he reported intermediate herbarium specimens. *Smallanthus riparius* also closely resembles *S. macroscyphus.* It is likely that at least two of the species in this group have contributed to the yacon genome. It is also possible that at least some of the material present in different germplasm collections as 'wild yacon' is actually *Smallanthus* species of this group, other than *S. sonchifolius.*

Wells placed four species *(S. glabratus, S. microcephalus, S. parviceps* and *S. fruticosus)* into a *'glabrata* complex', a group formed by shrubs or small trees reaching sometimes 10 m or more. *Smallanthus jelksii* and the related *S. pyramidalis* also reach tree size. Nevertheless, they appear to be more related to the yacon group than to the *glabrata* complex.

4 Species description

4.1 Botanical/morphological description

The yacon is a perennial herb, 1.5-3 m tall. The root system is composed of 4-20 fleshy tuberous storage roots that can reach a length of 25 cm by 10 cm in diameter, and an extensive system of thin fibrous roots. Storage roots are mainly-fusiform, but often acquire irregular shapes due to the contact with soil stones or the pressure of neighbouring roots. Roots have an adventitious nature, growing from a developed and ramified stem system formed by short, thick sympodial rhizomes or rootstock ('corona', crown) (Fig. 3).

Storage root growth is caused by the proliferation of parenchymatous tissue in the root cortex and particularly in the vascular cylinder. The parenchyma accumulates sugars and, in some cases, pigments typical of certain clone groups. According to pigments, flesh colour varies considerably: white, cream, white with purple striations, purple, pink and yellow. The tuberous root bark is brown, pink, purplish, cream or ivory white, thin (l-2 mm) and contains resin conduits filled with yellow crystals.

The aerial stems are cylindrical or subangular, hollow at maturity with few branches in most clones or ramified in others, densely pubescent, green to purplish. Lower leaves are broadly ovate and hastate or subhastate, connate and auriculate at the base; upper leaves are ovate-lanceolate, without lobes and hastate base; upper and lower surfaces are densely pubescent. Lower and upper epidermis have trichomes (0.8-1.5 mm long, 0.05 mm diameter) and glands which contain terpenoid compounds (Fig. 4a, b).

Inflorescences are terminal, composed of 1-5 axes, each one with 3 capitula; peduncles densely pilose. Phyllaries 5, uniseriate and ovate. Flowers are yellow to bright orange; ray flowers are 2 or 3-toothed, depending on the clone, to 12 mm long x 7 mm broad, pistillate; disc flowers about 7 mm long, staminate. Immature cypselas are purple, and turn dark brown or black at maturity (Fig. 5).

4.2 Reproductive biology

Flower production is more reduced in yacon than in other wild *Smallanthus* species. Reduced flowering and fruit set are features commonly present in other clonally propagated tuber crops. During yacon evolution, continued vegetative propagation and selection for root yield may have impaired flowering and fruit set.

Flowering is strongly dependent on the environment of the growing area. In some regions, such as northwestern Argentina, flowering happens very late in the growing cycle or not at all. On the contrary, flowering is intense in most clones in northern Bolivia, the growing areas around Cusco, southern Peru and Cajamarca, northern Peru. In the Cajamarca region flowering begins 6-7 months and peaks 8-9 months after planting. But even in the areas where flowering is abundant, seed set is frequently poor or nonexistent and a high proportion of the seeds are non-viable or show low vigour.

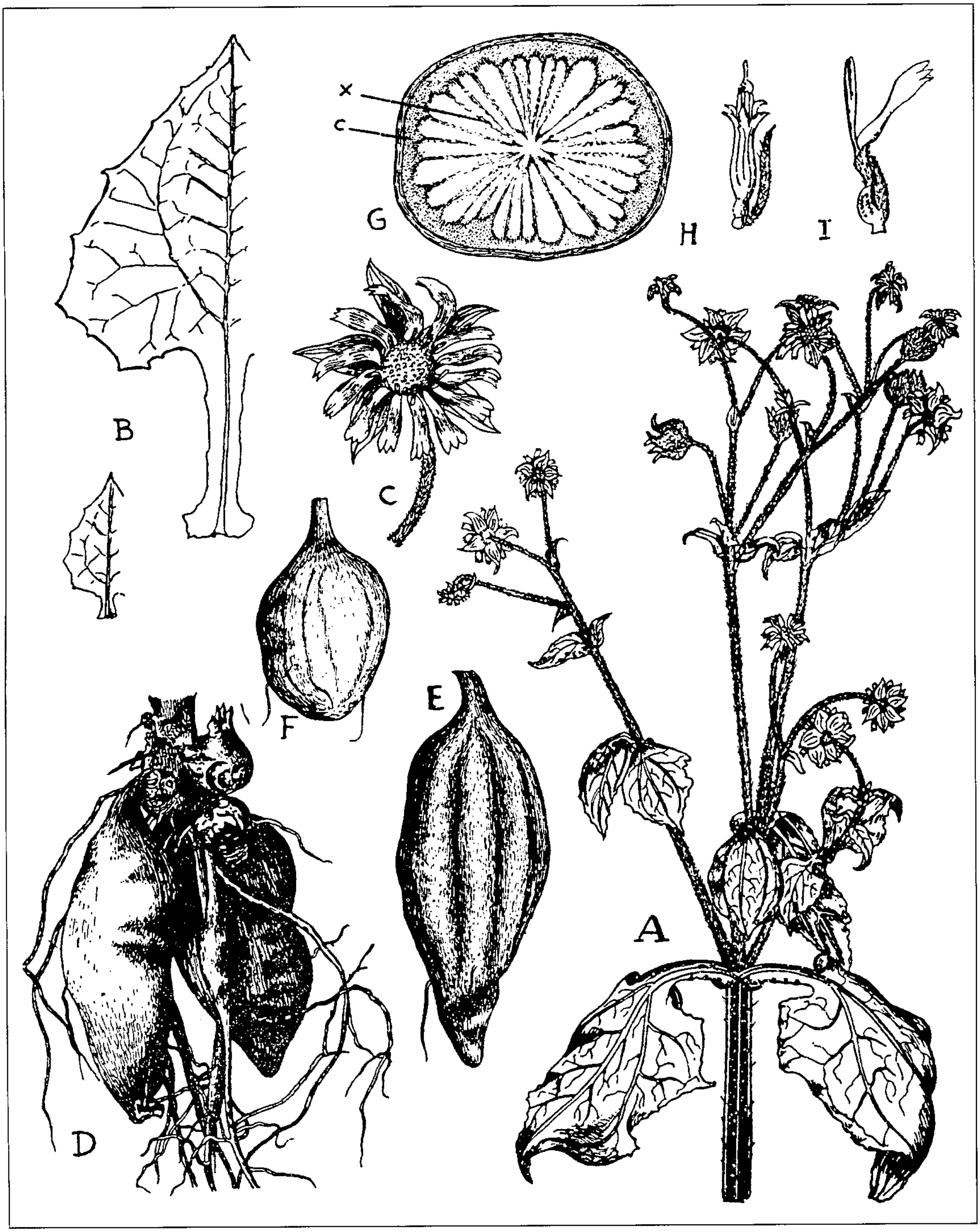
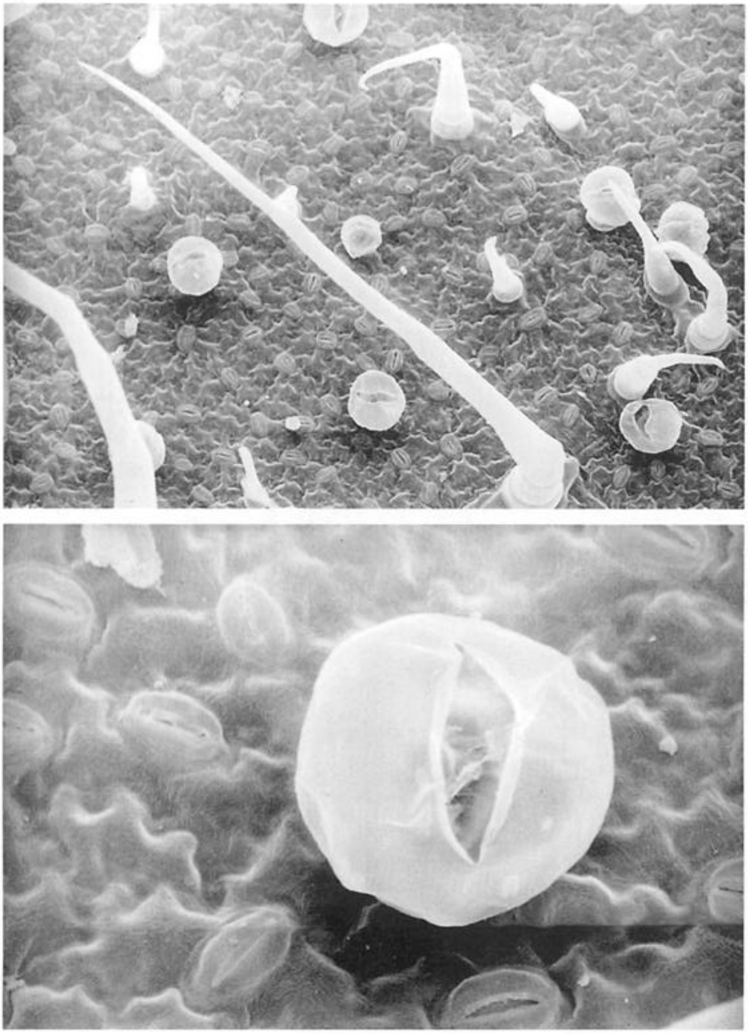


Fig. 3. Yacon *(Smallanthus sonchifolius)* morphological aspects (from León 1964). A: flowering branches. B: leaves. C: flowerhead. D-F: tuberous roots. G: transverse section of the tuberous root (x, xylem; c, cortex tissues). H: staminate disk flower. I: pistilate ray flower.

Poor seed set and low seed vigour can be the result of problems at different levels. One factor is high pollen sterility. Grau (1993) failed to obtain viable seeds under glasshouse conditions working with a single clone grown commercially in New Zealand. Artificial pollination was tried, but pollen was highly sterile and no filled fruits were produced. Low pollen fertility (0-30% fertility) also was observed in Argentine (Grau and Slanis 1996) and Ecuadorian clones (Grau, unpublished, material supplied by Dr R. Castillo, INIAP). In these cases pollen was stained using the Alexander methodology. Aberrant pollen grains have been observed in other species of *Smallanthus* (Fisher and Wells 1962; Wells 1971). Abnormal pollen development arises in many cases from irregular meiosis. However, meiosis appears



a

b

Fig. 4. Scanning microscope image of the upper epidermis showing epidermal trichomes (a) and epidermal glands (b).

be normal in yacon (Frías *et al.* 1997b), in spite of its high ploidy level and likely hybrid origin (see Section 4.3).

Lizárraga *et al.* (1997) analyzed seed set using paper bags, mesh bags and open-pollination. Open-pollination yielded twice as many seeds as mesh bags, which showed slightly better performance than paper bags. These results indicate that pollinators are very important, probably because pistillate ray flowers mature earlier than staminate disk flowers. In northwestern Argentina bumblebees *(Bombus* sp.) have been observed actively pollinating yacon and *S. macroscyphus.* Unidentified Hymenoptera have been observed playing the same role in Bolivia.

Other results point to inadequate germination conditions, dormancy or hard coat. Hard coat inhibiting germination is a trait present in *S. macroscyphus,* a wild species with high pollen fertility and high seed production (Grau and Slanis 1996), and may also be present in yacon. Experiments by Rea (1995a) yielded unfilled and filled cypselas, but he failed to germinate the filled ones. Low germination temperatures (12-15°C) may be partly responsible for this result. Meza (1995) obtained only one seedling out of about 300 seeds sown under glasshouse conditions. Chicata (1996, pers. comm.) obtained better results by selecting the filled cypselas from a sample containing empty and half-filled ones and germinating them at 28°C.

Fig. 5. Typical yacon flowerhead, photographed at Bárcena, Jujuy province, Argentina.

At present there are still many important gaps in the knowledge of yacon reproductive biology. Most perennial crops are outbreeders and this behaviour is also present in sunflower *(Helianthus annuus)* and topinambur *(Helianthus tuberosus),* two crop species in the same tribe as yacon. But there is no experimental report on the yacon mating system. It is also unknown whether yacon seeds are orthodox or recalcitrant. Flowering can be artificially induced in yacon by grafting onto sunflower (Nakanishi and Ishiki 1996), and this technique may represent a useful tool in future reproductive biology studies.

4.3 Chromosome numbers

The first report on yacon chromosome number ($2n$=60) was published by Heiser (1963), working with Ecuadorian material. A year later Leon (1964) reported $2n$=32 using material grown at the La Molina University in Peru. Recent reports by Talledo and Escobar (1996) indicated $2n$=60 in Peruvian material. However, more detailed studies (based on 1256 cell counts) by Salgado Moreno (1996) and Ishiki *et al.* (1997) on 15 clones from Ecuador (1), Peru (8), Bolivia (4) and Argentina (1) showed that all but one had $2n$=58. The remaining clone had a somatic number of 87. A somatic value $2n$=58 has also been observed by Frías *et al.* (1997b) in material from northwestern Argentina (Fig. 6).

Talledo and Escobar (1996) suggested that yacon is a tetraploid. Grau and Slanis (1996) speculated with the possibility of yacon being an allotetraploid, with

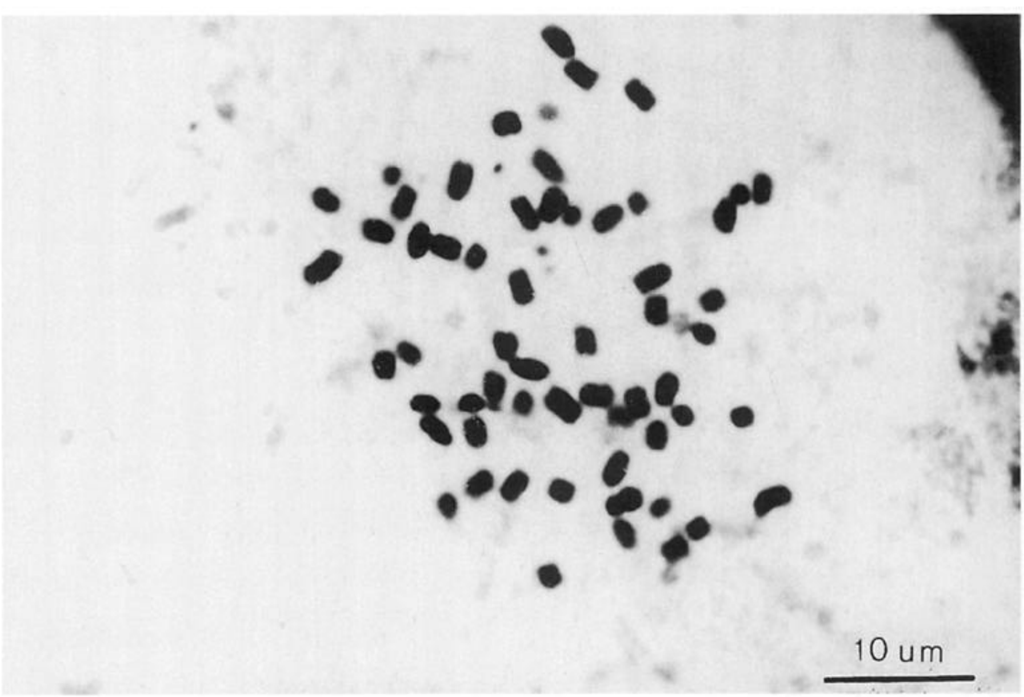


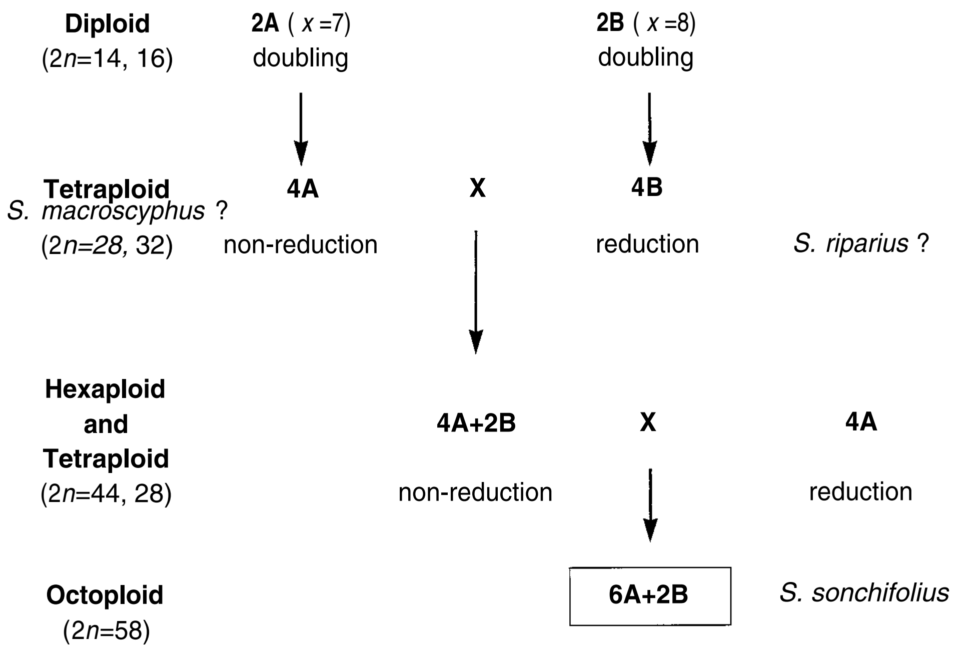
Fig. 6. Typical yacon caryotype with $2n$=58 chromosomes (from Frías *et al.* 1997b).

S. macroscyphus as one of the putative parents, a role that could also be played by *S. riparius.* The studies of Ishiki *et al.* (1997) are consistent with allopolyploidy, suggesting a yacon caryotype composed by two genomes. They propose an octoploid 6A+2B structure as the dominant in most yacon clones $2n$=58, while a dodecaploid 9A+3B structure would explain the $2n$=87. Box 1 shows the hypothetical crossings that occurred during the evolution of yacon.

The studies of Salgado Moreno (1996) and Ishiki *et al.* (1997) are the most detailed and comprehensive so far. Nevertheless more studies are necessary to assess the validity of the reports indicating different chromosome counts. As a clonal crop, yacon could exhibit considerable diversity in chromosome numbers. Another aspect to consider is the presence of B chromosomes, reported in other *Smallanthus* taxa (Wells 1971; Ishiki *et al.* 1997), which may be an important factor affecting results. Further studies are also needed to accept, improve or reject the hypothesis of yacon hybrid origin.

Wells (1967) published the first review of *Smallanthus (Polymnia)* chromosome numbers, and the most common value listed is $2n$=32 *(S. apus, S. oaxacanus, S. maculatus, S. uvedalius).* The same value has been obtained for *S. riparius* (Robinson

Box 1. Hypothetical evolution of yacon (by Ishiki *et al.* 1997, modified by A. Grau)



et al. 1981), *S. connatus* (Wulff 1984) and *S. macroscyphus* (Rozenblum *et al.* 1985; Frías *et al.* 1997a). However, the general picture is still blurred because of the different results reported for the same species by different authors and sometimes the same authors (Table 1). *Smallanthus jelksii* and *S. pyramidalis* share the $2n$=58 value with yacon. However, they are shrubs or small trees and seem unlikely ancestors.

Table 1. Chromosome numbers of *Smallanthus* species

Taxon	Somatic chromosome number	Reference
S. apus	32	Wells 1967
S. connatus	32	Wulff 1984
S. fruticosus	>50	Heiser 1963
S. jelksii	58	Sundberg *et al.* 1986
S. macroscyphus	32	Rozenblum *et al.* 1985
	32	Frías *et al.* 1997a
S. maculatus	32	Wells 1965
	66	Wells 1967
	32 and 68	Robinson *et al.* 1981
S. microcephalus	54 and 60	Robinson *et al.* 1981
S. parviceps	58	Jansen *et al.* 1984
S. pyramidalis	60	Heiser 1963
	58	Hunziker *et al.* 1989
S. oaxacanus	32	Turner *et al.* 1962
S. riparius	30	Heiser 1963
	32	Robinson *et al.* 1981
S. sonchifolius	60	Heiser 1963
	32	León 1964
	60	Talledo and Escobar 1996
	58	Salgado Moreno 1996
	87	Ishiki *et al.* 1997
	58	Frías *et al.* 1997b
S. uvedalius	32	Wells 1967
Smallanthus sp.	37 (32+5B)	Ishiki *et al.* 1997

5 Origin, evolution and history

Several wild *Smallanthus* species *(S. glabratus, S. riparius, S. siegesbeckius, S. macroscyphus* and *S. connatus)* show a clear preference for disturbed habitats, like riverbanks, landslides and roadsides. The growth habit of *Smallanthus* is well adapted to take advantage of vegetation gaps (Fig. la). The strategy of colonizing areas free of vegetation may be the reason why yacon became associated with humans in the first place. Agriculture in the steep eastern slopes of the Andes, particularly slash-and-burn agriculture practised by the Andean people since prehistoric times, may have provided an ideal niche for yacon relatives. In present times this behaviour can be observed in the Vilcanota river basin, Peru, where *S. siegesbeckius* is a common invader of abandoned fields and a weed in coffee plantations. The same strategy is used by *S. macroscyphus* in northwestern Argentina, invading abandoned sugarcane fields and shrubby vegetation patches between cultivated fields. It seems highly possible that a hybrid of two or more *Smallanthus* species colonizing disturbed habitats gave rise to a species ancestral to yacon.

It is likely that in a very early stage the Andean peasants discovered yacon properties and changed its status from weed to a managed plant, and later to a cultivated plant. The most probable area where these early events took place is the eastern humid slopes of the Andes, in the region extending from northern Bolivia to central Peru, the area with the largest clone diversity, and where native Quechua and Aymara names are used. Diversity of clones is more reduced in Ecuador, where modifications of the Mexican word *xicama* dominate. Both facts may indicate that the species was introduced there at later stages, perhaps with the Inca conquest of Ecuador, only decades earlier than the Spanish invasion.

Although the mountain forests of central Peru and northern Bolivia are evergreen and supplied with abundant rainfall and mist during most of the year, they are subjected to a relatively dry winter period lasting 2-4 months. This drier and slightly cooler interval may have played a critical evolutionary role, generating the conditions under which large tuberous roots could have an adaptive advantage.

From the humid mountain forests of Peru and Bolivia, yacon may have expanded to the north and south along the humid slopes of the Andes, to the dry inter-Andean valleys and to the Peruvian coast. It is in the coastal archeological sites of Nazca (500-1200 AD), Peru that the oldest phytomorphic representations of yacon have been identified, depicted on textiles and ceramic material (Safford 1917; Yacovleff 1933; O'Neal and Whitaker 1947). Further south, putative remains of tuberous yacon roots have been recovered at a site of the Candelaria culture, which developed between 1 and 1000 AD in the Salta province, south from the present area of cultivation in Argentina (Zardini 1991).

The first written record on yacon *(llacum)* is by Felipe Guaman Poma de Ayala (1615) in a list of 55 native crops cultivated by the Andeans, including eight crops introduced from Spain. The chronicler priest Bernabé Cobo (1653) produced a more detailed description, pointing out its use as a fruit and its capacity to withstand several days of transport by sea.

In the 19th century Weddell (1857) called attention to the qualities of yacon roots, named the species *Polymnia edulis* and collected the herbarium type. According to Perez Arbeláez (1956), yacon was exhibited for the first time in Europe at the Paris exhibition at the beginning of the century. European interest was not very significant though. In Italy there was a serious cultivation attempt in the late 1930s, which faded during World War II (Calvino 1940).

Affected by deep cultural changes, yacon cultivation has declined slowly and steadily throughout the Andes during most of the present century, to the point that the German researcher and Andean crop enthusiast H. Brücher mentioned it in his excellent monograph of useful Neotropical plants (1989), "for the sole reason of completeness." Fortunately a drastic change in the international awareness of the crop has occurred during the 1980s, particularly after the publication of Lost Crops of the Incas (National Research Council 1989). The growing interest in the crop outside the Andes has stimulated a new wave of attention and research on yacon in the Andean countries.

6 Geographical distribution and centres of diversity

Yacon is being grown in many localities scattered throughout the Andes, from Ecuador to northwestern Argentina. In most cases just a few yacon plants are cultivated for family consumption (Fig. 7a). Less frequently yacon is grown as a cash crop to be marketed at the local level (Fig. 7b). Even in this situation, farmers rarely cultivate yacon as the main crop and seldom dedicate a high-proportion of their arable land to it.

Yacon is a rare crop in northwestern Argentina, present only in a few localities in the Salta and Jujuy provinces, where it was reported close to extinction by Zardini (1991). Cultivation was probably more widespread in the past, but at present the number of clones available in the area is reduced to two or three, and at risk of further losses.

While genetic erosion has probably also happened in Bolivia, cultivation of the species is still very common in most Andean departments[1] of the country, Tarija, Chuquisaca, Cochabamba and La Paz. La Paz department, particularly the Camacho and Sud Yungas provinces, is most likely the one with the largest cultivated area and the largest germplasm diversity. However, Cochabamba, Chuquisaca and Tarija departments have been poorly researched up to now and may hold valuable material.

Fig. 7. The different scales of yacon cultivation: small home garden at 2700 m asl, Leon Cancha, Tarija department, Bolivia (a), medium size (large size for Andean standards) yacon parcel at 2000 m, Erquis, Tarija department, Bolivia (b), large size yacon farm at 600 m, Capão Bonito, São Paulo state, Brazil (c).

Yacon is grown in many localities throughout the Peruvian Sierra. The largest germplasm diversity is found in southeastern Peru, in the valleys around Cusco and east of Puno. Another region of diversity and widespread cultivation is located in northern Peru, particularly the province of Cajamarca and the area close to the Ecuadorian border.

Within Ecuador, yacon is predominantly grown in the southern provinces of Loja, Azuay and Cañar. The crop is also present in the central highland provinces, such as in Bolivar and Chimborazo and in the north of the country, namely in Pichincha, Imbabura and Carchi.

Cultivation of yacon in Venezuela and Colombia has been reported in the literature (National Research Council 1989; Zardini 1991; Rea 1992). In his monograph Wells (1965) indicates its presence in Cauca, Colombia, presumably because he studied specimens from that region. Three decades ago yacon traditional use appeared to be restricted to the eastern Colombian mountainous range (Patiño 1964, cited in Debouck and Libreros Ferla 1995). However, recent explorations have not confirmed the presence of yacon in Colombia, specifically in Boyaca, Cundinamarca, Huila, Nariño (Dr M. Hermann, 1997, pers. comm.).

A strip stretching along the eastern Andean slopes, from the Apurimac river basin (12ºS) in Peru to the La Paz river basin (17ºS) in Bolivia, encloses the area richest in yacon germplasm. This is also an area where at least three wild *Smallanthus* species, taxonomically very close to *S. sonchifolius,* occur spontaneously *(S. macroscyphus, S. riparius* and *S. siegesbeckius).* Thus, this area seems to be the most likely 'origin centre' of the species (Fig. 8).

In the last three decades yacon cultivation has extended to other continents. There are reports of cultivation in several states of the USA (National Research Council 1989), but not at a significant commercial level. An interesting experience is underway in the North Island of New Zealand, where the crop has reached the supermarkets as a specialty vegetable (Grau 1993). From New Zealand yacon has been introduced into Japan, where approximately 10 ha are being grown by several small farmers (Dr K. Ishiki, 1997, pers. comm.). From Japan it was distributed to Korea and Brazil. In Brazil the crop is being cultivated commercially in São Paulo state. The crop has apparently failed in the Czech Republic (Matejka 1994) and it is likely to fail in most of Central Europe because of the long winter period.

[1] **Provinces** in Argentina and Ecuador are formally equivalent to **departments** in Bolivia and **regions** in Peru (where they replaced departments in 1987). They are the main political divisions of the state. Departments in Bolivia and regions in Peru are subdivided into provinces.

Fig. 8. Yacon distribution in the Andean region. Doubtful presence in Colombia at present is indicated by a question mark.

7 Properties and uses of the species

7.1 Chemical composition

Several carbohydrates are stored in the roots of yacon: fructose, glucose, sucrose, low polymerization degree (DP) oligosaccharides (DP 3 to 10 fructans), and traces of starch and inulin (Asami *et al.* 1989; Ohyama *et al.* 1990). Inulin, a high-DP oligofructan with DP of about 35, is a main storage compound in many plants of the Compositae family, such as *Helianthus tuberosus* and *Dahlia* sp. However, in yacon inulin appears to be only a minor component. On the contrary, oligofructans with a lower DP (average 4.3) may account for up to 67% of the dry matter content at harvest (Asami *et al.* 1991). Oligosaccharides purified from yacon have been identified as beta-(2→1)-fructooligosaccharides with terminal sucrose (inulin type oligofructans; Goto *et al.* 1995). The relative proportions of oligofructans and monosaccharides fluctuate significantly during the growing cycle and after harvesting (Asami *et al.* 1991; Fukai *et al.* 1995), leading to apparently contradictory results. For example a detailed analysis of yacon root carbohydrates has been published by Ohyama *et al.* (1990) (Table 2) indicating that oligofructans account for just 20%, instead of 67% as reported by Asami *et al.* (1991). However it is important to note that Ohyama and coworkers used material after more than 3 months in cold storage, while Asami's team utilized roots immediately after harvest. Unfortunately, a significant amount of information concerning storage sugars in yacon has been published only in Japanese, and it is not intelligible to most readers.

Table 2. Content of soluble carbohydrates in yacon tuberous roots, 96 days after harvest, maintained under cold conditions (Ohyama *et al.* 1990)

Carbohydrate	Content (mg/g dry wt.)
Fructose	350
Glucose	158
Sucrose	74
GF_2	60
GF_3	47
GF_4	34
GF_5	21
GF_6	16
GF_7	13
GF_8	10
GF_9	7
Total GF_{2-9}	201

GF_n= fructosylsucrose; n indicates depolymerization degree.

Besides storage carbohydrates, the tuberous roots contain small amounts of fiber, vitamins and minerals (Table 3). Interesting protein levels have been reported for stems (11% DW) and leaves (17% DW) (Calvino 1940).

Table 3. Chemical composition of yacon roots (summarized from Lizárraga *et al.* (1997), a compilation from different sources)

	Fresh weight basis	Dry weight basis
Water (%)	93 - 70	-
Ash (%)	0.3 - 2.0	1.1 - 6.7
Protein (%)	0.4 - 2.0	1.3 - 7.3
Fat (%)	0.1 - 0.3	0.4 - 1.0
Fiber (%)	0.3 - 1.7	1.0 - 5.7
Calcium (mg/g)	23	-
Phosphorus (mg/g)	21	-
Iron (mg/g)	0.3	-
Retinol (mg/g)	10	-
Carotene (mg/g)	0.08	-
Thiamin (mg/g)	0.01	-
Riboflavin (mg/g)	0.1	-
Niacin (mg/g)	0.33	-
Ascorbic acid (mg/g)	13	-

7.2 Uses

In the local markets of the Andes yacon is classified as a fruit and sold together with chirimoyas, apples, avocados, pineapples, etc. and not with potatoes, oca, ulluco or mashua *(Tropaeolum tuberosum),* as a foreign observer would expect.

Yacon tuberous roots possess an agreeable sweet flavour, an attractive crunchiness and are commonly eaten raw, usually after a period of exposure to the sun. The drying time varies from site to site, being shorter in the dry inter-Andean valley than in the cloud forest region. This procedure, called *ckochascca* (Herrera 1943), increases the sweetness of the roots, and they are considered ready for consumption when the skin is slightly wrinkled. They are eaten peeled, as the skin has a somewhat resinous taste, and they are particularly tasty chopped up in fruit salads mixed with bananas, oranges, pawpaws, etc. Tuberous roots also can be stewed, retaining in part their crispiness, or grated and squeezed through a cloth to obtain a sweet refreshing drink.

In an extended area from Peru to northwestern Argentina yacon is consumed particularly during the ‘Corpus Christi’ festival, which displaced the K’apac Raymi feast of Inca times (Cárdenas 1969). In Ecuador, yacon roots are especially consumed during the 'Todos los Santos' and 'Day of the Dead' festivals (National Research Council 1989). These current practices may indicate old religious values, modified after the advent of the Catholic religion.

In Bolivia yacon is commonly consumed by diabetics and persons suffering from digestive problems. Properties to treat kidney problems and skin-rejuvenating activity also have been mentioned. Medicinal (antidiabetic) properties have been attributed to yacon leaves (Kakihara *et al.* 1996) in Brazil, where the dried leaves are used to prepare a medicinal tea. Dried yacon leaves are used in Japan, mixed with common tea leaves. Hypoglycemic activity has been demonstrated in the water extract of dried yacon leaves, feeding rats with induced diabetes (Volpato *et al.* 1997).

Yacon can be processed in different ways. The juice obtained from pressing the tuberous roots can be boiled and concentrated to produce solid dark-brown blocks called *chancaca* (National Research Council 1989), similar to the product obtained from concentrating sugarcane juice. The juice also can be concentrated at low pressure, with the addition of sodium bisulphate to inhibit enzymatic darkening. The final product is a dense syrup similar to sugarcane syrup but with significantly lower energy value for humans (Chaquilla 1997). Another promising processing technique is the production of dry chips. In this case yacon tuberous roots are peeled and cut in thin slices. The slices are first dried in a plastic tunnel, then oven-dried at 60°C (Kakihara *et al.* 1996). Dried yacon chips can be stored indefinitely.

Yacon pulp can be preserved after heating at 89°C for 10 minutes and washing with sodium bisulphate (0.5%) for 5 minutes, by adding potassium sulfate (0.1%), ascorbic acid (0.3%) and adjusting the pH to 4.5. The heated and washed material can also be added to sugar syrup and made into 'glacé' fruit. Yacon pickles are produced and marketed in Japan (Dr K. Ishiki, 1997, pers. comm.).

All yacon carbohydrates including oligofructans can be rapidly metabolized by ruminants, so tuberous roots can be used to feed cattle or sheep. The foliage, with a protein content of 11-17% (dry weight basis) has been suggested as forage (National Research Council 1989). However, there is no experimental information on the subject. Terpenoid lactones produced by epidermal glands may affect the palatability of the foliage.

8 Genetic resources

8.1 Genetic variation

Although yacon is a clonal crop, there is some morphological and physiological variation. However, this variation may reflect to some extent the phenotypic plasticity expressed in the contrasting environments where it is grown rather than genetic variation. Dr M. Hermann (1997, pers. comm.) found it very difficult to differentiate yacon clones from a wide geographical range, from Ecuador to Argentina, when they were grown in the same environment.

Even if the traits available can be exploited, yacon could gain significant variation by incorporation of genes from its wild relatives. Thicker root bark, looser storage root arrangement (which would reduce deforming pressures), reduced sweetness (which may indicate higher oligofructans level) and tuberous roots with sprouting capacity that could be used as propagules are some of the traits that could be incorporated from wild relatives.

A number of morphological descriptors have been proposed by Seminario (1995a). The variation of characters of potential breeding value is presented below.

- **Morphological characteristics:** erect and semi-erect plant type; internode length (8-25 cm); stem colour (purple, green, pale green); stem and leaf pubescence (dense, medium); number of flowerheads (0-70); colour (pale yellow, yellow, orange); shape and teeth number (2-3) of the corolla; root grouping (compact, lax); root shape; root skin colour (white, cream, pink, purple, brown); root flesh colour (white, cream, white with purple striation, purple, pink and yellow); number of tuberous roots per plant (5-40); root size (6-25 cm length).
- **Physiological characteristics:** flowering habit and duration (6-9 months until flowering); tuberous root yield (1-15 kg/plant) and quality; dry matter content (10-30%); oligofructan content; reducing sugar content; changes in sugar patterns during post-harvest period.

8.2 Geographical distribution of important traits

Considerable variability for tuberous roots yield has been found by Castillo *et al.* (1988) in Ecuador (30-73 t/ha), Seminario (1995b) in northern Peru (1.5-9.5 kg/plant) and Lizárraga *et al.* (1997) in southern Peru (<1.7 to > 3.3 kg/plant).

Variability for flesh colour is higher in southern Peru (Meza 1995; Lizárraga *et al.* 1997) and northern Bolivia, where clones with white, cream, yellow and purple flesh can be found, than in Ecuador or southern Bolivia and northwestern Argentina, where only white and yellow clones have been reported.

8.3 Importance of wild relatives as a source of diversity

The possibility that some of the wild relatives may have contributed to the yacon genome makes them good candidates for future breeding attempts, as part of introgression programmes. However, wild *Smallanthus* species are still poorly known and only a few potential useful traits that could be introduced into yacon have been mentioned in Section 8.1.

8.4 Institutions holding germplasm

Systematic collecting of yacon germplasm began in the 1980s, sponsored by the IBPGR. It focused mainly on crops of global importance such as potato. However, some work was diverted to secondary crops such as the other Andean tubers and yacon. The collecting effort lasted about 5 years and concentrated on Ecuador and Peru.

A second collecting period began in 1993, guided by the Programme of Roots and Tubers in the Andes (RTA), administered by the CIP and funded by COTESU (Cooperación Técnica Suiza - Swiss Technical Cooperation) for a 5-year period. More emphasis was placed on secondary Andean crops and the collecting activities were expanded to Bolivia, aiming mainly at *in situ* conservation.

8.4.1 Ecuador

Ecuadorian Andean root and tuber germplasm is managed by the INIAP (Instituto Nacional Autónomo de Investigaciones Agropecuarias) at the Santa Catalina Research Station, located in Pichincha Province, Mejía Canton, at 3058 m (Tapia *et al.* 1996). The station keeps 777 accessions of Andean roots and tubers (November 1995), of which 32 correspond to yacon (jícama). Material is planted in the field once a year and duplicates are maintained *in vitro,* stored at 5°C. The provinces of Cañar, Azuay and Loja in Southern Ecuador have yielded the largest number of accessions for the Santa Catalina collection.

8.4.2 Peru

Peruvian researchers are the ones in Latin America who dedicated most attention to yacon. Collecting efforts were initiated by Arbizu and Robles (1986) and several germplasm collections have been established in different sites of the country, holding a total of about 200 accessions. However, it is likely that many duplicates are included in this figure.

In the north of the country yacon material is maintained at the Los Baños del Inca research station, Cajamarca, where 45 accessions are being characterized and evaluated (Franco and Rodriguez 1997). The northern departments, Cajamarca and Piura, have been explored by Seminario (1995b), who collected 62 accessions in 1993-94.

The International Potato Center (CIP, Centro Internacional de la Papa) in Lima holds 44 accessions, including 37 from Peru, 4 from Bolivia and 1 from Argentina (Dr C. Arbizu, 1997, pers. comm.).

In the Ayacucho department, collections are kept by the University of Ayacucho (10 accessions) and the Instituto de Investigaciones Agrarias at the Canaan center (6 accessions) (De la Cruz 1995). Material is being maintained under field conditions and *in vitro* (De la Cruz and Jiménez 1997).

Material from southern Peru is concentrated in Cusco. The CICA (Centro Internacional de Cultivos Andinos) of the University of Cusco maintains 33 accessions at the Kayra research station (3249 m). A collection of 87 accessions is maintained by the CERGETYR (Centro de Recursos Genéticos de Tubérculos y Raíces) of the Cusco University at Ahuabamba (2000 m), in the Vilcanota river valley (Lizárraga *et al.* 1997). The University of Cusco has also initiated an *in situ* program at five localities ranging from 3000 to 3500 m asl (Meza 1995).

8.4.3 Bolivia

Very little yacon material is held in *ex situ* collections in Bolivia. Just two accessions are reported at Toralapa (3400 m asl), Cochabamba. Much more important is the amount of material maintained within an *in situ* strategy (Rea 1995b). The conservation network involves 17 families in the La Paz department, which are currently managing 32 different morphotypes. The sites are distributed along a wide altitudinal gradient from 900 to 3600 m, with the largest concentration at 3100-3200 m asl. Information summarizing the experience is shown in Table 4.

8.4.4 Argentina

The Cerrillos research station in Salta (INTA, Instituto Nacional de Tecnología Agropecuaria) has collaborated with CIP during collecting campaigns of Andean tubers in northwestern Argentina, but maintains only one yacon accession. A small *in situ* conservation project for several Andean crops including yacon is being set up in the Santa Victoria area, Salta province, northwest Argentina by the LIEY (University of Tucumán).

8.4.5 Availability of data on individual accessions

Data available on individual accessions vary considerably from institution to institution. They usually indicate origin, collector and a few observations. In general little or no information is available on climatic, edaphic, ecological and agronomic data associated with the accessions, a fact that could constrain future evaluations.

8.5 Gaps in existing collections

An important deficiency in the existing germplasm collections is the limited amount of wild forms available. One ‘wild’ yacon accession from Ecuador is held by CIP (Ishiki *et al.* 1997) and three more are at the CICA center, Kayra, Cusco. However, these are most likely wild *Smallanthus* species other than *S. sonchifolius*. Positively wild *S. sonchifolius* material would provide not only valuable information on the phylogeny of the species but may be useful in future breeding programmes. Furthermore, wild species may represent an interesting source of valuable genes.

Material from the dry inter-Andean valleys is better represented in the collections than material from the humid eastern slopes. Assuming that yacon evolved in the forested slopes of the Andes, diversity is presumably higher in that region. Communities in the humid slopes are generally more isolated and less connected to the main road systems; this increases the likelihood of finding rare clones in these areas.

Table 4. Material held *in situ* in the La Paz Department, Bolivia

Province	Canton	Altitude (m)	Community	Family	Type†	Destination‡
Caranavi	Caranavi	1200	Colonia Sabaya	Calle	Y, 1	A
		1300	Colonia Uchumachi	Mamani	Y, 1	A
Sud Yungas	Quiquibey	880	Colonia Cascada	Ayma	W, 1	A
	Irupana	1950	Chica, Choropata	Apaza	W, 1	A
	Pariruayan	2720	Pariguaya	Cuentas	W, 1	A
					P, 2	A
Camacho	Ambaná	3400	Ambaná	Mantilla	W, 2	B
					Y, 2	C
					P, 1	C
		3100	Stgo. Pampa	Aliaga	Y, 1	C
					W, 2	B
		3150	Mojsahuma	Kamasa	Y, 1	C
		3200	Kapahuaya	Villca	W, 2	B
				Catacora	Y, 2	C
	Moco-Moco	3400	Moco-Moco	Jimenez	W, 2	A
					Y, 1	A
		3350	Tara-Marca	Chahua	W, 2	A
					Y, 1	A
	Italaque	3600	Italaque	Uriarte	W, 2	A
					Y, 1	A
		3200	Huayanka	Toledo	W, 2	C
					Y, 1	C
		3200	Huatacana	Sevahcollo	P,1	C
					W,2	A
					Y 2	C
		3500	Tamampaya	Quilli	P, 1	C
					Y, 2	C
		3400	Yok'arhuaya	Paco	Y, 1	C
					W, 2	C
Muñecas	Pusillani	3225	Pusillani	Bosque	W, 1	A

† Y=yellow; P=purple; W=white; 1=main clone; 2=secondary clone.
† A=home consumption; B=exceptionally marketed; C=commonly marketed.

8.6 Conservation of the cultivated yacon and its wild relatives

No survey of the conservation status of *Smallanthus* species has been made. It would be important to evaluate their presence in the existing national parks and reserves. However, *Smallanthus* species may not be favoured by pristine, conventional protected environments. As plants adapted to invade vegetation gaps, *Smallanthus* may also prefer disturbed habitats created by human intervention. If this proves to be true, an ideal environment would be areas where slash-and-burn agriculture is practised. This also may be valid for the relatives or wild forms of other crop species and it would be important to consider areas like these within the framework of park and reserve systems.

An interesting example of these aspects is present in the Machu Picchu sanctuary in Peru. Sanctuary officials have always tried to expel the peasants established within the limits of the sanctuary. However, besides the growing of yacon landraces, the activities of these people create an environment ideal for at least two wild *Smallanthus* species and many other crop-related species (e.g. *Cyphomandra, Physalis).* It would be very important to carefully evaluate if these peasants and the partially disturbed environment that they create do not actually belong in the sanctuary. In areas like this, a compromise between conservation efforts aiming at different aspects (historical, biological and agronomical) should be possible.

Closely related to the last consideration is the idea of *in situ* conservation, a system that maintains not only the germplasm but also all the information associated with that germplasm. Rea (1995a) has described a successful *in situ* conservation system set up in Bolivia that could be used as a model in other areas of the Andes.

Yacon can be grown *in vitro* using modified Murashige & Skoog media (Kuroda *et al.* 1993; Estrella and Lazarte 1994). De la Cruz and Jiménez (1997) and Velasque and Ortega (1997) have evaluated several alternative modified Murashige & Skoog media to reduce growth and extend *in vitro* conservation for at least 6 months.

9 Breeding

There are no reports of breeding attempts involving yacon. Characterization and evaluation of existing accessions in germplasm banks are being carried out in Ecuador (Castillo *et al.* 1988; Tapia *et al.* 1996), northern Peru (Seminario 1995b; Franco and Rodríguez 1997) and southern Peru (Lizárraga *et al.* 1997). Kuroda and Ishihara (1993) were able to select lines of higher sugar content by tissue culture. Nevertheless, no information is available on selected yacon clones being released for wider cultivation.

A first difficulty while breeding yacon will be its reduced fertility However, this is by no means an insurmountable hurdle. On the other hand the presence of staminate and pistillate flowers makes pollination control considerably easier than in other Compositae, such as sunflower, which requires the use of male sterility to facilitate hybridization.

Yacon is especially amenable to *in vitro* culture, opening an attractive window of opportunities for modern biotechnological manipulation. However, it is essential to define objectives in order to apply the tools available.

Future breeding and selection objectives may diverge depending on the type of farmers, production scale, fresh produce, industrial processing (e.g. purified oligofructans, syrup, chips) and target market (Andean, international). For example, throughout the Andes clones with yellow flesh are preferred at the market level (see data by Rea in Table 4, Tapia *et al.* 1996), while other types are cultivated mainly for family consumption. In contrast, westernized supermarkets may favour a wider range of flesh colours. A more uniform size would be another important characteristic to standardize commercialization and processing.

Evaluation trials have yielded some potentially useful correlations. Productivity (t/ha) is correlated with number of roots/plant (Franco and Rodriguez 1977). The refractive index of the root juice as a rapid estimator of sugar content, a measurement commonly used in other crops, is also valid for yacon (Kuroda and Ishihara 1993).

10 Ecology of the species

There is very little published information about the environmental requirements of yacon, as there has been virtually no conventional research on yacon ecophysiology. Yacon and most yacon relatives are believed to have evolved in the humid eastern slopes of the Andes not far from the equator, a region with mild temperatures and generally with abundant rainfall although with a distinct dry period. These conditions have probably shaped yacon's ecological requirements.

10.1 Photoperiod

Yacon has been described as day-neutral for stem and tuberous root formation (National Research Council 1989). However, this process begins very late in the growing season at higher latitudes (23°S, Jujuy province, Argentina; 46°S, Otago province, New Zealand). This behaviour may indicate that the plant has a weak short-day response.

10.2 Temperature requirements

While native from subtropical to warm-temperate environments, yacon shows a high plasticity, being able to grow and produce in a wide altitudinal range (900-3500 m in Bolivia, Peru and Ecuador; 600-2500 m in northwestern Argentina; 600 m in Brazil; sea level in New Zealand and Japan). Aerial parts are frost-sensitive, with leaves damaged at -1°C. Cultivation is common in some regions with light frost, like the Ecuadorian highlands or many inter-Andean valleys in Peru, Bolivia and northwestern Argentina, because in these regions frosts generally occur at the end of the growing season. In New Zealand, stems were killed almost to the ground by -3 to -4°C, and a temperature of -7°C for several hours damaged all underground organs. Temperatures below 10-12°C combined with high solar radiation led to chilling damage of the leaves (Grau 1993). Optimum growth occurs in the range 18-25°C. Foliage is able to tolerate high temperatures (at least up to 40°C) without damage symptoms, provided that an adequate water supply is maintained. Low night temperatures appear to be necessary for optimum storage root formation. Farmers in Argentina and southern Bolivia indicate that medium-altitude sites (1500-2000 m) are best for storage root production while warmer lowland sites are better for 'seed' (rhizome) production, but root yields are lower.

10.3 Water requirements

Adult yacon plants possess a developed canopy with a high transpiration capacity, requiring a good and regular water supply. Irrigation is a necessary complement in most dry Andean intermontane valleys where yacon is cultivated. Production areas in Bolivia receive 300-600 mm, while 800 mm are considered the optimum. In many regions temporary wilting is very common on sunny summer days, even when the soil has an adequate water level. On the other hand, yacon can survive long dry spells. However, productivity is significantly affected under these conditions. While irrigation may be critical in some cases, overwatering can lead to cracking of the root skin, which affects the exterior quality and market value and may promote root rot during storage.

10.4 Soil requirements

Yacon adapts to a wide variety of soils, but does better in rich, moderately deep to deep, light, well-structured and well-drained soils. Growth is poor in heavy soils. It grows very well in the humus- and mineral-rich soils of the Andean slopes after slashing and burning of the forest. Very good crops are also obtained in sandy river terraces in the Tarija area, Bolivia, and in lateritic soils corrected with dolomite in the state of São Paulo, Brazil. Yacon can tolerate a wide pH range, from acid to weakly alkaline.

11 Agronomy

11.1 Propagation

Yacon is propagated vegetatively with 8-12 cm long offsets (‘seeds’) taken from the underground and aboveground rootstock (‘crown’), with a few or no roots attached. The rootstock can be divided into pieces easily, and these offsets are normally obtained during the harvesting of the roots. Storage roots with no stem attached are not able to produce shoots.

Aerial stem cuttings can be easily rooted if protected from desiccation. Rooting is best under mist, and it can be significantly accelerated using auxins (Indol-butyric acid).

11.2 Crop husbandry

Field preparation varies considerably from region to region and by production scale. The system used at present in the Cusco region, southeast Peru, may be very similar to the one used at the time of yacon domestication. According to Lizárraga *et al.* (1997), in that region field preparation begins with tree-cutting and land-clearing *(roce),* usually in June-July. The material is left to dry, then placed in rows and burned in during August. The material not burned (branches, stems) is taken out of the field *(manq’opeo).* From the beginning of September until the end of November, depending on rainfall, the yacon offsets are planted manually. Planting distance varies: 70-100 cm between rows and 60-80 cm between plants.

In northern Bolivia traditional cultivation begins with the preparation of ploughed maize or potato fields, where the offsets are planted in furrows (Rea 1992). Rows are cultivated and earthed-up during the growing season. Where irrigation is available, planting can be done throughout the year.

In São Paulo, Brazil, yacon offsets are placed in furrows, 1 m wide and 30-40 cm high, at a depth of 15 cm, 90-140 cm apart (Kakihara *et al.* 1996). Soil pH, normally around 4.0 in these lateritic soils, is modified to 6.0 with the addition of dolomite. Management includes fertilization with N-P-K plus Zn (4-14-8 at 2000 kg/ha) and ammonium sulphate (200 kg/ha), and irrigation by aspersion.

11.3 Pests and diseases

In cloud forest areas, like the Cusco region, Peru, yacon crops are affected by a wide range of insects. However, natural control agents are present and effective (Lizárraga *et al.* 1997). Pest pressure is much lower in the dry intermontane valleys. In any case, control measures are not commonly used in the Andes. Table 5 lists some of the species associated with yacon.

A few bacteria and fungi have been cited affecting the underground organs and stems of yacon. *Fusarium* in Peru (Lizárraga *et al.* 1997) and *Erwinia chrysanthemi* in Japan (Mizuno *et al.* 1993) have been identified as causal factors of wilting, while an unidentified rot affects the xylem of stems in Bolivia. *Sclerotinia* causes soft rot of the tuberous roots in Peru (Lizárraga *et al.* 1997). *Alternaria* has been found producing marginal necrosis of the leaves in Ayacucho, Peru (Barrantes 1988).

Table 5. Yacon pests

Pest	Damage/activity	Region, Country	Reference
Liriomyza sp . (Agromyzidae, Diptera)	leaf-mining	Cusco, Peru	Lizárraga *et al.* 1997
Stink bugs (Pentatomidae, Coridae, Hemiptera)	leaf-sucking	Cusco, Peru	Lizárraga *et al.* 1997
Diabrotica sp. (Chrysomediae, Coleoptera)	flower-chewing	Cusco, Peru	Lizárraga *et al.* 1997
Unknown larvae, (Scarabeidae, Coleoptera)	tuberous root-boring	Cusco, Peru	Lizárraga *et al.* 1997
White fly	leaf-sucking	New Zealand	Endt 1992
Looper caterpillar	leaf-chewing	New Zealand	Endt 1992
Papilio sp. (Lepidoptera)	leaf-chewing	São Paulo, Brazil	Mr S. Kakihara, 1996, pers. comm.
Nematodes	root damage	São Paulo, Brazil	Mr S. Kakihara, 1996, pers. comm.

Few studies are available on viruses affecting yacon. There is a report indicating that yacon is free of several common tuber viruses, including those affecting potato (potato leaf-roll, X, Y, S, M; National Research Council 1989). However, clonal decline (cansancio = fatigue) and the need to 'rejuvenate' the 'seed' have been reported by farmers in the La Paz region, a phenomenon that strongly suggests viral infection. Kuroda and Ishihara (1993) indicated that cucumber mosaic cucumovirus infected yacon under field conditions, yielding less vigorous plantlets *in vitro*.

Agoutis, rodents of the genus *Dasiprocta,* have been mentioned attacking yacon tuberous roots in the La Paz region, Bolivia.

Yacon, being a perennial plant, has been suggested as a crop adequate to reduce soil erosion in steep slope areas of the Andes. Yacon leaves tolerate partial shading, a trait that could be used with advantage in agroforestry systems. These two traits warrant a more detailed study, as they can be critical in many regions of the Andes. Yacon may have been associated with slash-and-burn agriculture since prehistoric times. In modern times, however, population pressure and land scarcity make this strategy unsustainable in many areas. Therefore, it would be critical to develop sound agroforestry systems where yacon could fit as a stabilizing component.

11.4 Harvesting and post-harvest handling

Roots reach maturity in 6-7 months in the medium-altitude sites and up to a year in high sites. Storage roots are very brittle when turgid and the plant must be dug carefully to prevent breaking them. Tuberous roots are usually dug and separated manually from the crown. Mechanical potato harvesters have been successfully employed in Brazil (Kakihara *et al.* 1996).

For consumption the roots are exposed to sunlight for a few days to increase their sweetness. This procedure leads to the partial hydrolysis of oligofructans, yielding larger amounts of reducing sugars (fructose, glucose and sucrose). Table 6 shows the changes in reducing sugars and non-reducing sugars.

For long-term storage the roots are placed in a dark, dry, cool room. Under these conditions yacon roots can be kept for several months. Virtually no changes have been observed in the relative amounts of sugars in yacon tuberous roots stored at 4°C (Table 7).

Metabolic activity of harvested yacon tuberous roots is low, similar to potatoes and lower than oca *(Oxalis tuberosa)* and mashua *(Tropaeolum tuberosum)* (Table 8).

Table 6. Changes in reducing sugars and non-reducing sugars (as % of dry matter) after sun exposure for several days (from Vilehna *et al.* 1996)

Days	1	2	3	6	8
Reducing sugars	61.5	59.8	56.1	58.0	56.3
Non-reducing sugars	21.8	21.5	25.1	25.0	25.0

Table 7. Changes in reducing sugars and non-reducing sugars (as % of dry matter) in yacon tuberous roots maintained at 4°C for several days (from Vilehna *et al.* 1996)

Days	0	5	10	20	40
Reducing sugars	58.3	58.1	58.2	58.0	58.0
Non-reducing sugars	23.5	23.9	23.7	23.4	23.5

Table 8. Respiratory rate of different roots and tubers at 17°C, 96 hours after harvest (Grau 1993b)

	Respiratory rate (mg CO_2/kg FW per hour)
Yacon	29
Oca	47
Mashua	56
Potato	20

11.5 Yields

A very interesting trait of yacon is its high productivity. Table 9 summarizes some data available on yacon fresh matter yield. Dry matter varies from 15 to 30% of fresh weight. More detailed information concerning dry matter productivity is required to assess accurately its potential for processing and industrial purposes.

Table 9. Maximum yacon productivity obtained in different environments

Site	Yield (FW t/ha)	Source
Ahuabamba, Peru	28	Lizárraga *et al.* 1997
Santa Catalina, Ecuador	74	Castillo *et al.* 1988
Cajamarca, Peru	95†	Seminario 1995a
Capão Bonito, Brazil	100	Kakihara *et al.* 1996

† Assuming a density of 10 000 plants/ha.

12 Limitations

While in some situations they can affect yields in the Andean region, none of the pests and diseases mentioned in Section 11.3 appears to be decisive in limiting yacon production. Yacon's progressive disappearance from many areas seems to be more dependent on its intrinsic characteristics, cultural change and market factors. As a limited source of energy, yacon does not play a vital role in subsistence agriculture, and priority is probably given to crops that are essential in the diet. As a rather unusual sort of 'fruit', yacon is always in danger of being displaced by conventional fruits, especially when they are associated with 'westernizing' cultural changes. Local Andean markets are not organized adequately to promote yacon qualities and to present it in a stimulating form to the customers. Unlike other, colourful Andean tubers (e.g. oca, ulluco), yacon's comparatively dull aspect may be a deterrent to anyone who does not have a strong cultural attachment to it.

If yacon were to increase its importance as a crop, several agronomic aspects may pose limitations.

- Viral infections are the likely cause of 'seed decline', an issue that may require the development of virus-free propagation material schemes.
- Fungal and bacterial rot and wilt problems under field conditions.
- Splitting and cracking of the tuberous roots before harvest is a problem under certain environmental conditions. Irrigation management is a critical aspect to be addressed to avoid this problem.
- Tuberous roots are easily affected by physical damage during harvest and post-harvest handling, and the wounds can easily lead to fungal or bacterial rot during storage.

13 Prospects

13.1 Advantages of yacon

Yacon possesses an attractive set of features advantageous to producers, processors, consumers and the environment.

- High fresh weight productivity
- Adaptability to a wide range of climates and soils
- Potential good fit in agroforestry systems
- Erosion control
- Potential use as a forage for both underground and aerial parts
- Wide range of processing alternatives
- Good post-harvest life, if managed properly
- Exceptional qualities for low-calorie diets
- Medicinal properties.

13.2 Development objectives

Yacon has been suggested as an industrial crop, particularly as a source of sugar syrup (National Research Council 1989). Yacon productivity is much higher than that of topinambur, an older source of inulin and a potential competitor. It is tempting to speculate about yacon being transformed into a modern industrial crop with the application of modern agronomic technology, fertilization, genetic engineering, etc. However it is yet to be seen if yacon could compete with other established starch and sugar crops, which are being subjected to enormous breeding efforts, in an age when many of them are still heavily subsidized. Even if a strategy like this succeeds, it is unlikely that the Andean region would benefit much from it. In general, Andean ecosystems pose severe limitations to large-scale industrial crops.

Less spectacular but more attractive may be the further development of yacon as what it already is, a specialty and health food. Urban populations are increasing in the Andean countries and urban inhabitants are the ones who could require the sort of food properties that yacon can provide. Small- or medium-scale Andean systems that emphasize low input, environmentally friendly and organic production of yacon could compete advantageously with large-scale and probably higher-yielding crops in other regions.

14 Research needs

Compared with most other Andean root and tubers, yacon knowledge is rather limited and many fundamental aspects of its biology and agronomy are virtually unknown. As a first approach, several specific courses of action can be proposed:

- Field collecting, conservation and evaluation of local clones should continue.
- Field collecting of wild *Smallanthus* species/wild yacon.
- Chromosomic and molecular analysis of the different yacon accessions/morphotypes in order to clarify their relationships.
- Taxonomic and phylogenetic studies of the genus *Smallanthus* in South America using conventional morphological, numerical systematic, chromosomic and molecular analysis in order to clarify the relationships between the different wild species and yacon.
- Artificial crossing between different clones of yacon and different species of *Smallanthus.*
- Breeding interspecific hybrids to increase variation.
- Physiological analysis of tuberous root formation and development, propagation material and dormancy.
- Physiological analysis of pollen viability and longevity.
- Physiological analysis of seed viability, germination, dormancy and longevity.
- Evaluation of pests and diseases and the resistance/tolerance present in different clones.
- Development of IPM and organic management systems for yacon. While pest pressure appears to be low at present, this may rapidly change if there is an increase in the cultivated area.
- Study traditional yacon farming systems as models of organic management.
- Experiment with yacon in agroforestry systems and polycultures.
- Evaluation of the aerial parts as forage.
- Development and evaluation of post-harvest technologies, particularly for small farmers.
- Development and evaluation of different processing technologies.
- Development of standardized techniques for quantitative estimation of oligofructans.
- Biochemical and nutritional/medicinal studies
- Evaluation of the medicinal properties of the leaves.

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