Promoting the conservation and use of underutilized and neglected crops. 25.

Mashua

Tropaeolum tuberosum Ruíz & Pav.

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CENTRO INTERNACIONAL DE LA PAPA CIP

IPGRI

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Foreword

Humanity relies on a diverse range of cultivated species; at least 6000 such species are used for a variety of purposes. It is often stated that only a few staple crops produce the majority of the food supply. This might be correct but the important contribution of many minor species should not be underestimated. Agricultural research has traditionally focused on these staples, while relatively little attention has been given to minor (or underutilized or neglected) crops, particularly by scientists in developed countries. Such crops have, therefore, generally failed to attract significant research funding. Unlike most staples, many of these neglected species are adapted to various marginal growing conditions such as those of the Andean and Himalayan highlands, arid areas, salt-affected soils, etc. Furthermore, many crops considered neglected at a global level are staples at a national or regional level (e.g. tef, fonio, Andean roots and tubers, etc.), contribute considerably to food supply in certain periods (e.g. indigenous fruit trees) or are important for a nutritionally well-balanced diet (e.g. indigenous vegetables). The limited information available on many important and frequently basic aspects of neglected and underutilized crops hinders their development and their sustainable conservation. One major factor hampering this development is that the information available on germplasm is scattered and not readily accessible, i.e. only found in 'grey literature' or written in little-known languages. Moreover, existing knowledge on the genetic potential of neglected crops is limited. This has resulted, frequently, in uncoordinated research efforts for most neglected crops, as well as in inefficient approaches to the conservation of these genetic resources.

This series of monographs intends to draw attention to a number of species which have been neglected in a varying degree by researchers or have been underutilized economically. It is hoped that the information compiled will contribute to: (1) identifying constraints in and possible solutions to the use of the crops, (2) identifying possible untapped genetic diversity for breeding and crop improvement programmes and (3) detecting existing gaps in available conservation and use approaches. This series intends to contribute to improvement of the potential value of these crops through increased use of the available genetic diversity. In addition, it is hoped that the monographs in the series will form a valuable reference source for all those scientists involved in conservation, research, improvement and promotion of these crops.

This series was born out of a joint project between the International Plant Genetic Resources Institute (IPGRI) and the Institute of Plant Genetics and Crop Plant Research (IPK) with financial support provided by the Federal Ministry of Economic Cooperation and Development (BMZ) of Germany.

Series editor:

Dr Jan Engels, International Plant Genetic Resources Institute (IPGRI)

1 Introduction

Mashua (*Tropaeolum tuberosum* R. & P.), along with several potato species (*Solanum* spp.), ulluco (*Ullucus tuberosus* Caldas) and oca (*Oxalis tuberosa* Molina), pertains to the group of edible tuber crops indigenous to the cool-temperate Andes. Mashua is economically much less important than the other Andean tuber crops, but, as this monograph is intended to show, the crop's potential has been largely overlooked and opportunities for wider use within its native range and beyond have remained unexplored (Fano and Benavides 1992; Hermann and Heller 1997). Mashua contributes to tuber diversity, resulting in greater production stability in the heterogeneous Andean environments. So far this has resulted in the conservation of a wide range of native cultivars. However, the future role of mashua as a crop in the region seems to be uncertain. Apparently a range of positive attributes such as rusticity, pest tolerance and high productivity under low levels of inputs cannot counterbalance the present lack of 'market interest'.

Mashua possesses a range of phytochemicals, which protect not only the crop itself, but possibly also associated crops, against pests. Also, except in soils of poor drainage, mashua has very few diseases. Mashua's aggressive growth makes it a very good ground cover, adequate for soil protection on the steep slopes of the Andes. Low input requirements, pest and disease tolerance, high productivity and multipurpose uses, are features that make mashua a very attractive plant for organic agriculture.

Mashua's particular and strong taste has often been mentioned as a main cause for its neglect and abandonment. However, similarly pungent phytochemicals occur in several horticultural crops, such as in the Brassicaceae family (radishes, mustards) and *Allium* species (onions, garlic), which are well liked in many cultures and have a variety of uses in cooking. Rather than treating mashua as a starchy staple, as in Andean food systems, it might have potential as a spicy resource in raw dishes, pickles or fermented specialties. For example, thinly sliced raw mashua adds a pleasant pungency to salads, like *Brassica* species, which also contain glucosinolates. Mashua's reputed antiaphrodisiac action, however, imposes constraints on the marketing of the crop. Its demonstrated hormonal effect in rats indicates that there may be a physiological basis for the popular belief that it reduces libido. The possible hormonal activity in humans, and the effect of different processing methods on that activity, will have to be investigated in detail.

If a wider market could be identified and marketing resources made available, mashua would be an excellent candidate for crop improvement. This is because of the considerable diversity available in mashua germplasm collections, the ease of hybridization of domesticated with (conspecific) wild mashua and with other *Tropaeolum* species, as well as mashua's prolific seed set, thus making conventional breeding possible.

Visually distinguishing the tubers of mashua from those of oca takes a little practice, especially in the case of the yellow forms, which can look confusingly similar to the untrained eye (Fig. 1). Melchiorre (1985) provides a list of morphological features that identify the two species, but a bite into the raw tuber provides an immediate answer: oca has a tart, acidulous taste owing to its high content in organic acids, notably oxalate, whereas the taste of mashua is reminiscent of the pungency of a radish.

Fig. 1. Andean tuber crops: oca (*Oxalis tuberosa* Molina), ulluco (*Ullucus tuberosus* Caldas) and mashua (*Tropaeolum tuberosum* R. & P.) (Photo M. Hermann).

2 Crop history and dispersal

Wild and cultivated *T. tuberosum* is found in the high Andes from Colombia to northwest Argentina. Cárdenas (1989) and Hawkes (1989) assume that domestication occurred in the region encompassing Ecuador to Bolivia. This is supported by the large diversity present in this wide area. However, in the absence of a comprehensive study on the diversity of wild and cultivated forms of mashua, it is difficult to pinpoint a smaller area as the likely centre of origin of the crop.

Similarly, little is known about mashua crop history and dispersal. Mashua is more widespread than the minor Andean tubers maca (*Lepidium meyenii* Walpers) or mauka (*Mirabilis expansa* (Ruíz & Pav.) Standl.), species known only from isolated and 'insular' distributions, but is less common than the cool-temperate oca and ulluco. Excavations at Guitarrero cave in Peru suggest (Pearsall 1992; Smith 1980), that oca, and probably also ulluco, may have been consumed as early as 8000–7500 years before the present. The first archaeological evidence of mashua dates from 650–1350 AD (Pearsall 1992) in the Huachumachay cave sediments, located in the Jauja valley, Peru. The reduced economic scope of mashua in the colonial past and today, as well as its relatively late appearance in the archaeological record, suggests that its domestication may have taken place relatively late.

On the basis of current medicinal uses and beliefs surrounding mashua, as well as the plant's use as (a rare) ornamental in northwest Argentina (Fernández 1973, Hermann 1992, personal observation), Johns *et al*. (1982) suggest that mashua had a significant place in the distant past for reasons other than food, and that its domestication may relate to its importance as medicine (see Section 7.5). In the same vein, Fernández (1973) argues for it to be a relict of a primordial agricultural complex.

Beautiful, unambiguous depictions of mashua are present in the Nazca pottery at Pacheco, dated 1000 AD (Yacovleff and Herrera 1935; Towle 1961) (Fig. 2),

Fig. 2. Nasca pottery designs representing Andean tubers. Clockwise from upper left: potato, ulluco, oca and mashua. (Reproduced from Yacovleff and Herrera, 1935, p. 308, with permission from Museo Nacional de la Cultura Peruana, Lima, Peru.)

suggesting that, in spite of being a highland crop, it was also well known in coastal Peru. The first historical reference to the plant appears in a chronicle cited by Yacovleff and Herrera (1935) as: 'Various, Bello Gayoso, on Cuenca and its Province, 1582'. Under its alternative common names 'añus' and 'masuas' (plural), mashua is later described by Garcilazo de la Vega (1966 [first published in 1609]) and Guamán Poma de Ayala (1936 [first published 1615]). The Jesuit Bernabe Cobo (1956 [1639]), gives a detailed account of mashua, emphasizing its similarity with oca in size and shape. This author also mentions the antiaphrodisiac effects attributed to mashua, and how these were exploited by the Inca military to keep their soldiers quiet. Much later, Ruíz and Pavón (1802) made the first and still valid botanical description, accompanied by a detailed drawing, which is reproduced in Fig. 3.

Although less common in the past and present than oca and ulluco, mashua was important enough to deserve significant selection efforts by the Andean peasants. This resulted in a large number of cultivars. In the last decades the demand for mashua seems to have decreased, to judge from its diminished presence in city markets. However, it is still available in small amounts in rural markets and from farmers who use it largely for home consumption.

Fig. 3. Mashua plant (upper right) and reproductive parts (lower right) depicted in Ruíz and Pavón's 'Flora Peruviana et Chilensis' (1802).

3 Production and distribution

According to agricultural statistical data provided for Peru by Deza (1977), total mashua production in that country reached 19 500 t in the mid 1970s, with a total area of 5290 ha and an average yield of 3.7 t/ha. More recent data (Anonymous 1999) suggest an increase in yields and cropped area to 32859 t and 7244 ha, respectively, with an average yield of 5.2 t/ha. However, these figures must be treated with caution, as the small and fragmented plots in remote mountain areas are difficult to estimate, and agricultural census data in the Andean countries are notoriously unreliable. Peru is generally believed to be the largest Andean producer.

One of the few rural women seen in 2001 offering a small amount of mashua in the market of Huánuco, a mid-sized town in the Peruvian highlands, is pictured in Fig. 4. This photograph illustrates and typifies the limited scale of mashua production and commercialization in Peru. The woman also displays yacon (*Smallanthus sonchifolius* (Poepp.) H. Rob.), another neglected Andean root crop, as well as roasted calabaza (*Cucurbita ficifolia* Bouché). Her attire, and the choice of these 'orphan products'—rarely present on urban markets—clearly identifies her as a specialist supplier of indigenous crops.

Fig. 4. Mashua, yacon roots and roasted calabaza fruits (*Cucurbita ficifolia* Bouché) in a market display in Huánuco town, Peru (Photo M. Hermann, September 2001).

Data for the other Andean countries are extremely scarce. Tapia (1994) estimates the cultivated mashua area in Bolivia at no more than 100 ha, with yields of 2–3 t/ha. However, both figures seem too low since production characteristics similar to those in Peru can be expected in Bolivia. There are no statistics for Ecuador, where we estimate the cultivated area to be around 50 ha, all located in isolated areas of the Sierra region. Nieto (1993) provides an overview of the use of mashua in Ecuador and the status of germplasm conservation. The area dedicated to mashua in Colombia is concentrated in Boyacá.

In Argentina, mashua is restricted to the northwestern provinces, where one of us has seen cultivated plants in Colanzulí, Salta, and Chalguamayoc, Jujuy (Hermann 1992, personal observation). However, mashua, or 'sisaño' as it is known locally, is hardly more than a botanical curiosity, not seen on local markets and known to only a few farmers, who occasionally grow it for food or as an ornamental.

Latcham (1936) lists mashua in his book on pre-Colombian plants of Chile, but neither the crop nor the product was found on a collecting mission in the high-altitude oases of the Atacama desert in 1993, an area once belonging to Peru, where other Andean tubers such as native potatoes, oca and ulluco are still fairly common (Hermann 1993, personal observation).

4 Vernacular names

Mashua (or maswa), a Quechua word for which no meaning is known to us, is the most widely used common name for the plant and the tuber, especially in southern Colombia, Ecuador and Central Peru, and is often understood even where other names prevail. Masua (or maswa) is the form used in Quechua from the Ayacucho region. A set of other terms, such as maxua, majua, mazuco, maswallo, mascho, are probably post-Columbian variations under the influence of the Spanish language. Quechua speakers also refer to mashua as 'añu', a word derived from the Aymara term isañu or isaño. Añu is used in the Cusco region, while isaño is common around Lake Titicaca and further south in Bolivia, including the Cochabamba region. In Colombia, mashua is also referred to as 'cubio', a term whose origin is unknown to us but could be from a pre-Columbian language, thus perhaps indicating the antiquity of mashua cultivation in this country. 'Navo', 'navios' or 'nabos' are also terms for mashua restricted to Colombia that appear to be modifications of 'nabo', the common Spanish name for *Brassica napus*. A list including less common names is presented in Table 1. The presence of at least three completely different name groups—mashua, añu and cubio—suggests that the crop was widely established before the homogenizing effect of the Inca and Spanish conquests. This phenomenon supports the notion that either the crop was domesticated and dispersed very early, or it was domesticated independently in different areas in the Andes.

Mashua tubers show a notably wide range of colours and qualifiers in varietal names often refer to them. A list of the more frequent names is presented in Table 2.

Some varietal names apparently refer to attributes such as shape or taste (Hermann and Cruz 1991): 'Huaka hasta' or 'Huagra hasta' (cow horns) refers to elongated, curved mashuas. 'K'eya-añu' indicates foetid smell. 'Take-añu' or 'Taqui añu' refers to tuber stores common in Cusco, and might indicate that this type holds well in storage. 'Kita-añu' and 'Añu-añu' are terms used for wild mashua (Herrera 1921).

Table 1. Vernacular names of mashua

Name	Language	Region/country	Reference
Allausu		Peru	Mejía 1931
Añu	Quechua	Peru	Cárdenas 1989
Apilla	Quechua	Bolivia	Cárdenas 1989
Apiñamama	Quechua	Peru	Herrera 1941
Capuchinha tuberosa	Portuguese	Portugal	Sánchez-Monge 1981
Capucine tubéreuse	French	France	Sánchez-Monge 1981
Cubios	Spanish (?)	Colombia	Pérez Arbelaez 1947
Gallu Gallu			Sparre and Andersson 1991
Isaño	Aymara	Bolivia/Titicaca	Cárdenas 1989
Majua	Spanish	Ecuador	Lescano 1994, Espinosa *et al*. 1997, Patiño 1964
Mashua	Quechua	Ecuador	Tapia *et al*. 1996, Espinosa *et al*. 1997, Estrella 1986
Mashua		Peru	Herrera 1941
Maxua	Spanish	Ecuador	Lescano 1994, Patiño 1964
Mishua		Peru	Mejía 1931
Navios	Spanish	Colombia	Pérez Arbelaez 1947
Navos	Spanish	Colombia	Pérez Arbelaez 1947
Ocaquisaño	Quechua	Bolivia	Cárdenas 1989
Pane	Guambiano	Colombia	Patiño 1964
Peruanische Knollenkresse	German	Germany	Sánchez-Monge 1981
Puel	Paéz	Southern Colombia	National Research Council 1989, Patiño 1964
Sisaño	Aymara (?)	Argentina, Jujuy	Hermann 1992, personal observation
Tropeolo del Peru	Italian	Italy	Sánchez-Monge 1981
Tuber nasturtium	English	United Kingdom	Sánchez-Monge 1981

Table 2. Mashua varietal names

Name	Tuber attributes	Source
Occe-añu	Leaden	Herrera 1941
Yana-añu	Black	Herrera 1941
Checche-añu	Grey	Herrera 1941
Ckello-añu, K'ello-añu	Yellow	Herrera 1941
Muru-añu	Purple	Herrera 1941
Phutilla añu	Red	Hermann and Cruz 1991
Puca-añu	Red	Herrera 1941
Yana-añu	Black	Hermann and Cruz 1991
Yurac-añu	White	Herrera 1941
Zanahoria-añu	like a carrot	Hermann and Cruz 1991
Zapallo-añu	like a pumpkin	Herrera 1941
Quillu-mashua	Yellow	Espinosa *et al*. 1997
Putsu-mashua	Yellow background covered in red stripes	Espinosa *et al*. 1997
Sucsu-mashua	Yellow background covered in pink stripes	Espinosa *et al*. 1997
Mashua yana-saco	Black	Espinosa *et al*. 1997
Mashua-chaucha	Early-maturing	Tapia *et al*. 1996
Mashua-shira	Yellow with purple dots	Tapia *et al*. 1996
Mashua-zapallo	Yellow and red	Tapia *et al*. 1996
Mashua-zapallo	Yellow	Tapia *et al*. 1996
Sangre de Cristo ('Christ's blood')	Yellow background covered in red stripes	Tapia *et al*. 1996, Espinosa *et al*. 1997
Yawar waqac ('weeping tears of blood')	Yellow background covered in red stripes	Hermann and Cruz 1991
Huaka hasta or Huagra hasta	Long curved	Hermann and Cruz 1991
K'ella añu	Foetid smell	Hermann and Cruz 1991
Take-añu or taqui-añu	Good for storage	Hermann and Cruz 1991
Kita-añu	Wild mashua	Herrera 1921
Añu-añu	Wild mashua	Herrera 1921

5 Crop biology

5.1 Crop cycle and development

Mashua has often been mistakenly described as an annual, because of its yearly production cycle (e.g. Arbizu and Tapia 1992; Zela *et al.* 1997). However, the term 'annual' is reserved for plants in which only sexually formed seeds give rise to a new generation, whereas both cultivated and wild mashua persist through tubers, although aerial organs may die back at the end of the growing season. Mashua is therefore clearly a perennial species, with some genotypes presumably being very old clones. Small tubers are frequently left in the field and sprout easily, especially under the wetter conditions in the northern Andes. Under such circumstances, mashua can become a weed problem, thus fully confirming the species' perennial nature.

Unlike ulluco, mashua flowers profusely, starting 3–5 months after planting and lasting for 1–2 months. The plants also set abundant seed. Tubers are ready for harvest 6–9 months after planting. A schematic representation of mashua's development is shown in Fig. 5.

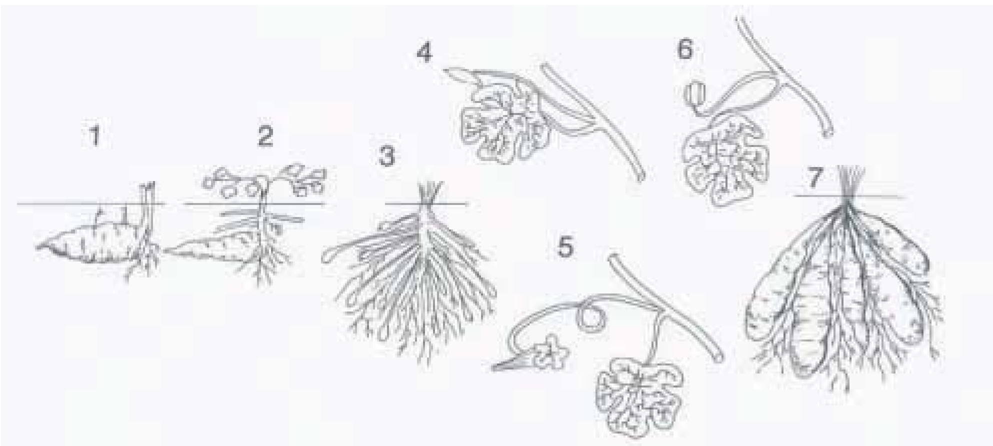

Fig. 5. Mashua development: 1, Emergence; 2, Stolon formation; 3, Tuberization; 4–5, Flowering; 6, Fruiting; 7, Tuber maturity (Source: Lescano 1994, p. 74).

5.2 Plant architecture and morphology

Mashua is a stout climber with thick or slender, often reddish, glabrous stems. Stems arising from sprouting tubers are erect but the plant soon adopts a semiprostrate or prostrate habit, producing a very dense soil cover. Stems and petioles are twining and able to climb on any available support, reaching 2 m or more in height. The tubers are usually 5–15 cm long and 3–6 cm broad in their distal part. Most tuber growth is due to pith proliferation. The tuber is covered by an epidermis with thick exterior walls, which gives a waxy aspect to the surface. Tuber colour and shape vary considerably, as seen in the cultivar samples from Peru and Colombia in Fig. 6 and Fig. 7 respectively. Some cultivars are of spectacular beauty, such as the Peruvian Yawar waqac (Fig. 8), which has a skin pattern reminding the name-giving Quechua Indians of 'tears of blood' (yawar = blood, waqac = to cry).

Petioles are reddish, 4–20 cm long, with thin, reddish, inconspicuous and caducous stipules. Leaf blades are peltate, suborbicular, 4–6 cm long and 5–7 cm

Fig. 6. Sample of mashua variation in Peru (Photo G. Chang).

Fig. 7. Mashua cultivars from the market in Tunja, Boyacá, Colombia, locally called 'cubios' or 'nabos' (Photo M. Hermann, November 1986; coin is 2 cm in diameter).

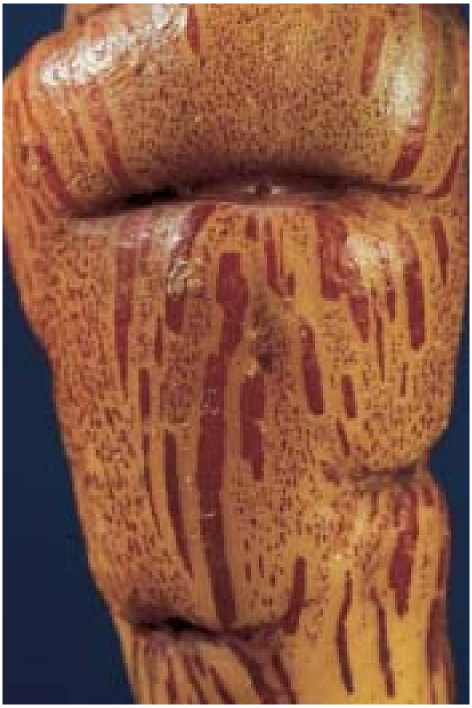

Fig. 8. Mashua cultivar 'Yawar waqac' from Cuzco, Peru. The Quechua name of this cultivar means 'tears of blood' (Photo M. Hermann, 1991).

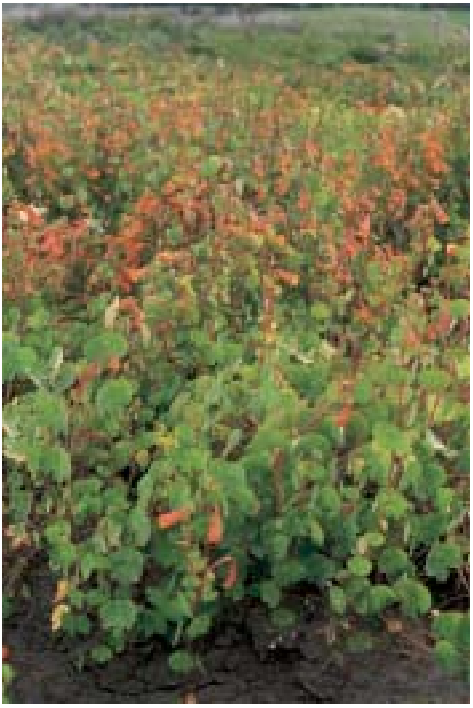

Fig. 9. Flowering mashua plants, near Quito, altitude 3050 m (Photo M. Hermann, May 1990).

broad, at base rounded to subtuncate, with normally 5 lobes (sometimes 3–4), rotundate, with an obtuse to truncate apex, mucronate, upwards and slightly sideward directed. The upper surface is dark green while the lower surface is pale green with marked purple palmate nervation. The hypogynous flowers are solitary, zygomorphic, placed on long (15–25 cm) peduncles (Fig. 9). Calyx with 5 sepals, 5-lobed, mostly red or reddish, but sometimes yellow; inferior lobes lanceolate, 12–14 mm long, 4–5 mm broad at the base; sepals fused at the base forming a nectar containing spur, often referred to as calcar, of the same colour, tubular with a very broad, straight or curved appendix, 18–22 mm long, 5–6 mm in diameter at the base. Petals, 5, free, commonly yellow or orange with darker veins, sometimes light lilac or reddish; posterior petals are unguiculate with a rotundate blade, 6–9 mm long, 5–8 mm broad; anterior petals are elliptical, unguiculate, 10–15 mm long and 4–6 mm broad. Stamens 8; the syncarpic ovary is superior from 3 carpels, 3 locules and a simple style with 3 lobbed stigmata; each locule contains one ovule in axilar position.

The described floral morphology is typical for *Tropaeolum*. A number of aberrations have been described by Pocco (1976) and Vallenas (1977) in clones of the

Puno area. They include an increased number of sepals and petals to 6 or 7 per flower, flowers with 2 spurs, increased number of stamens (up to 13), increased number of carpels to 4 or 5 and a corresponding number of stigmata.

At maturity the fruit, a schizocarp, separates into 3 mericarps, each one with 3 pronounced ribs and a rugged surface and containing 1 seed. The pericarp is thin but epicarp, mesocarp and endocarp can be easily distinguished. Some morphotypes from Ecuador present 2–5 mericarps per fruit at maturity. This may be an environmentally modified trait. The bulk of the seed is formed by the cotyledons rather than endosperm, with cells containing aleuron grains and thick cell walls formed by galactoxyloglucans that are mobilized following seed germination (Bewley and Black 1994).

The mashua tuber is morphologically a thickened stem—it has 'eyes' from which it produces aerial stems and adventitious roots, which are slender and filiform. Lateral roots are less developed than the main ones (Chacón 1960).

5.3 Reproductive biology

Unlike oca and ulluco, mashua flowers profusely and sets seed easily. Unfortunately, little is known about mashua's reproductive biology. To date the most detailed research on the subject was carried out by Pocco (1976) and Vallenas (1977). According to Vallenas (1977) mashua begins to flower 3–4 months after plant emergence. Flowering lasts for 1–1.5 months. Each flower remains open for 8–15 days. Stigmata are receptive at the beginning of anthesis, and remain receptive for 40 hours. Pollen is viable 24 hours before anthesis and pollen viability reaches a peak 24 hours after anthesis. The abundant flowering attracts a considerable number of insects and birds. Pollen viability at anthesis was estimated at 50–53% by Pocco, but Johns and Towers (1981) found much higher values (95% viability) in *T. tuberosum* ssp. *tuberosum* and *T. tuberosum* ssp. *silvestre.* Information on pollination biology of Tropeolaceae is still limited. The best-known species so far is *T. pentaphyllum* Lam. (Fabbri and Valla 1998), a species of Southern Brazil, Uruguay and Northeast Argentina, which is pollinated by hummingbirds and several Hymenoptera.

In our experience mashua seeds can be desiccated to low moisture levels at the ambient conditions of the Andean highlands and will germinate after several months of storage, but formal experiments confirming the orthodox behaviour and germinability of the seeds have still to be conducted. The fact that mashua fields consisting of only one clonal cultivar form ample seeds suggests that mashua is self fertile. Plants grown from botanical seeds, apart from their distinct tuber morphology, resemble mother plants in terms of crop duration, phenology and capacity to reproduce asexually via the tubers. To our awareness, botanical seeds are currently not used to conserve germplasm.

6 Agronomy

6.1 Plant propagation

Mashua is propagated for production purposes in traditional Andean agriculture exclusively via the tubers, which need to be set aside from the harvest for that purpose. Rooted young tubers or aerial stems can also be used for accelerated bulking of particular clones, although this practice is limited to research purposes.

As in the case of other Andean tubers (potatoes, oca, ulluco) botanical seeds of mashua are not used for propagation purposes in current agricultural practice. The reasons are probably the same as for the other tubers: failure to breed true to type by sexual propagation, extended crop duration of seed-propagated plants and predominance of vegetative agriculture in traditional Andean systems. The abundant seed set of mashua and its apparent good germinability, however, afford plant breeders and researchers with opportunities to produce and select new genotypes with relative ease.

6.2 Cropping systems and crop husbandry

Mashua is part of the traditional, subsistence-oriented cropping systems of the Andean highlands. Like most of the agricultural production systems in the region these are polycropping arrangements, very intensive in land use, and labour intensive (Camino 1997). Mashua is interplanted with other tubers such as potato, oca or ulluco or with other crops such as faba bean (*Vicia faba* L.), quinoa (*Chenopodium quinoa* Willd.) or Andean lupin (*Lupinus* L.) (Fig. 10). In other cases, mashua together with oca and ulluco is part of crop rotation systems; they are planted in small monocrop plots before or after barley, broad bean or lupine. At lower altitudes, as in the inter-Andean valleys of Ecuador (altitude less than 3000 m), mashua is often intercropped with maize (*Zea mays* L.) and squashes (*Cucurbita* spp.). In any case, mashua is seldom monocropped

Fig. 10. Mashua intercropped in the foreground with oca and ulluco, next to faba beans and barley, Cotopaxi Province, Ecuador, 3700 m altitude (Photo M. Hermann, July 1988).

in plots exceeding 2000 m^2. In Colombia, mashua is often used in border rows surrounding potato fields. This practice is believed to repel potato pests. Johns *et al.* (1982) refer to a similar practice in Peru. This is supported by Rea's (1984) mention of ornamental *Tropaeolum* serving as pest barriers in Ecuador.

In Ecuador and in large parts of the Colombian Andes mashua has been reduced to the status of a botanical curiosity or that of a medicinal plant, often tolerated in backyard gardens rather than cultivated. Some farmers consider mashua a potential weed problem in successive crops, as it can persist in the field for two or three crop seasons. Mashua regenerates easily from tubers left in the field.

Because of agroecological and ontogenetic similarities and its common intercropping with oca and ulluco, mashua is subjected to similar cultivation practices, to the point that they are often dealt with together in the literature (e.g. Arbizu and Tapia 1992).

Small mashua tubers are preferred for planting (or are the only material left over at planting time), which may in fact be a poor agricultural practice. By using small tubers for seed, farmers may unconsciously select for less vigorous types, which may either represent somatic mutations or material affected by pathogens.

The tubers are planted on ridges 70–80 cm apart. Distances within ridges vary from 30 to 40 cm (Meza *et al.* 1997), giving total plant populations of 31 000–48 000 plants/ha. Barrionuevo (1975) indicates a wider distance, up to 100 cm between rows and up to 70 cm within rows. Under favourable growing conditions mashua can respond efficiently to the wider spacing. In Peru planting is done with the 'chaquitaclla', which is used to open a hole, at the bottom of which one or two tubers are placed. Planting is done from mid-August to mid-October, coinciding with the onset of the first rains.

When mashua is planted as a monocrop (Fig. 11), planting distance varies from 80 to 100 cm between rows and from 30 to 50 cm within rows, depending on soil

Fig. 11. Mashua (right) and oca plot (left), Cotopaxi Province, Ecuador, 3700 m altitude (Photo M. Hermann, July 1988).

quality. The wider distances are applied in soils with high fertility. Weed control is necessary only during the early stages. Once in the ground, tubers sprout quickly and mashua develops a very dense canopy that effectively starves competing plants of light. Quispe *et al.* (1997) found 160 days after planting a leaf area index (LAI) of 3.6. This was less than the LAI in potato (4.5) but more than the LAI in oca (2.5) grown under the same conditions. Similar results were obtained by Valladolid *et al.* (1982). Fertilized mashua can reach much higher LAI values of 4.7–5 (Valdivia *et al*. 1999).

Plants are hilled twice. Hilling is believed to increase yields by stimulating stolon and tuber formation, but no formal experiments have been conducted to confirm this. The first hilling is normally done after the plants have emerged and the soil has been moistened by the first rains. A second hilling is done at the beginning of flowering.

According to Valdivia *et al*. (1999), mashua harvest index varies between 0.52 and 0.69.

6.3 Fertilization

In the Andean rotation system, the first crop after fallow is always the potato. It is the preferred crop because of its importance in subsistence and for income generation. The benefits of restored soil fertility after fallow and what little manure or fertilizer may be available are targeted to potato productivity. Mashua frequently follows the potato. In Peru, such fields are called 'kqalpares de papa', a term indicating the condition of residual soil fertility. Mashua may also be used to conclude the rotation before fallow, which indicates the crop's comparatively low nutrient demands.

Knowledge on mashua response to the application of mineral fertilizers is still limited. Valdivia *et al.* (1999) found a significant increase response to fertilization (from 28.8 t/ha in the unfertilized control to 36.1 t/ha using 80 kg N, 160 kg P and 80 kg K per hectare). However, mashua was found to be significantly less responsive than oca to fertilization. This result was obtained in the relatively poor soils of the Toralapa research station (Cochabamba, Bolivia). According to these authors an even weaker response is to be expected in the soils normally used for mashua, which usually contain more NPK.

6.4 Pests and diseases

Rusticity is one of the attractive attributes of mashua. Information on the severity of mashua pests and diseases is still very limited. Some reports, such as Morales and Rea (1982), indicate no relevant damage through pests or diseases. Of the 131 mashua accessions observed by these authors in Belén (3820 m altitude) and Italaque (2800 m), La Paz Department, Bolivia, few were affected by biotic agents. Nevertheless some pests and diseases are reported in the literature and are discussed in the following paragraphs. Rarely, though, do they cause significant damage. No pests or diseases are currently known that constitute serious constraints to mashua cultivation.

6.4.1 Viruses

The first virus reported in mashua was a mosaic, which can be easily transmitted to a range of hosts including Amaranthaceae, Chenopodiaceae, Asteraceae, Fabaceae, Solanaceae and other Tropaeolaceae (Delhey and Monasterios 1977). Brunt *et al.* (1996) have isolated and named two mosaic virus species: Tropaeolum 1 *potyvirus* and Tropaeolum 2 *potyvirus*. They frequently occur together and are transmitted by mechanical inoculation. The aphid *Myzus persicae* can act as a vector. However, these viruses are not transmitted by seed. A similar potyvirus has been reported by Soria *et al.* (1998). The authors named the virus Tropaeolum mosaic *potyvirus* (TropMV). This virus can also be transmitted mechanically and by *Myzus persicae* aphids. A survey of Ecuadorian germplasm from INIAP's Santa Catalina Experimental Station revealed that 34 out of 46 accessions were infected by TropMV; all eight fields surveyed contained infected plants. Observations at Santa Catalina also suggest that virus infection increases when mashua is cultivated in the same field for more than one cropping season.

There are still important aspects of mashua viral diseases that are unknown, such as the actual impact of these viruses under field conditions, how easily virus-free material can be obtained and how fast reinfection would occur in the field (Lizarraga 1993).

A wide spectrum of viruses has been reported to infect the garden nasturtium *Tropaeolum majus* L. (Soria *et al.* 1998), which suggests that other viruses might be found in the closely related mashua. Viruses have not, however, been found to affect mashua cultivation significantly.

6.4.2 Fungi

A comprehensive treatment of mashua diseases by Ames de Icochea (1997) describes several fungal pathogens, some of them causing considerable damage, particularly those that affect the harvested tubers. *Acroconidiella* leaf spot is always present in mashua crops, and its symptoms increase at the end of the cropping season, when all plants are affected to some extent. The causal agent, *Acroconidiella tropaeoli,* affects other wild and cultivated Tropaeolaceae. *Sclerotinia sclerotiorum* includes mashua within its wide host range. *Sclerotinia* usually affects localized sectors of the crop at the middle of the cropping season. It can cause considerable damage but this appears to be restricted to exceptionally wet conditions, as is the case with an as yet unidentified species of *Phytophthora* which can affect mashua.

Ascochyta pinodes affects mashua under field conditions. However, this so-called black tip disease is only significant as a storage problem. Species of the fungal genera *Mucor, Rhizopus, Cylindrosporium, Penicillium* and also bacteria such as *Erwinia* and *Pseudomonas* have been isolated from mashua; however, they represent opportunistic pathogens affecting the crop in the wake of frost or desiccation damage (Ames de Icochea 1997).

López (1986) reported *Rhizoctonia* spp. and *Phytium* affecting tubers and roots; *Fusarium* spp. that produces wilting plants and rotting roots; *Verticillium* spp. and

Acrocylindrium spp., causing rotting in low stems and roots. Falconi and Morales (1983) reported mashua as host for several fungal species: *Acrocylindrium, Cylindrophora, Phytium, Arthrobrotis, Fusarium, Verticillium and Mucor*, producing some rotting in tuber roots; *Graphium, Epiccocum*, affecting the aerial stems; *Pyronema, Alternaria, Ovularia, Heterosporium, Stemphylium, Eriocercospora, Mycosphaerella and Ulocladium,* producing leaf spots. Nevertheless, none of these fungal diseases appear to significantly decrease yields. Mashua is still considered a highly tolerant crop and the application of fungicides is not recommended, even in the presence of the fungal pathogens listed above.

6.4.3 Nematodes

In a screening for nematodes in Andean tubers Montero (1993) found species of several genera affecting mashua: *Criconemoides*, *Paraphelenchus*, *Discocriconemella, Drylaimus*, *Aphelenchus*, *Neocriconema and Heiciclophora*, a larger number than those affecting oca and ulluco. Members of the Criconematidae (*Criconemoides, Discocriconemella* and *Neocroconema*) were present only on mashua, suggesting that mashua has a particular interaction with members of this family.

Mashua has been mentioned as a host of the oca nematode, *Thecavermiculatus andinus* (Franco and Mosquera 1993). However, its sensitivity is low, similar to wild herbs like *Salvia* spp. and *Senecio vulgaris*, and well below potato, ulluco and oca.

Similarly, mashua can be infected by the potato nematode *Nacobbus aberrans*, but most genotypes showed no symptoms. Only one from eight genotypes developed nematode nodules and two were not infected at all (Balderrama and Franco 1994). Similar results were reported in Toralapa, Bolivia (Anonymous 1995b), where three accessions tested did not show any infection with *N. aberrans.* These results strongly suggest that mashua has a high level of tolerance to nematodes.

6.4.4 Insects

INIAP (1988) indicates that the mashua germplasm in the INIAP collection was affected by *Copitarsia turbata* (‘gusano cortador’) and the leaf miner (*Philionorycter* sp.). A later report (INIAP 1993) found that most of the accessions held at Santa Catalina, Ecuador, had been affected by *Copitarsia* spp. However, 33% of the accessions suffered no or only minor damage (0–2% of the tubers damaged).

Interestingly, mashua was more sensitive than oca to the Andean weevil, *Premnotrypes vorax*, and was less effective when used as a control barrier (Calvache 1991). Ruales and Moscoso (1983) reported the following insects in mashua at farm level: *Copitarsia turbata*, attacking aerial stems; *Phyllonoryeter* spp., mining leaves, and *Thysanoptera* spp., also affecting leaves.

6.5 Harvest and yields

Information on mashua yields still reflects predominantly small trial plot results, rather than actual farm yields (Table 3). Experimental plot results indicate that mashua is very productive, particularly on a fresh weight basis. Yields frequently

Table 3. Mashua yields in relation to environmental conditions and localities

Locality, Department (Country)	Altitude (m asl)	Latitude °S	Max. temp. (°C)	Mean temp. (°C)	Min. temp. (°C)	Rainfall (mm)	Plot size	Tuber yield (t/ha)	Source
Santa Catalina, Pichincha (Ecuador)	3058	0	18	11	6	1400	n.a.	n.a.	Tapia *et al*. 1996
Moyocancha, Chimborazo (Ecuador)	3800	0	14	8	0	n.a.	4 m²	9–74	Romero *et al*. 1989
Santa Catalina, Pichincha (Ecuador)	3058	0	18	11	0	1400	5 m²	12–70 average: 37	Vimos 1987
Llocllapampa, Junin (Peru)	3500	11	n.a.	n.a.	n.a.	n.a.	n.a. cultivar trial	24–74	Figueroa *et al*. 1997
Allpachaka, Ayacucho (Peru)	3500	14	n.a.	11	n.a.	664	88 m²	14–24	Valladolid *et al*. 1976
Condorpaccha, Ayacucho (Peru)	3200–4200	14	16	n.a.	–5 –1	450–600	n.a.	n.a.	Anonymous 1996
K'ayra, Cusco (Peru)	3349	13	19	13	5	792	n.a. cultivar trial	21–50 average: 36 25 cultivars tested	Meza *et al*. 1997
Yunguyo, Puno (Peru)	3835	16	12–14	n.a.	0–4	450–650	n.a.	n.a.	Anonymous 1996
Pocanche, Cochabamba (Bolivia)	3200–3700	17	12–16	n.a	0–8	500–600	Family plots	32	Anonymous 1996
Toralapa, Cochabamba (Bolivia)	3450	17	18	n.a.	2	623	40 m²	36	Valdivia *et al*. 1999
Toralapa, Cochabamba (Bolivia)	3450	17	18	n.a.	2	623	26 m²	33	Quispe *et al*. 1997
Candelaria, Cochabamba (Bolivia)	3200	17	8–12	n.a.	0–6	900–1200	Family plots	16	Anonymous 1996
Lincoln, Canterbury (New Zealand)	10	45	17–22	n.a.	n.a.	666	n.a. research trial	46	Martin *et al*. 1996

n.a.: not available.

are well over 30 t/ha . Single plant yields under favourable conditions can exceed 2 kg of tubers (Fig. 12). Nevertheless, mashua yields at commercial level reach only 5–10 t/ha (Vimos 1987; Romero *et al.* 1989). Harvest time is 6–9 months after planting. The crop is ready to harvest when plants become yellowish or brown, when they lose their lower leaves or, in some cases, when they produce the tubers on the soil surface (Cabrera 1986; Vimos 1987).

Owing to the small size of cultivated areas and predominant intercropping, mashua is harvested manually. The soil is opened using a hoe and tubers are collected in baskets or sacs. Farmers prefer to harvest in dry soil, which falls off the tubers completely and leaves them clean. Mature tubers can be left in the soil for some time before harvest. They will not sprout immediately after the aerial parts have senesced. Once tuber dormancy is over, sprouts emerge from the tuber eyes. Sprouting tubers lose weight and their quality deteriorates rapidly, because of water loss and nutrient translocation to the new tissues.

6.6 Post-harvest

Since mashua is a secondary crop, very little research has been done on post-harvest practices. Standard traditional practices include cleaning the tubers to eliminate soil (if harvested in wet, clayey soil), tuber classification according to size and colour, and the elimination of injured or bruised material. Like other tubers, mashua are often stored in farmhouses. South of central Peru the tubers are commonly held outdoors

Fig. 12. Two freshly harvested mashua plants with senescent aerial parts shown by Ing. Pedro Cruz, Fierroccata, Cusco, Peru, 3500 m altitude (Photo M. Hermann, May 1991).

in heaps, called 'phinas' (Fig. 13), that are covered with a layer of dry ichu grass (*Stipa ichu* (R. & P.) Kunth). This layer is a few centimetres thick, enough to maintain the tubers in darkness and insulate them against night frosts (which are common after the harvest period) and high day temperatures. The temperature variation underneath the cover is small and oscillates minimally around the average ambient temperature, which in the high-altitude location shown in Fig. 13 is probably below 8°C.

Before consumption mashua tubers are exposed to direct sunlight for a few days to improve sweetness and palatability. This practice increases sugar content, probably by inducing starch degradation; it may also reduce isothiocyanates.

Mashua tubers have relatively high hourly respiration rates: 75 mg CO_2/kg of tuber fresh weight 3 hours after harvest and 54 mg CO_2/kg 3 days after harvest, at 20ºC. This is approximately the same as oca and twice as much as potato and yacon stored under the same conditions at 17°C in the shade (Grau 1993).

6.7 Crop ecology

As with most other Andean root and tuber crops, the information on mashua ecology is scarce, and the crop's ecological requirements must be derived from its distributional record. The latitudinal range of mashua cultivation in the Andes is from 8°N to 24°S, and the altitude ranges from 2400 to 4300 m, with the most frequent occurrence between 3000 and 3700 m, where annual mean temperatures are in the range of 8–11°C.

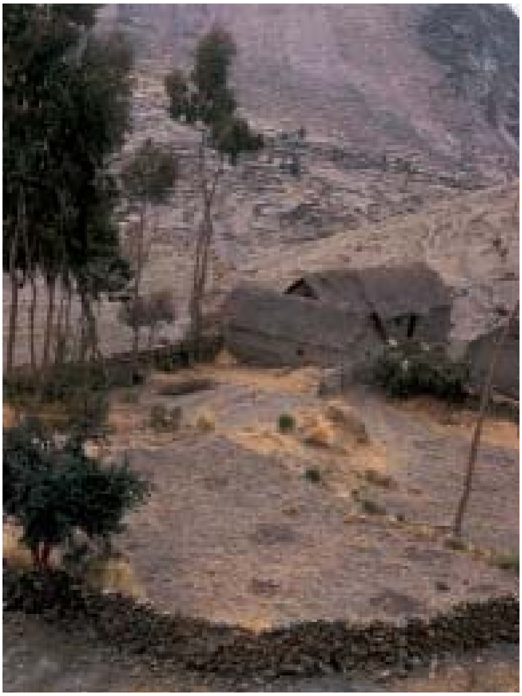

Fig. 13. Farmhouses with 'phina' tuber stores at Accha Alta, Calca Province, Cusco, Peru, at 3900 m altitude (Photo M. Hermann, September 1990).

Morales and Rea (1982) indicate that mashua aerial organs behave similar to those of oca and ulluco in relation to frost, tolerating –1°C, but they are completely destroyed at –5°C. Reports from Romero *et al.* (1989) indicate that at early crop stages mashua is able to recover completely after exposure to –2 to –4°C. Recovery may not be complete at later stages. For instance, Valdivia *et al*. (1999) indicate that a frost event of –3.5°C at Toralapa, Cochabamba, Bolivia, killed aerial plant parts. Above freezing temperatures, mashua tolerates long chilling periods. It is able to tolerate temperatures of 30°C or slightly higher, at least for short periods.

Although mashua is normally grown at high altitude, it is the cool conditions and not altitude *per se* which are required by the plant. Mashua is able to tuberize and produce good crops outdoors at sea level at 46°S in Christchurch, New Zealand (Martin *et al.* 1996) and at 49°N in Vancouver, Canada (Johns and Towers 1981).

In general mashua is not irrigated. However, it has high water requirements and receives between 700 and 1600 mm on most cultivation sites. It tolerates the misty and cloudy weather typical of the eastern Andean ranges, and indeed thrives there, but it also seems capable of tolerating dry spells.

Mashua is a short-day plant, requiring less than 12 hours for tuberization. Razumov (1931) obtained no tubers with 18 hours, while plants exposed to 10-hour or 12-hour days produced tubers. Bukasov (1930) indicates that 9 hours is the optimum day length for tuberization. Under long-day conditions (14–20 hours, in Finland) mashua is unable to tuberize (Kalliola *et al.* 1990). Day length also affects bud number, stem number, leaf size and pigments in stem and leaves. Tuberization in New Zealand at 46ºS begins when day length becomes less than 12 hours. In South Island, New Zealand and Vancouver Island, Canada, tuberization and yield formation are still possible because autumn temperature minima are moderated by maritime influence. Under colder continental conditions crop development is truncated by frost before tuberization occurs. This may explain why there is no report for the successful production of mashua tubers in continental Europe, although the species may have been introduced several times by botanists and hobby gardeners (Bukasov 1930, Kalliola *et al.* 1990).

Apparently, mashua has a wide tolerance to soil pH, growing from 5.3 to 7.5 (National Research Council 1989). However, there has been little systematic research in this area.

7 Composition and uses

7.1 Chemical composition

The water content of mashua tubers is comparatively high, ranging from 79 to 94% in the fresh or edible matter (Table 4). As seen in Table 4, the main nutritional contribution of mashua is its high carbohydrate content, particularly of starch but also of sugars. The protein content of the mashua tuber in the fresh matter approaches potato values, although potatoes are much higher in dry matter content. Amino acid analyses of mashua tuber protein show a satisfactory nutritional composition compared with the WHO recommendations (Shah *et al.* 1993; Stegemann and Shah 1993). These authors also indicate that there is considerable variation between the different clones analysed. The high content of ascorbic acid or vitamin C as determined by Collazos *et al.* (1996) (77.5 mg per 100g fresh matter) is nutritionally also important.

Like other Tropaeolaceae, mashua contains isothiocyanates present as glucosinolates (Kjær *et al.* 1978), compounds similar to those found in other crucifers and also known as mustard oils. Isothiocyanates are well known for their antibiotic, insecticidal, nematocidal and diuretic properties, which substantiates mashua's extensive use in Andean folk medicine (Johns *et al.* 1982). The characteristic piquant flavour of mashua is produced by *p*-methoxybenzyl isothiocyanate. This compound appears to be specific to subspecies *T. tuberosum* ssp. *tuberosum*, which also contains small amounts of 2-propyl isothiocyanate. This compound and 2-butyl isothiocyanate are the main isothiocyanates in subspecies *T. tuberosum* ssp. *silvestre* (Johns and Towers 1981). Thiocyanates liberate cyanide by hydrolysis and could lead to poisoning.

Thiocyanate values higher than 20 mg/100 g are common in uncooked mashua. Dolores and Espín (1997) found values of 23–33 mg/100 g in mashua accessions of the Ecuadorian collection at INIAP.

7.2 Food uses

As explained above, most mashua tuber types contain high levels of isothiocyanates, which give them a pungent taste, and make them unsuitable for raw consumption except in small quantities. Boiling causes the isothiocyanates to hydrolyse, eliminating cyanide and improving taste. Mashua tubers are usually boiled to form a stew with other tubers and meat (Cortés 1981). Mashua can be used as a component in many dishes, ranging from soups and stews to desserts.

The widespread Andean practice of exposing tubers and roots to direct sunlight is also used for mashua, as mentioned above, in order to increase sweetness and reduce cyanide levels before cooking (Dolores and Espín 1997). Another common procedure is baking mashua in the *huatia*, an earthen field oven, which is typically prepared at harvest time from sods or stones. Baked mashua has an aromatic flavour and a mushy texture like that in moist sweet potatoes.

Cárdenas (1989) indicates that in the recent past it was a common practice for the middle class of La Paz, Bolivia, to eat cooked and frozen mashua soaked in sugarcane syrup ('thayacha') during the winter. This is a rare practice today.

Table 4. Chemical composition of mashua tubers per 100 g of edible portion (fresh weight)

Component	Unit	Range*	Average	Source
Moisture	g	79.2–93.8	n.a.	Barrionuevo 1975, Brito and Espín 1999
Raw protein	g	1.1–2.7	1.5	Barrionuevo 1975
Fat	g	n.a.	0.7	Collazos *et al.* 1996
Fiber	g	0.5–1.5	0.9	Barrionuevo 1975
Minerals (ash)	g	0.6–1.1	0.8	Barrionuevo 1975
Total sugars	g	n.a.	3.5	Brito and Espín 1999
Reducing sugars	g	n.a.	2.9	Brito and Espín 1999
Starch	g	7.0–10.5	8.9	Barrionuevo 1975
Food energy	kcal	35–50	n.a.	Collazos *et al.* 1996; Brito and Espín 1999
Calcium	mg	n.a.	12	Collazos *et al.* 1996
Potassium	mg	1.3–1.8	1.5	Barrionuevo 1975
Iron	mg	n.a	1.0	Collazos *et al.* 1996
Phosphorus	mg	0.6–0.8	0.7	Barrionuevo 1975
Vit. A (β-carotene equivalent)	µg	n.a.	10	Collazos *et al.* 1996
Thiamine	mg	n.a.	0.10	Collazos *et al.* 1996
Riboflavin	mg	n.a.	0.12	Collazos *et al.* 1996
Niacin	mg	n.a.	0.67	Collazos *et al.* 1996
Ascorbic acid	mg	n.a.	77.5	Collazos *et al.* 1996
Lysine	mg/g protein	35–69	n.a.	Shah *et al.* 1993, King and Gershoff 1987
Threonine	mg/g protein	22–46	n.a.	King and Gershoff 1987; Shah *et al.* 1993
Valine	mg/g protein	25–88	n.a.	King and Gershoff 1987; Shah *et al.* 1993
Isoleucine	mg/g protein	25–44	n.a.	King and Gershoff 1987; Shah *et al.* 1993
Leucine	mg/g protein	35–56	n.a.	King and Gershoff 1987; Shah *et al.* 1993
Tyrosine	mg/g protein	13–62	n.a.	King and Gershoff 1987; Shah *et al.* 1993
Tryptophan	mg/g protein	5–12	n.a.	King and Gershoff 1987, Gross *et al.* 1989
Cysteine	mg/g protein	1.4–29	n.a.	Gross *et al.* 1989

* Ranges indicate minimum and maximum values provided by either one or several authors, typically working with different cultivars.

The *per capita* consumption of mashua tubers is difficult to assess and its derivation from national production and population figures makes little sense because consumption varies hugely from place to place. In rural areas, where native Amerindian people predominate, consumption can be considerable, especially during and after harvest, when mashua is a frequent side dish or ingredient in main dishes, and weekly *per capita* consumption may be well over 1 kg. However, consumption is limited by the seasonal availability of tubers.

Mashua flowers can be consumed fresh in salads, and flower buds can be consumed pickled in vinegar in a similar way to capers (King 1987).

7.3 Feed uses

Peasants in Ecuador (Tapia *et al*. 1996) and in the Candelaria area, Cochabamba, Bolivia (Terrazas and Valdivia 1998), feed mashua tubers to pigs. Few studies have been published on the use of mashua tubers as feed, but this use is presumably much more widespread than the reports suggest. The first research trial was apparently conducted by Bateman (1961) in Costa Rica. According to this author raw mashua plus skimmed milk and grains performed better than grains alone, and acceptability of mashua was considerably improved by cooking. Similar results were obtained by Ramos *et al*. (1976) in a more comprehensive experiment comparing a standard ration (barley, oats (*Avena sativa* L.), maize, cotton paste, hay and milk) and a ration in which the cereals and cotton had been replaced by cooked mashua. They concluded that the increase of weight in calves fed with mashua did not differ significantly from that of the control, and that including mashua in the diet was a cheaper alternative. They suggested that cooked mashua can be replaced by raw mashua, to feed animals over 12 months of age

However, there is evidence indicating that raw mashua can be toxic. One of us observed a donkey in San Juan, Chimborazo, Ecuador, dying immediately after ingesting a portion of fresh mashua tubers (Nieto 1988, personal observation). Lethal effects of mashua intake on donkeys or mules have also been reported during ethnobotanical field work in Pisac, Cusco (King 1988), and in Colanzulí, Salta, northern Argentina (Hermann 1992, personal observation). Presumably, cultivars producing such effects contain high levels of isothiocyanide.

There are no reports of aerial parts being used as forage, which is somewhat surprising, because mashua produces much above-ground biomass. This may be partly explained by the presence of the same antinutritional substances that accumulate in the tubers. Salcedo (1986) indicates that 'stems and leaves are as poisonous as tubers'. There is no information on hay production or silage, treatments that may reduce or eliminate isothiocyanates.

7.4 Flour and starch

Information on mashua processing into flour and on starch properties is limited. The first published report on mashua flour production indicates disappointing results. Processing yielded a piquant and strongly smelling product with a yellow greyish colour, not suitable for human consumption (Deza 1977; Cortés *et al.* 1982). Recent studies (Ramallo 1999) suggest that mashua flour could be an interesting alternative as pig feed. Mashua flour has an acceptable protein (8%) and high energy content (416 kcal/100 g). Protein levels are similar to those of maize but energy content is 30% higher (Ramallo 1999). The high water content of mashua, however, implies relatively high drying costs.

Although production of flour for human consumption still has technical problems to be solved, mashua starch has interesting characteristics. Compared to potato, ulluco, oca, achira (*Canna indica* L.), maize, rice and manioc (*Manihot esculenta* Crantz), mashua and arracacha (*Arracacia xanthorrhiza* Bancroft) starch gels are the most resistant to freezing (minimal syneresis), after 4 weeks at –20ºC (Dufour *et al.* 1997). However, these results are partially contradicted by Villacrés and Espín (1996), who found high syneresis values after a freeze–thaw cycle. These authors also found that gelatinization temperature of mashua starch (60°C) is similar to that of oca starch (60°C) and ulluco starch (63°C), and higher than that of potato starch (55°C). A factor making mashua starch use economically unfeasible would be its very low extraction yield—2.3 %, according to Villacrés and Espín (1996). However, starch recovery rates reported by these authors for a number of tuber species appear to be unreasonably low. Mashua starch granules are small, with an average size of 8.8 µm (Cortella and Pochettino 1995) to 15.6 µm (Villacrés and Espín 1996).

7.5 Medicinal uses

> *'. . . llamada añus. Dizen los indios que comida es contraria a la potencia generativa; para que no les hiziesse daño, los que se preciavan de galanes tomavan en la una mano una varilla o un palillo mientras la comían, y comida assí dezían que perdía su virtud y no dañava. Yo les oí la razón y algunas vezes vi el hecho, aunque davan a entender que lo hazían más por vía de donaire que no por dar crédito a la burlería de sus mayores'*[1]
>
> Garcilaso de la Vega, writing in the sixteenth century in his 'Comentarios Reales', in reference to folk beliefs of antiaphrodisiac properties of mashua in what is today Peru (as quoted in Patiño 1964).

Mashua diets are reputed to have beneficial effects on liver and kidneys (Hodge 1946; Oblitas 1969) and to alleviate prostate and urinary disorders (Salcedo 1986;

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[1] 'It is called *añus*; and the Indians say that it reduces the procreative powers, but in order to prevent it from harming them, those who prided themselves on their gallantry used to hold a little rod or stick in one hand while they ate it, saying that in this way it lost its peculiar property and did them no harm. I heard them give this explanation and often saw them do this, though they implied that it was intended rather as a joke than as a serious acceptance of the foolish tradition of their elders.' (Translation taken from Garcilaso de la Vega (1966)).

Brack 1999). In Bolivia mashua is still used in treating prostate ailments and is sold in small quantities in urban areas (Terrazas and Valdivia 1998). Bateman (1961) indicates that mashua fed to pigs seemed to have a diuretic effect. This is consistent with similar effects on humans as recognized by Andean folk medicine (Cárdenas 1948, 1958; Brack 1999).

Rea (1984) reported the use of mashua by people with diabetes, using both the cooked tubers and water in which they were boiled. In their catalogue of Ecuadorian mashua germplasm Tapia *et al*. (1996) list several accessions with collector information on medicinal uses for the treatment of tonsillitis, dengue and malaria fever, and postpartum conditions. Pérez Arbelaez (1947) indicates that mashua is useful for the treatment of skin ailments, such as eczema and 'skin spots'. The same dermatological properties are attributed to kita-añu (*T. tuberosum* ssp. *silvestre*) (Herrera 1921). Without specifying used plant parts, Oblitas (1969) indicates that mashua is used as vermifuge and 'to induce menstruation'.

Among its numerous reputed medicinal effects, mashua is best known in the Andes for its alleged capacity to suppress sexual appetite and decrease reproductive potential and erectile function in men (Herrera 1933; Hodge 1951; Leon 1967; Oblitas 1969; Brack 1999). According to traditions recorded by the sixteenth century chroniclers, the Inca fed mashua to their troops 'so that they would forget their women' while on military operations (Patiño 1964, citing Padre Bernabé Cobo). With similar intentions, rural women in Cusco today prepare concoctions from mashua and add these surreptitiously to their men's food, in the hope of preventing them from becoming unfaithful (Hermann 1992). Johns *et al.* (1982), who review such folk beliefs, showed experimentally that they are perhaps not unsubstantiated. Male rats fed with mashua tubers had significantly reduced testosterone and dihydrotestosterone levels (45%). However, test animals maintained their capability to impregnate females.

Hormonal effects may also be responsible for the reputed effects on menstruation. Johns *et al*. (1982) failed to find any oestrogenic activity in guinea-pigs. However, their results indicate that *N*,*N*-di-(methoxy-4-benzil)thiourea present in mashua can competitively inhibit radioactively marked estradiol using a preparation of estrogen receptor in calf uterine cytosol, suggesting that mashua may still have estrogenic activity.

Considering the hormonal effects of mashua in rats, and its range of active substances, it would not be surprising if these attributes were found to be the basis for some of the reputed medicinal properties. However the experimental background is still limited to the work of Johns and co-workers (1981, 1982).

8 Taxonomy and biosystematics

8.1 Taxonomic history and synonyms

The Tropaeolaceae is a small and quite homogeneous family of herbaceous, mostly climbing species. The family includes three genera, with two of them, *Trophaeastrum* Sparre and *Magallana* Cav., restricted to Patagonia. The largest genus is *Tropaeolum*, which contains 86 species, distributed from southern Mexico throughout South America (Sparre and Andersson 1991).

The tuber forming capacity is present in all genera of the family. Species that have been positively identified as tuber forming are listed in Table 5. The list may not be complete, as in many cases Sparre and Andersson (1991) report 'subterranean parts not seen, probably tuberous'. *Trophaeastrum patagonicum* (Speg.) Sparre yields white edible tubers that can reach a length of 10 cm. These tubers were used by several Patagonian tribes, baked or boiled with milk (Martínez Crovetto 1982). There

Table 5. Tuber-forming species in the Tropaeolaceae (after Sparre and Andersson 1991)

Species	Distribution
Magallana porifolia	Patagonia
M. trialata	Northern Patagonia
Tropaeolum rhomboideum *	Chile
T. azureum *	Chile
T beuthii *	Chile
T. brachyceras *	Chile
T. ciliatum *	Chile
T. hookerianum *	Chile
T. leptophyllum ssp.	Chile, Argentina
Leptophyllum = T. edule *	
T. pentaphyllum †	Central Argentina, Southern Brazil, Uruguay
T. polyphyllum *	Chile, Argentina
T. sessilifolium *	Chile
T. tricolor *	Chile
T. umbellatum ‡	Southern Ecuador
T. patagonicum = T. patagonicum	Patagonia

* Section Chilensia; † Section Chymocarpus; ‡ Section Umbellata.

are also reports of *T. leptophyllum* G. Don being eaten by Chilean indigenous people in times of scarcity (Bridges 1842).

Tropaeolum L. was referred to originally as *Cardamindum* Adans. Linnaeus (1735) introduced the name *Trophaeum* (= trophy), because of the flowers resembling a warrior's helmet and leaves resembling shields; he later changed the name to *Tropaeolum*, using the original Greek word 'trópaion', which has the same meaning.

Tropaeolum tuberosum was described by Ruíz and Pavón (1802) in their magnificent work 'Flora Peruviana et Chilensis', in which for the first time they gave an original, detailed and illustrated (Plates CCCXIII, CCCXIV) account of the species (Fig. 3).

Synonyms of *T. tuberosum* are *T. mucronatum* Meyen, *T. suberosum* Walpers (1857) and *T. denticulatum* (Kuntze 1891). Heynhold (1840) proposed to transfer the species to a different genus as *Chymocarpus tuberosus* (Ruíz & Pav.) Heynh.

Bukasov (1930) proposed the name *T. cubio* for the mashua forms found in Colombia, which he considered taxonomically distinct from those cultivated in Ecuador, Peru and Bolivia. Sparre and Andersson (1991) dismissed this proposal, indicating that the features pointed out by Bukasov are of little taxonomic value.

The only other widely cultivated *Tropaeolum* species is *T. majus* L., the garden nasturtium, which is a popular ornamental in temperate areas.

8.2 Wild species closely related to cultigen

T. tuberosum has been placed within the section *Mucronata* by Sparre (1973). This section includes five well-defined species, of which *T. longiflorum* Killip, *T. crenatiflorum* Hook. and *T. purpureum* are endemic to Peru; *T. cochabambae* Buchenav. occurs in Peru and Bolivia. All species within the section, except *T. tuberosum*, have relatively reduced geographic ranges.

Sparre (1973) and Sparre and Andersson (1991) recognize two subspecies of *T. tuberosum*; the cultivated *T. tuberosum* ssp. *tuberosum* and the wild *T. tuberosum* ssp. *silvestre*, with the latter being smaller and more slender in all parts (Fig. 14).

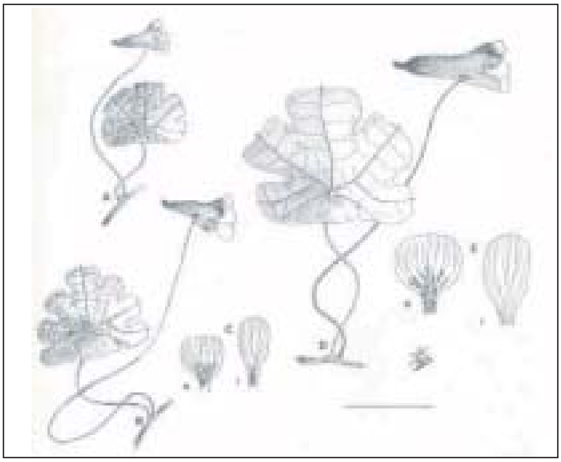

Fig.14. A–C: Wild mashua (*Tropaeolum tuberosum* ssp. *silvestre*). D–E: Cultivated mashua (*Tropaeolum tuberosum* ssp. *tuberosum*). C, E: Petals: i, inferior petal; s, superior petal. Scale A, B, D, 3 cm; C, E, 1 cm (Reproduced from Sparre and Andersson 1991, p. 53, with permission from the Nordic Journal of Botany/Opera Botanica).

According to Sparre and Andersson (1991), the only consistent character to differentiate both subspecies is the lack of tubers in *T. tuberosum* ssp. *silvestre*. This appears to be a questionable distinction, for the authors state that the presence or absence of tubers 'can usually not be ascertained in herbarium material' of *T. tuberosum*. Moreover, the authors' classification does not accommodate clearly wild but tuberous *T. tuberosum*, such as the 'kipa isaño' used by Johns and Towers (1981) and material known to the authors of this monograph from Paruro Province, Cusco, Peru. This material has elongated and twisted tubers, a feature retained in cultivation and setting this species apart from the domesticate (Fig. 15). Ortega (2000) in his thesis on 'noncultivated' mashua pictures over a dozen accessions with similar tuber shapes, predominantly collected in Cusco's Calca and Paucartambo provinces. Notably, the same author reports the frequent occurrence of escaped mashua cultivars that could be mistaken by the collecting botanist for wild *Tropaeolum* species.

Nevertheless, phytochemical analyses of isothiocyanates by Kjær *et al*. (1978) and Johns and Towers (1981) support the assessment of two subspecies in *T. tuberosum*: cultivated mashua and a tuber-bearing wild species, referred to by these authors as *T. tuberosum* ssp. *silvestre*. Mashua produces *p*-methoxybenzyl isothiocyanate, whereas the wild material is characterized by benzyl-2-propyl isothiocyanate and 2-butyl isothiocyanate.

Fig. 15. Tubers of wild mashua from Paruro Province, Cusco, Peru. (Material shown is from cultivation in a field genebank near Cusco, 3500 m alt; planted October 1990, harvested May 1991, Photo M. Hermann).

Both wild and cultivated *T. tuberosum* extend from Venezuela to northwest Argentina along an impressive latitudinal gradient (Fig. 16). Sparre and Andersson (1991) show two areas of high concentration of ssp. *silvestre*, one in northern Peru and a larger one in Ecuador. However, Hermann (field observations) found wild mashua with sizeable tubers in Peru, Bolivia and Argentina, but not in Ecuador or Colombia. To accommodate the different observations within a model it seems necessary to consider the presence of wild *T. tuberosum* and plants escaped from culture overlapping at least partially along a wide range.

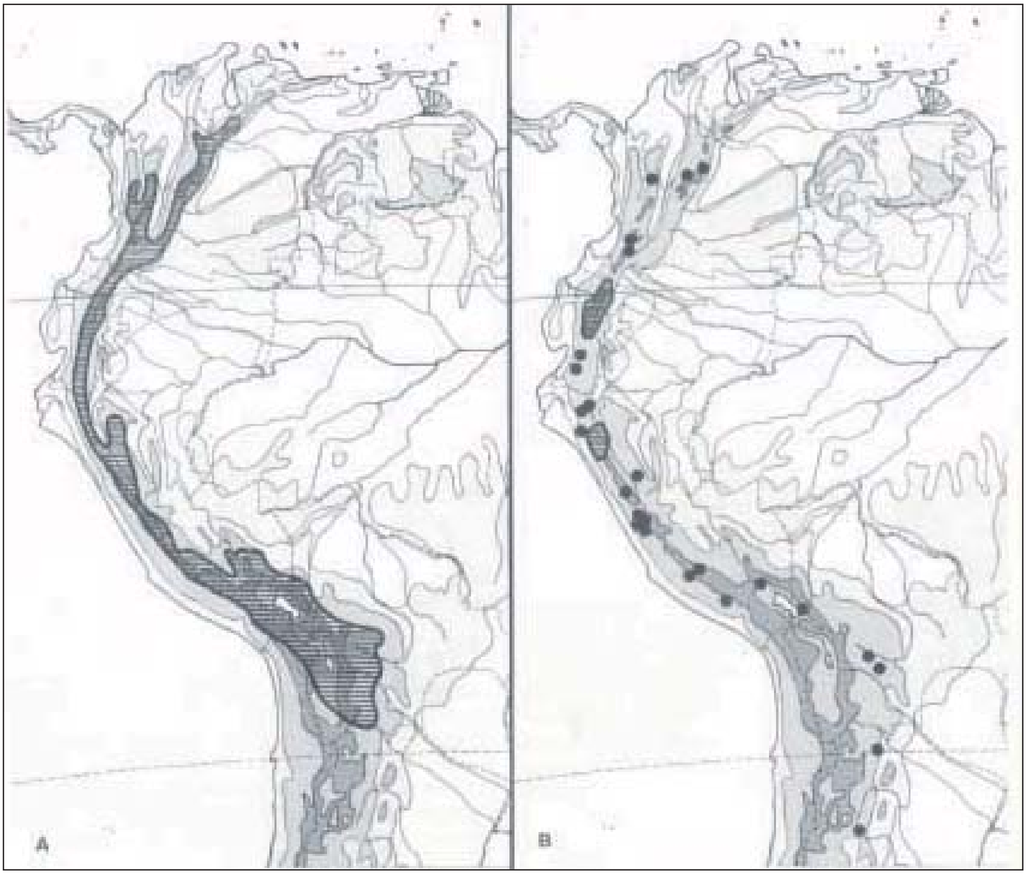

Fig. 16. Distribution of (A) cultivated mashua (*Tropaeolum tuberosum* ssp. *tuberosum*) and (B) wild mashua (*T. tuberosum* ssp. *silvestre*) (Reproduced from Sparre and Andersson 1991, p. 54, with permission from the Nordic Journal of Botany/Opera Botanica).

9 Genetic resources

9.1 Chromosomal variation

Chromosome studies of mashua have shown contradictory results (Table 6). The presence of two subspecies, high ploidy levels, hybridization, and sexual and asexual reproduction, are the likely factors that contribute to a blurred picture. Huynh (1967), Gibbs *et al*. (1978) and Johns and Towers (1981) have reported a sporophytic number of $2n = 52$ for *T. tuberosum* ssp. *tuberosum*. However, Gibbs *et al.* (1978) also propose $2n$: 43, 48, 51 and 64 as less frequent values emerging from abnormal meiotic configurations. Johns and Towers indicate $2n = 42$ for subspecies *silvestre*. Huynh (1967) and Gibbs *et al.* (1978) propose that mashua is of autopolyploid origin, on the basis of the frequent formation of multivalent and secondary associations during meiosis. However, Gibbs and co-workers do not rule out segmental allopolyploidy with a closely related species, such as *T. cochabambae*.

Table 6. Chromosome numbers of *Tropaeolum* species

Species	2*n*	Cultivated/ Wild	Source
T. canariense	28	n.a.	Heitz 1926*
T. cochabambae	26	n.a.	Huynh 1967
T. majus	28	n.a.	Sugiura 1925*
T. minus	28	n.a.	Heitz 1926*
T. peltophorum	28	n.a.	Sugiura 1925*
T. peregrinum	24, 26–30	n.a.	Warburg 1938*
T. pubescens	28	n.a.	Huynh 1967
T. tricolor	52	n.a.	Huynh 1967
T. tuberosum	42	n.a.	Sugiura 1925*
T. tuberosum	42	n.a.	Acosta Solís 1980
T. tuberosum	48	Cultivated?	Marks 1976†
T. tuberosum ssp. *tuberosum*	52, 64, 51, 48, 43	Cultivated	Gibbs *et al*. 1978
T. tuberosum ssp. *silvestre*	42	Wild	Johns and Towers 1981
T. tuberosum ssp. *tuberosum*	52	Cultivated	Johns and Towers 1981
T. tuberosum ssp. *tuberosum*	18, 27, 36	Cultivated	Román and García 1997

* Cited by Darlington and Ammal 1945; † cited by Gibbs *et al*. 1978.

Hybridization between species has been observed in several other cases in the Tropaeolaceae (Sparre and Andersson 1991). Combining phytochemical and chromosomal information, Johns and Towers (1981) reinforce this hypothesis. They maintain that *T. tuberosum* ssp. *tuberosum* is of allopolyploid origin and resulted from the hybridization of *T. tuberosum* ssp. *silvestre* with another *Tropaeolum* species of $2n = 26$, probably *T. cochabambae*. Nevertheless these authors analysed a relatively narrow sample of *T. tuberosum* germplasm. Recent findings by Román and García (1997) working with 20 Peruvian accessions of cultivated mashua indicate different ploidy levels, $2n = 18$, 27 and 36, with a basic number of $x = 9$, and thus have added further complexity to the issue. To shed more light on this complex picture a more comprehensive study is warranted, including a range of accessions of both subspecies along the whole latitudinal gradient.

9.2 Molecular variation

Some variation has been detected at the molecular level in different mashua clones. Shah *et al.* (1993) studied the protein patterns in mashua tubers using polyacrylamide gel electrophoresis (PAGE). They found that porosity gradient PAGE was the most suitable method for discriminating varieties, and SDS disk PAGE was the least suitable. The main protein bands in mashua are located in the 43–110 kD range. Monteros *et al.* (1997) found variation for phosphoglucomutase and malate dehydrogenase and were able to classify the INIAP mashua collection in 10 groups using this isoenzymatic information.

9.3 Genetic erosion, germplasm collection and genebank holdings

There is general agreement that mashua has suffered a progressive reduction in its production and consumption, particularly during the last decades of the twentieth century. However, there has been no systematic evaluation of that process and there is no quantitative information on its present status.

Efforts to safeguard genetic resources of mashua and other Andean roots and tubers began relatively early in the Andean countries. The first record of mashua accessions being maintained date from 1958 (Holle 1986). In Peru, the first collecting activities are documented in the 1970s. However, mashua *ex situ* conservation gained momentum during the 1980s. At present Peru maintains the largest number of holdings and the largest number of accessions (Table 7). In Ecuador, collecting and conservation efforts have been spearheaded by INIAP, at the Santa Catalina research station, which also holds a few accessions from Colombia (Tapia *et al.* 1996).

The initiative of the Collaborative Program of Andean Root and Tuber Crop Diversity funded by the Swiss Development Cooperation and implemented by CIP and numerous national programmes ensured that exploration and collecting activities continued in Bolivia, Ecuador and Peru during the period 1993–1997.

In conclusion, large areas of the Andean countries have been covered by collecting missions. As seen in the plot of mashua genebank accessions reported

Table 7. Mashua holdings reported for Bolivia, Ecuador and Peru

Organization	Number of accessions	Report year	Source
Bolivia			
IBTA	110	1980	Holle 1986
IBTA	131	1983	Holle 1986
IBTA-PROINPA	71	1995	Ugarte 1995
Ecuador			
Santa Catalina, INIAP-DENAREF	43	1985	Holle 1986
Santa Catalina, INIAP-DENAREF	36	1986	Holle 1986
Santa Catalina, INIAP-DENAREF	89	1996	Tapia *et al*. 1996
Peru			
Camacani, Puno	19	1981	Holle 1986
Camacani, Puno	28	1986	Holle 1986
University of Puno	47	1995	Velazco 1995
Ayacucho University	78	1979	Holle 1986
Ayacucho University	94	1983	Holle 1986
Ayacucho University	146	1986	Holle 1986
Ayacucho University	14	1995	Anonymous 1995a
Ayacucho University	10 (*in vitro*)	1995	Anonymous 1995a
INIA Ayacucho	68	1995	Anonymous 1995a
University of Cajamarca	7	1995	Velazco 1995
INIA Cajamarca	103	1995	Velazco 1995
INIA Huanuco	22	1995	Velazco 1995
University of Huanuco	50	1995	Velazco 1995
INIA Huancayo	125	1995	Velazco 1995
Kayra Research Station	101	1986	Holle 1986
INIA Cusco	14	1995	Velazco 1995
University of Cusco	302	1995	Velazco 1995
University of Pasco	35	1995	Velazco 1995
University of San Marcos	48 (*in vitro*)	1986	Holle 1986
University of San Marcos	112 (*in vitro*)	1995	Velazco 1995
Experimental Station La Molina	151	1986	Holle 1986
University of La Molina	65	1995	Velazco 1995
CIP	119*	2002	CIP corporate databases

* 55 of these accessions are FAO designated.

from 1986 to 1998 (Fig. 17), there are several distributional discontinuities within the species range from Colombia to northern Argentina. Mashua appears to be absent from large areas of the Colombian highlands, except for Boyacá where mashua consumption and market presence is atypically high, with no obvious explanation for this phenomenon. Mashua also seems to be absent in Peru north of Cajamarca and in Loja, Ecuador, perhaps because of the low altitude of the Andes there and the lack of contiguous paramo environments suitable for mashua cultivation. Finally, there are no genebank records of mashua accessions collected in the inhospitably dry southern Altiplano in Bolivia. It is important to note that not all reported accessions, perhaps only a fraction of the total ever collected, are actually available from genebanks. This is mainly due to the fact that large numbers of accessions were lost from field genebanks in the 1980s and early 1990s.

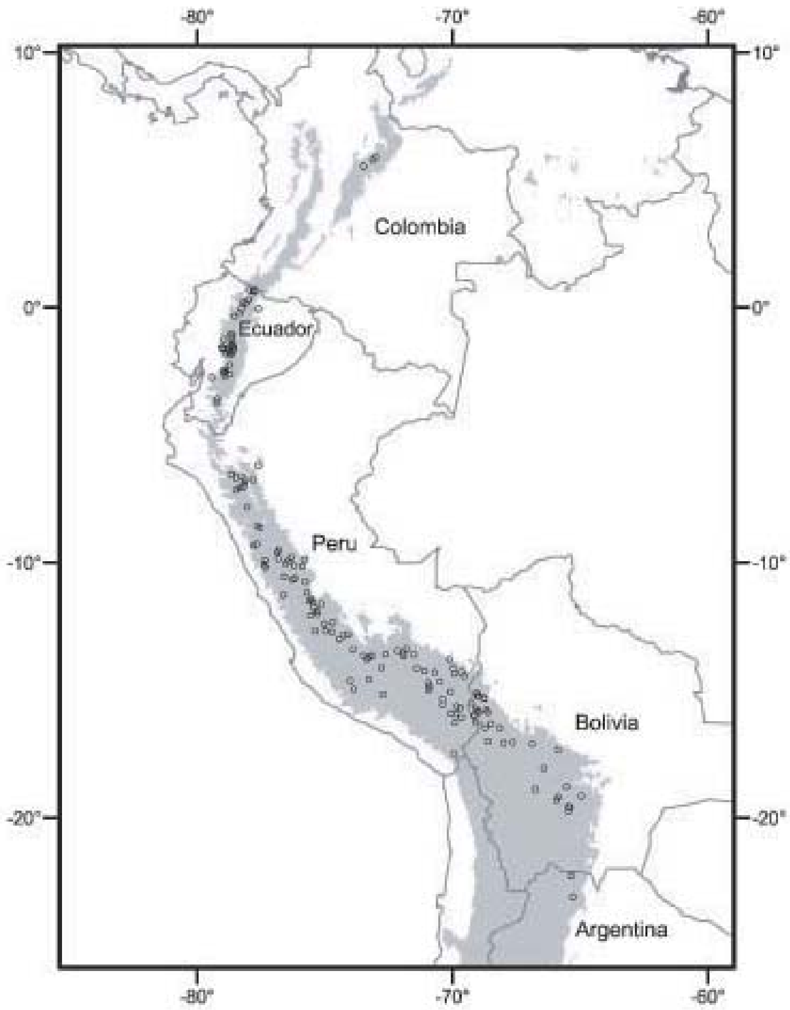

Fig. 17. Distribution of cultivated mashua (dots represent collecting sites of genebank accessions reported from 1986 to 1998, source: CIP databases; shaded area is over 2000 m above sea level).

In situ conservation has been proposed as a strategy to complement genebanks and *ex situ* conservation (for a review see Maxted *et al.* 1997, Ortega 1997). The concept of *in situ* conservation has become fashionable and often a political issue. In the case of mashua *in situ* and *ex situ* conservation should complement each other. However, at present a systematic framework for *in situ* conservation is largely lacking. As in the case of most other crops, on-farm maintenance of mashua germplasm by farmers just happens as a normal part of farming practice (Fig. 18).

9.4 Maintenance of the collections and conservation strategies

Conservation of genebank holdings has been considered difficult to some extent. This is because mashua needs to be replanted and harvested in field collections every cropping season. This (clonal) conservation method is not only labour-intensive, but can also be unsafe, because of the associated risks posed by pathogens, weather conditions or poor management practices.

Micropropagation of mashua as plantlets grown *in vitro* using modified Murashige and Skoog media (MS 4.6 g, AG3 0.25 ppm, sucrose 3%, agar 0.8%) as first reported by Castillo (1991) is now widely practised to maintain clonal collections under sterile conditions. A comprehensive study including protocols for callus and

Fig.18. Germplasm collectors examining mashua on-farm diversity at Ajchahuata, Calca Province, Peru, 3700 m altitude (Photo M. Hermann, September 1990).

meristem culture, micropropagation by multiple shoot formation and nodal cuttings has been published by Torres *et al.* (1992).

Conservation in genebanks as seed could be a less expensive and safer alternative for germplasm conservation, as mashua produces sexual seeds that are easy to collect and to store. However, more research is needed, in relation to the segregation of seed progeny, seed physiology, storage conditions, longevity and germination conditions (see Section 5.3). As far as we are aware, sexual mashua seed is currently not used for mashua conservation, which entirely relies on clonal maintenance in field collections and, to a lesser extent, on tissue culture.

No protocols are currently available for pollen storage and cryopreservation of mashua.

10 Crop limitations

Pests and diseases do not seem to pose significant constraints to mashua culture. The main limitation appears to be the low acceptance outside family or local consumption. Urban demand for mashua is far below that for ulluco and oca, as evidenced by the marginal presence of mashua in markets. The flavour of some mashua lines is so strong that it deters potential consumers, even those used to spicy foods and eager to try 'novel' foods. The shelf life of mashua is short as the tubers lose water rapidly under the prevailing (rustic) storage conditions and deteriorate within weeks after harvest, yielding a product with little or no market value. Some cultivars do not tolerate storage at all: almost immediately after harvest, the tubers of such cultivars sprout or rapidly rot, especially if they have been damaged during harvest or transport. In summary, the main limitations for expanded use of mashua at the present relate essentially to demand, marketing and post-harvest aspects, not to production.

11 Breeding

Several potentially high-yielding clones have been identified in Ecuador (Vimos 1987, 1989; Romero *et al.* 1989; Monteros 1996), and these could be used to increase the fresh tuber yields. Similarly, clones already identified for high protein content or low isothiocyanate content should be used in breeding programmes.

Rea (1984) mentions the selection of high-protein mashua clones from plants reproduced sexually. Some clones already identified by high protein content are:

- Asuti from Huancavelica, Peru, with 17% protein (on a dry matter basis)
- IBTA 3132, also from Huancavelica, Peru, with 16% protein
- Amarillo, from Italaque, Bolivia, with 15% protein
- the ornamental clone Pajarillo, from Puno, Peru, with 11% protein.

However, Rea suggests that the 'bitterness' trait (high levels of isothiocyanate) in mashua may be associated with higher protein content. Thus, selecting for high protein may reduce palatability but simultaneously increase tolerance to pests and diseases.

Some potentially useful correlations have already been established in mashua. Yield is correlated with size of tubers, number of tubers per plant, plant height and crop duration. It seems that clones with black tubers are higher yielding than clones with yellow or white tubers (Vimos 1987; Romero *et al.* 1989). Yield is not associated with stem width, stem number and tuber length (Delgado 1978a, 1978b). In any case, because mashua produces sexual seeds, crosses between different clones are possible. Although seed germination in mashua is low, breeding programs by hybridization should be an easy way to increase variation and to select clones with desired characters.

12 Prospects and research needs

12.1 Advantageous features of mashua

Mashua has many attractive features, actual or potential:

- high productivity, in terms of tuber fresh and dry weight
- high pest and disease tolerance
- good ground cover and prevention of erosion
- feed potential for tubers and aerial parts
- adaptation to chilling temperatures and poor soils
- reasonably good post-harvest life, if managed properly
- medicinal properties
- potential as bioinsecticide
- potential as an ornamental.

12.2 Development objectives and research needs

Subsistence Andean farmers need to maintain mashua's good characteristics, such as rusticity, high tolerance to pests and growth habit, while improving palatability and post-harvest life. However, improving the palatability of mashua for both humans and domestic animals would mean reducing the isothiocyanate content, and this may reduce its capacity to resist pests and diseases. Developing mashua as a commodity for city consumption will require focusing on external aspect, colour and shape, palatability and post-harvest life, and may require a trade-off with maintaining pest tolerance and rusticity.

Mashua has attracted some research attention in recent years. Nevertheless, it is the least well known of the Andean tubers. Several research areas and specific activities can be suggested:

- Mashua's reputed medicinal properties deserve more attention. In the same way that 'aphrodisiac' properties have been a key element of the recent success of maca (*Lepidium meyenii* Walpers), reputed libido-reducing properties may be responsible for the failure of mashua. No research has been conducted in this field since the pioneering work of Johns *et al*. (1982). It is essential to quantify the effect of mashua diets in humans, especially in the long term. Similar attention needs to be paid to all the reputed medicinal properties of mashua.
- If substantiated, mashua's libido-reducing property may be an attribute of economic interest for the formulation of animal feed, in order to reduce sexual drive and accelerate growth and weight gain.
- Some research has been conducted on the use of mashua tubers for feed, but more detailed information is needed to promote its use, and to assess safe intake levels. The chemical composition and nutritional properties of the aerial parts of the plant is poorly known, as is the potential for silage production that may reduce or eliminate isothiocyanates.
- Sound dietary information of the tubers may be one of the elements required to overcome lack of market demand in the cities, particularly by social groups with

higher purchasing power. The development of city markets would also require the development of post-harvest technologies and associated information on tuber physiology. Mashua starch may have some interesting properties, but more information is required to evaluate if it is sufficiently attractive to succeed in the competitive starch market. Processing technologies focusing on pickling and canning, pigment and texture preservation need experimentation.

- Although mashua appears to be highly tolerant to a range of pests and diseases, recent studies have shown that there is a range of potentially harmful pathogens. It is necessary to evaluate whether mashua's apparent tolerance will remain intact if it is cultivated on a larger scale, and if it could still be produced as an essentially 'organic' crop as is currently the case.
- The extent to which mashua is affected by virus disease should be quantified under field conditions, and the advantages of using virus-free material need to be assessed. Fungal diseases also require consideration, particularly those affecting mashua after harvest.
- Although little is known about mashua's floral biology and its crossability with wild species and other *Tropaeolum* species, the crossability observed in other *Tropaeolum* species provides pointers for the potential ease of mashua breeding. Studies on pollen viability and longevity, seed viability, germination, dormancy and longevity need to be conducted.
- The present germplasm collections probably contain a representative sample of the variability available. Field collecting should continue, especially in Colombia and southern Bolivia, which are the least explored areas. Wild *T. tuberosum* and related wild species have received only limited attention so far. All species of section Mucronata of *Tropaeolum tuberosum* and the closely related *T. umbellatum* should be the first targets. *T. umbellatum*, with tubers reputedly reaching 3–4 pounds per plant (Sparre and Andersson 1991), was last collected in its native Ecuador in the nineteenth century, and may be on the brink of extinction, if not extinct already. Section *Chilensia* of *Tropaeolum*, with most members producing tubers, also deserves attention.
- In spite of several chromosomal studies, mashua cytology still requires clarification. A comprehensive chromosomal study is necessary, including a range of accessions of both subspecies along the whole latitudinal gradient. Chromosomal studies should be combined with molecular analysis of the different mashua morphotypes in order to understand their relationships. This analysis should be extended to other relevant wild species.
- The taxonomic revision of the genus by Sparre and Andersson (1991) using conventional tools is sound and comprehensive. However, numerical and molecular analysis would certainly add a quantitative dimension to the relationships between the different species and help to identify 'wild' mashua types as members of subspecies *silvestre* or as escapes from culture.
- A separate aspect would be the development of mashua as an ornamental. It is an exceptionally beautiful species. Nasturtium (*T. majus*) and *Tropaeolum* hybrids

already have a place as ornamentals worldwide. Mashua would add the advantages of asexual propagation, as begonias and lilies do, to nasturtium beauty. Beckett (1979) describes its use in Britain. A place in the home garden, as an ornamental edible plant may be a way to introduce mashua to a wider public.

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Institutions maintaining germplasm collections

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