
Arracacha

(*Arracacia xanthorrhiza* Bancroft)

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1 Introduction

Arracacha (*Arracacia xanthorrhiza* Bancroft) is the only umbellifer domesticated in South America and still largely confined to that continent in its distribution. There are numerous domesticated umbellifers from Eurasia, many of which form edible roots or other subterraneous storage organs, such as parsnip, parsley, carrot and celeriac. All these cultigens and the vast majority of other umbelliferous crops from the Old World are biennials and seed-propagated. Most remarkably, cultivated arracacha is a vegetatively propagated perennial. The recent discovery of wild *Arracacia xanthorrhiza* populations with tuberous storage roots could shed light on an old discussion of the origin of agriculture or, more specifically, on the reasons for the preponderance of vegetative propagation in South American crops as opposed to seed-based agriculture in the Old World (Hawkes 1969). Evidence for both biennial (in Peru) and perennial wild arracacha (in Ecuador) will be presented in this paper for the first time. If the hypothesis that both forms occur over larger areas in the Andes can be confirmed, an interesting question arises: Why did early people in the Andes domesticate the perennial form and not the biennial, seed-propagating one?

There are several reasons to consider arracacha the most promising crop among the nine minor Andean root and tuber species. Not only does arracacha have the widest range of culinary uses but it also appears to be free from undesirable substances that seem to limit the acceptability of oca (oxalates), ulluco (mucilage), mashua (isothiocyanates) and mauka (astringent principles). Arracacha adds an interesting texture and flavour to a variety of dishes and it seems to be much less of an acquired taste than other Andean roots and tubers. Little arracacha is currently being processed, but various processed arracacha products have received praise for their quality. Undoubtedly, versatility in processing will be instrumental in promoting arracacha for urban consumption.

As opposed to high-altitude species (oca, ulluco, mashua, maca) with their narrow ecological range and short-day requirements for tuber formation, arracacha adapts to a wide range of mesothermic and tropical highland environments as well as daylength regimes, although the environmental plasticity of the crop does not match that of achira (*Canna edulis*). Another comparative advantage of arracacha is the fact that the propagule is derived from aboveground plant parts. The economic product - the storage roots - can therefore be marketed entirely and no part of it needs to be reserved as seed for the next crop. Diseases and pests, though, can become a problem, certainly more so than in other ARTC. Many diseases and pests that afflict arracacha, however, can be controlled by long rotations and integrated management practices.

Arracacha is essentially a starchy food and its utilization is intimately related to its elevated starch content. Arracacha can, however, be recommended for human nutrition also on the grounds of other nutrients, namely P-carotene, ascorbic acid and calcium, the daily requirements of which are contained in comparatively small portions. In cuisine, this fine vegetable has versatile uses and adds diversity to poor and rich people's diet alike, but it is not a staple food as is occasionally stated. The

average per capita consumption of this root rarely exceeds 10 kg per year. From information presented in the next section, which will analyze the status of arracacha use across growing regions, we can conclude that arracacha is a secondary food item for some 80 to 100 million people. With this figure in mind, and in view of the eminent commercial role of arracacha in major producing countries, it becomes clear that it is far more important economically than other Andean roots and tubers. Their combined value is probably exceeded by arracacha alone.

Although it is little known that arracacha was introduced to Brazil, in the southern states of this country it now probably covers a larger area than in any Andean country. Not only is the crop expanding into areas in Brazil where it was previously unknown or thought to be poorly adapted, there is also considerable and rising interest in arracacha on the part of industrial processors, extensionists, researchers and, notably, small farmers who value the crop's low-input requirements. The clearest indication of the high interest in arracacha in Brazil is the comparatively large body of literature on the crop in Portuguese. An exhaustive bibliography, the result of many years of searching of arracacha literature, including theses, reports and other unpublished material, yielded 274 titles, of which 186 were in Portuguese, 53 in Spanish, 33 in English and two in French (Santos and Spina 1994). The literature in Portuguese deals extensively with crop husbandry and related themes, and it is virtually our only source on reproductive biology, seed physiology and breeding efforts. Although much of this literature has been published in obscure journals of limited distribution, this paper will draw on it heavily.

2 Geographical distribution, economic importance and varietal diversity

"El señor o cacique de los Chibchas había mandado alzar el bastimento, de manera que tuvieron algunos hambre, por lo cual les fue forzado aprovecharse de lo que por naturaleza la tierra produce, y así debajo della sacaban unas raíces amargas, que yo creo tienen por nombre 'arracachas', porque si no me engaño no pocas dellas he comido; su sabor declina un poco a zanahorias; destas y de otras yerbas comían los que con Centeno andaban."¹

(Cieza de León, a Spanish chronicler describing the use of arracacha in 1545, in what is today Colombia, by Spanish rebels fleeing from Pizarro's troops; cited in Patiño 1964)

Several lines of evidence point to Andean South America as the place of domestication of arracacha. Although the genus *Arracacia* is particularly diverse in Mexico, the wild species most closely resembling arracacha are known from Peru and especially Ecuador (Fig. 1; see Section 6.2.1). The linguistics of the vernacular names of arracacha also provides clues to its Andean origin. *Racacha*, *virraca*, *lacache*, *arrecate* and other related words of autochthonous languages used for the crop attest to its great antiquity in the Andes. Outside the Andes, names for arracacha are derived mostly from European languages. Finally, the chroniclers of the Spanish conquest of South America refer to arracacha frequently (reviewed in Patiño 1964) and its cultivation is documented for what is today Peru (upper Huallaga, 1533), Colombia (Popayán, 1545) and Ecuador (Rio Chinchipe, 1549; Cañar, Chimborazo, 1582). Using historical accounts of the conquest, Hodge (1954) convincingly argues that the "dispersal of arracacha as a cultigen throughout most of its present range in the Andes clearly came in pre-Columbian times" and, one might add, probably a long time before the Inca conquest subjugated much of South America.

Today, arracacha is produced mainly in four countries - Brazil, Colombia, Ecuador and Venezuela - whose total production area is probably somewhat over 30 000 ha. In these countries, arracacha is a regular item in urban markets, and is consumed and known by a majority of the population (in Brazil, only in the southeast region). Implicit to this observation is that arracacha is traded over long distances to supply regions where the crop cannot be grown for climatic reasons (tropical lowlands, high Andes). In the Andes, arracacha is also widely grown in Peru and Bolivia, but most production is for subsistence; some surplus goes to local markets.

¹ "The chief or cacique of the Chibchas had ordered a limit on provisions, so that some of the people were hungry, and they were forced to exploit what the land produces naturally. As a result, from under the ground they pulled out some bitter roots, which I believe are given the name 'arracachas', because, if I don't deceive myself, I have eaten several of them: their taste slightly resembles that of carrots. Of these and other herbs the people who went around with Centeno were eating." (Translation by Bill Hardy).

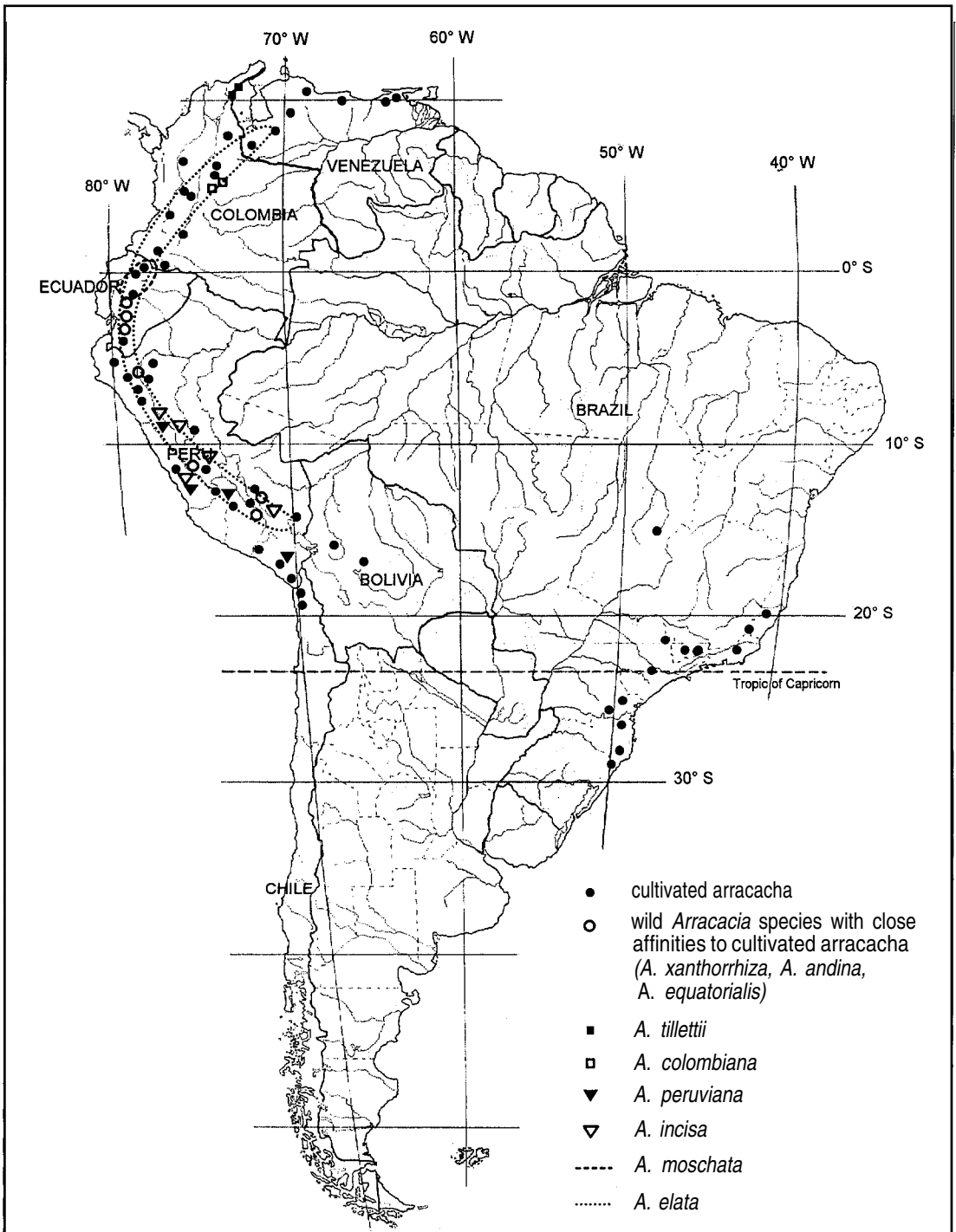


Fig. 1. Distribution of arracacha cultivation and wild *Arracacia* species in South America (Goode's series of base maps, University of Chicago, 1937; sinusoidal equal-area projection).

The crop has also spread to Central America and the Caribbean, but significant production seems to be limited to Costa Rica and Puerto Rico. Some reports mention attempted introductions to the Old World, but to my knowledge, nowhere outside the New World has arracacha ever been established as a crop.

2.1 Andes

Importance, distribution and other characteristics of arracacha production relevant to the crop's genetic resources will be presented for the Andean range, from north to south, which roughly coincides with the declining economic importance of the crop. Arracacha production areas in the Andes range over 32 degrees of latitude from 10°N (Mérida, Venezuela) to 22°S (southern Bolivia), with marketed production coming mostly from north of the equator.

2.1.1 Venezuela

Of all the Andean countries, it is perhaps in Venezuela where arracacha is held in the highest esteem. This is reflected by frequent consumption (Camino and Díaz 1972) and high prices for arracacha compared with those of other commonly used tubers such as cassava, potato, ocumo (*Xanthosoma* sp.) and ñame (*Dioscorea* sp.) (Revetti 1967). *Apio*, as the crop is called in Venezuela because of its resemblance to celery (celery, *Apium graveolens*, is referred to as *apio España*), is considered ideal to wean children (Revetti 1967). Moreover, elegant restaurants have it on the menu (Dr María L. García, 1996, pers. comm.) in dishes such as *sancocho*, purées and *buñuelos de apio* (see Section 5.3).

According to official statistics, in 1970, 8451 ha of arracacha were grown in the Andean Cordillera and the coastal mountain range in the north of the country. Average yield was 5.4 t/ha (Camino and Díaz 1972). A recent document gives a total of 3619 ha for 1988-89 (Anonymous 1990). Major production regions are Monagas, Trujillo, Sucre, Táchira, Yaracuy and Mérida. There appears to be only one commercial cultivar with yellow flesh (Reyes 1970; Dr María L. García, 1996, pers. comm.) and comparatively small roots of 5-15 cm length and a mean weight of 100 g as determined by Czyhrinciw (1952) in the market of Caracas. Yields are between 5 and 10 t/ha after a typical crop duration of 14 months (Reyes 1970). The high perishability of arracacha has prompted research by Venezuelan scientists into storage behaviour and storage diseases (Czyhrinciw and Jaffé 1951; Czyhrinciw 1952, 1969; Revetti 1967; Camino and Díaz 1972; Díaz and Camino 1976).

2.1.2 Colombia

At the time of Bukasov's explorations in Colombia (1925-26), 20 000 ha, or the equivalent of 75% of the total arracacha area in the country, were grown in Cundinamarca (Bukasov 1930). Bukasov speaks of arracacha as the favourite tuber in this department, taking up 20% of total arable land (versus potato with 10%!). He reports significant areas also from Boyacá Santander, Norte de Santander and Tolima, but limited cultivation in the rest of the country. In 1954, when Hodge

published his account of arracacha use in Colombia (Hodge 1954), the most significant arracacha area was in Antioquia.

In 1991, Colombia had a total of 12 000 ha, of which 6000-8000 ha were grown in the department of Tolima, with 4000-5000 ha in the municipality of Cajamarca. The better part of the Tolima production goes to the three major Colombian cities: Bogota, Medellín and Cali. Other arracacha-producing departments are Nariño, Cundinamarca and Boyacá, and, to a minor extent, Antioquia. National yield averages about 12 t/ha; thus, national production of arracacha in 1991 would have been around 144 000 t (Mr J.J. Rivera, 1996, pers. comm.). Thompson (1980) reported marketed production at 123 000 t in 1977; hence arracacha consumption appears stable, if not slowly growing, over the last two decades.

Surveys of consumers stratified by income and conducted by Ríos (1985) in Manizales, Caldas Department showed that annual per capita consumption of arracacha ranged between 8 and 22 kg. The very poor and the wealthy share low consumption levels, the former probably because of lack of purchasing power for a relatively expensive root vegetable, the latter because of high dietary diversification and increased consumption of animal products.

Disease problems in Tolima and falling prices for coffee in recent years have stimulated interest in arracacha. Typically, arracacha is intercropped with maize, which is harvested after 150 days. According to altitude, arracacha can be harvested 10-14 months after planting. There is a wide range of producers, with smallholders at one extreme and large absentee landowners at the other (Mr J.J. Rivera, 1996, pers. comm.).

Although yellow-rooted clones are preferred in Colombia, especially in Bogota (Higuita 1969; Hermann 1994; Mr J.J. Rivera, 1996, pers. comm.), local preference for white roots in Medellín has been reported (Higuita 1969). This city is supplied with the variety *Salamineña Blanca*, which reportedly accounts for most of the production of the La Ceja valley in Antioquia (Higuita 1968). *Salamineña Blanca* matures in 10 months.

Higuita (1969, 1970) recognizes nine morphologically distinct varieties in Colombia, with yellow and white clones being the most common. On the basis of linguistic and morphological data, Bristol (1988) claims the existence of at least 18 distinct clones in the Sibundoy valley near Ecuador, known for its Kamsá-speaking population. Little is known about the arracacha in Sibundoy and since more than 30 years have passed since Bristol's explorations, it is urgent that collecting what remains of presumably unique genotypes be done.

2.1.3 Ecuador

As in Colombia and Venezuela, arracacha in Ecuador is a root vegetable known and consumed by the vast majority of the population and found regularly on supermarket shelves. According to a consumer survey conducted in the three major cities – Guayaquil, Quito and Cuenca – 91, 97 and 68%, respectively, of the households interviewed reported consumption of arracacha (Espinosa *et al.* 1995). It is the fourth

most popular root crop after potatoes (*Solanum* spp.), melloco (*Ullucus tuberosus*) and cassava. The same survey found no evidence for a continuous decline in arracacha consumption as stated by Castillo (1984). Annual per capita consumption was found to be 2.7 kg in Cuenca, 8.1 kg in Quito, and the highest in Guayaquil, with 8.9 kg. The latter finding is noteworthy because Guayaquil is a tropical lowland city where the perishability of arracacha would seem to limit its use. If we assume that in this nation of about 12 million people the mean annual per capita consumption of arracacha is at least 2 kg, and yield averages 10-20 t/ha, then the total arracacha area in Ecuador would be at least somewhere between 1200 and 2400 ha. This is in striking contrast to the 150 ha accounted for in 1993 by official statistics of the Ministry of Agriculture.

Although the arracacha crop is widely distributed across the Sierra, commercial exploitation is concentrated in San Jose (northeast of Quito), Baños (Tungurahua), Imbabura and Loja. San Jose de Minas is located on the western slope of the Andes. Its humid Pacific climate at 2000 m altitude with rainfall throughout the year makes it one of the most productive arracacha areas, with yields well above 30 t/ha. The average altitude for arracacha cultivation in Ecuador is 2500 m, but some germplasm accessions have been collected at as low as 1450 m and up to 3200 m (Hermann 1988).

A range of cultivars has been collected in Ecuador and several root shapes and pigmentations, from white over yellow to orange, have been observed (Mazón 1993); however, 70% of the accessions of the national collection have white-fleshed roots. Only white roots are available in urban markets throughout Ecuador (Espinosa *et al.* 1995). Another peculiarity in Ecuador is that the name arracacha, widely used for the crop in the Andes and beyond, will not be understood. Ecuadoreans eat *zanahoria blanca*, Spanish for 'white carrot'. In Loja, the crop is simply called *zanaharia*, with the real carrot (*Daucus carota*) receiving the name *zanahoria extranjera* (the foreign carrot) (Mrs Joy Horton de Hofmann, 1996, pers. comm.). The use of the term *zanahoria* apparently extends into Nariño, southern Colombia (Jaramillo 1952), and Cajamarca, northern Peru (Arbizu and Robles 1986).

Five wild *Arracacia* species occur in Ecuador (*A. andina*, *A. elata*, *A. equatorialis*, *A. moschata*, *A. xanthorrhiza*; see Section 6.2.1), along with the closely related *Neonelsonia acuminata*. Rural people invariably refer to these plants as *sacha zanahoria* (*sacha* = *quechua* for 'wild') or 'wild carrots' and know their habitats, which is of great help to plant collectors. There is a widespread belief across the Sierra that these plants have medicinal qualities for a variety of uses, *post partum* applications being the most common.

2.1.4 Peru

A production manager of Nestlé-Brazil, a company known for its processed arracacha products in Brazil and Colombia, had lived for several years in Lima, Peru, where the company has a subsidiary. He had traveled widely in Peru, but returned to his native country thinking of arracacha as a genuinely Brazilian vegetable. He

had not seen it in Peru. Nothing could better illustrate the paradoxical situation of arracacha in Peru, a country so rich in genetic resources of this and other Andean crops. One can live a lifetime in Peru and yet never come across arracacha. It is used only sporadically in Lima (where roughly half of the national population lives); as a matter of fact, most limeños are not aware of it. Restaurants do not offer it and national cookbooks ignore it. Even in highland towns, there appears to be social prejudice against arracacha and other tuberous foods associated with the (economically and socially depressed) Indians (Fano and Benavides 1992).

Some authors suggest that some Nazca pottery designs, formerly attributed to cassava, may in fact represent arracacha (reviewed in Towle 1961, pp. 74-75). Vivid accounts of the Spanish chroniclers refer to arracacha as a food plant widely used in Peru in the 16th century (Patiño 1964). Today, arracacha continues to have some commercial scope in Cajamarca, Cusco and other highland cities and towns, but it has more importance for the subsistence and diet diversification of poor rural people.

According to Seminario (1995), Peru has about 2000-3000 ha of arracacha, of which 60-80% corresponds to the department of Cajamarca. The second most important department is Amazonas, also in the north of the country (Table 1).

Table 1. Altitudinal range of arracacha cultivation in Peru according to department (arranged from north to south)

	No. of sites	Elevation (m asl)	
		Average	Range
Piura	23	1788	1600 - 1900
Amazonas	22	2109	1610 - 3240
Cajamarca	56	2298	870 - 3460
La Libertad, Ancash, Huanuco	7	2877	2610 - 3240
Cusco	20	2286	1938 - 2590
Apurímac	11	2784	2540 - 3275
Arequipa	5	2918	2370 - 3190
Moquegua, Tacna	8	1848	950 - 3050

Source: Hermann, field notes.

Traditionally, arracacha has been cultivated in Peru in three different agroecologies with widely varying environmental conditions: the Ceja de Selva, the humid and rainy eastern slope of the Andean Cordillera toward the Amazon between 1500 to 2200 m altitude (Amazonas, Cusco, Huánuco, La Libertad, San Martín); the dry inter-Andean valleys between 2500 and 3200 m (Ancash, upper Apurímac and

Cajamarca); and the coastal desert oases of Moquegua, Piura and Tacna at 1000-2500 m (see Table 1 for details on the altitudinal range of arracacha cultivation in Peru).

On a visit to Tacna in 1993, a town known in the past for its arracacha production, I found only a few arracachas in the market from Moquegua, and none from Tacna. Farmers offered these explanations for their abandoning the crop: lack of planting material, lack of market demand and a common belief among Aymará and Quechua people that the crop became jealous and lazy once the Taceños had sent planting materials to the people of Moquegua. Only after an extensive search could one farmer be found who grows the plant for his own consumption (Don Uldarico Velasquez Rejas, Calana, Tacna).

The city of Cusco receives arracacha from Quillabamba. In the nearby Sacred Valley, arracacha has not had any importance in the recent past (Gade 1975). Peru has numerous cultivars with some variation in pigmentation and root shape, but yellow-fleshed clones are preferred over white material on urban markets (Meza 1995). Farmers often also grow a purplish variety that is not commercial.

2.1.5 Bolivia

Like Peru, Bolivia produces little commercial arracacha. This seems to have been so at the time of Vavilov, who wrote in the 1930s: "... Arracacha ... rare in Peru and Bolivia; a staple crop on the Bogota Plateau" (Vavilov 1992). According to an authority on Bolivian economic botany, the late Martin Cárdenas, arracacha has been grown traditionally in the Yungas of La Paz (Cárdenas 1969), in the provinces of Camacho and Larecaja, where I have seen it in the early 1990s. *Lacache*, as the crop is called in the Aymará language, is offered in the markets of La Paz and Cochabamba, the latter city being supplied from the Chapare, also known for its coca leaf production.

2.1.6 Chile

Latham (1936) reports the use of arracacha in the extreme north of Chile. This was confirmed during a 1993 collaborative germplasm-collecting mission conducted by Professor Andres Contreras from the University of Valdivia and me. However, the crop is so marginal that many inhabitants of this region are not aware of it at all. It is safe to say that arracacha is on the verge of becoming extinct in this country. The crop was found in three villages: Nama (37 km northeast of Camiña, Iquique Province, 19°11' S, 69°24' W, 2900 m altitude), Socoroma (Parinacota Province, 18°16' S, 69°36' W, 3050 m altitude), and Codpa (Arica Province, 18°50' S, 69°44' W, 2200 m altitude). All three localities are remote highland oases of the Atacama desert, with aging populations of no more than a few hundred people. Interestingly, the crop is called by its Aymará name *lacache*, evidence of cultural ties of the Atacama region with the Bolivian Altiplano. Codpa, for example, is known for its subtropical and temperate fruit production, which was traditionally bartered for potatoes and dry meat from Bolivia. The arracacha clones seen in Chile are white-fleshed and, in the

case of Nama, were said to be remnants from the 'old times' when this part of Chile still belonged to Peru (until 1879).

Arracacha has not been reported from neighbouring Argentina, nor have I seen the plant during explorations in 1992 in Jujuy and Salta, the two northernmost provinces where most of the other Andean roots and tubers are still cultivated.

2.2. Brazil

Zanin and Casali (1984a) present circumstantial evidence for the introduction of arracacha to Brazil early in this century. The crop must have been spread quickly since it was widely consumed as early as in the 1920s in rural areas of Minas Gerais, São Paulo and Rio de Janeiro (Hermann, unpublished field notes). Today, arracacha is mostly grown in the uplands of southern and southeastern Brazil, particularly in the Serra do Mar (Paraná, São Paulo, ca. 26° S), in the Serra de Mantiqueira (Minas Gerais, 22-23° S, 1000-1800 m altitude), in the Serra de Espinhaço (Minas Gerais, 16° S, under 1000 m), and the Planalto Central (Minas Gerais, Goiás, Tocantins, 15-18° S, 800-1000m). According to an extensive survey by Santos (1993), the four foremost arracacha-producing states in 1993 were Minas Gerais (3500 ha), Paraná (2800 ha), Santa Catarina (850 ha) and Espírito Santo (660 ha). The area is expanding in Espírito Santo and Minas Gerais and total national area in 1996 is estimated to exceed 12 000 ha. Moreover, the area under arracacha shows high growth rates in Goiás and Tocantins, states to which arracacha culture was introduced a few years ago (Dr F.F. Santos, 1996, pers. comm.). In São Paulo, where arracacha was in the 1960s a source of "great wealth" (Normanha and Silva 1963) and grown to a larger extent than in any other federal state, arracacha production has been reduced to some 200 ha in the 1992/93 growing season (Monteiro *et al.* 1993). Booming service industries have forced out arracacha culture around metropolitan São Paulo. For example, the former arracacha-growing municipality of Piedade near São Paulo nowadays acts as a transshipment point for arracacha from all over Brazil. Piedade no longer produces arracacha, but washes, classifies and packs arracacha from other states for sale on the wholesale market CEAGESP in São Paulo (Fig. 2C).

The average farm-gate price in recent years has fluctuated between US\$0.40 and \$0.60/kg and, assuming an average value of \$0.50/kg, the off-farm value of total arracacha production in Brazil should have been around US\$55 million in 1996. Arracacha is a regular item in all major cities of southern Brazil (São Paulo, Rio de Janeiro, Belo Horizonte, Curitiba, etc.). Retail prices are typically between US\$1.50 and 2.00/kg; arracacha is thus the most expensive root and is as highly valued as fruit vegetables such as *giló* (*Solanum* sp.), *Capsicum* peppers and *quiabo* (*Abelmoschus esculentus*) (Hermann, field notes, 1991, 1994, 1995). In early 1995, arracacha retail prices soared to unprecedented levels, because of frost-related crop losses in the 1994/95 season. In August of 1995, supermarket prices in Brasilia were still between US\$4.00 and 6.00/kg. This suggests inelastic demand, which is likely the result of habitual purchases of small quantities of arracacha for child nutrition by many



A



B



C



D

Fig. 2. Arracacha utilization in Brazil. **A:** arracacha specialist Dr Fausto Santos (CNPQ-EMBRAPA) interviewing Japanese immigrant farmer in Distrito Federal (loc. Alexandre Gusmão, 50 km S of Brasília, 1100 m asl, photograph July 1992); **B:** productive arracacha plant in EMBRAPA germplasm collection, Brasília (photograph 1994); **C:** arracacha on wholesale market CEAGESP in São Paulo (photograph August 1994); **D:** processed arracacha flakes ready for shipment at Nutrimental Company, São José dos Pinhais, Curitiba, Paraná (photograph August 1994).

Brazilian families. During a visit to the Federal District in August 1996, I noted that arracacha prices had decreased but were still high (farm-gate value varied between US\$1.40 and 1.80/kg washed roots).

Brazilian researchers agree that only one yellow-rooted clone is being grown in Brazil. This is based on the evaluation of germplasm accessions from different parts of the country, which have not revealed morphological or agronomic variation attributable to genetic causes. The Brazilian clone which is often referred to in publications as Amarela de Carandai has an intensive yellow root pigmentation, purplish petiole bases and, compared with the more common Andean germplasm, a strong flavour. Intensive yellow colour and strong flavour are required by the fresh market and the processing industry. Casali *et al.* (1984) report germplasm trials conducted at the Instituto Agronômico Campinas (IAC) which did not result in the identification of clones superior in this regard to the Brazilian material. Likewise, introduced materials from Ecuador were not considered promising in evaluations in Brasilia. Although this predominantly white-fleshed germplasm yielded more than the Brazilian clone, root colour and flavour were considered unsatisfactory (Dr F.F. Santos, 1994, pers. comm.).

Arracacha is typically grown by small farmers with less than 1 ha of arracacha per holding. Yields average 6-14 t/ha in Paraná and Minas Gerais (Hamerschmidt 1984; Santos 1984), 15-30 t/ha in São Paulo (with irrigation; Monteiro *et al.* 1993) and a nation-wide mean of 8 t/ha has been reported (Santos 1993). Plantings are year-round, with marketed volumes reaching a maximum between July and September when prices are lowest (Santos 1993). Several Brazilian companies process arracacha for instant food (see Section 5.4.1, Fig. 2).

Since 1984, five biannual *mandioquinha-salsa* meetings have brought together the major players of the arracacha industry in Brazil, namely farmers, market people, industrial users, extensionists and researchers, and their informal cooperation has greatly stimulated research and arracacha utilization.

2.3 Central America and Caribbean

Arracacha as a botanical genus (*Arracacia* Bancroft) and species was described from cultivated material introduced to Jamaica in the early 19th century (Mathias and Constance 1944). The plant seems to have been spread widely in the Caribbean, although it is only sporadically grown. We have only limited knowledge on its cultivation in Puerto Rico and Cuba.

Williams (1981) quotes reports of arracacha in Central America, specifically in Guatemala and Costa Rica, but says he has not seen it there. According to Dr Jorge Leon (1996, pers. comm.), the crop was cultivated in Panama around 1920. Hodge (1954) relates some evidence pointing to limited arracacha culture in the past in this country, specifically in the highlands around the Chiriquí volcano near the border with Costa Rica (approximate latitude: 8°45' N). Significant commercial arracacha production in Central America appears to be limited to Costa Rica's central highlands (Cordillera Central).

2.3.1 Costa Rica

According to Andean crop and Central America specialist Dr Jorge Leon (1996, pers. comm.), there are no references of arracacha cultivation in Costa Rica until the 1940s. He specifically refers to publications of Pittier (1908; 'Plantas usuales de Costa Rica') and Wercklé (1914; 'San Jose market survey') who do not mention arracacha (full bibliographic data not available). Since the 1940s, however, arracacha is reported to have been grown in the central highlands, especially in Cartago (Pacayas, Capellados), Heredia (San Isidro, Santa Barbara, Irazú region) and Alajuela (Zarcero, San Ramón, Carrizal) at altitudes of 1500-2200 m. There are probably not more than 10 ha of arracacha in all of Costa Rica, typically grown in small plots. The only variety referred to in the country under the name of arracacha has white roots and green foliage (Dr J. Leon, 1996, pers. comm.). Finely chopped arracacha ready for cooking is sold in farmers' markets at a price of US\$2.00-2.50/kg. It is used as a filling for *picadillos*, a traditional Costa Rican dish served on patron saint's day (see Section 5.3) (Mr J.A. Morera, 1996, pers. comm.).

2.3.2 Puerto Rico

This small island's cosmopolitan past has made it a 'melting pot' for food plants from Europe, Africa, South America and Asia. Cultural influences and exotic ingredients in Puerto Rico have blended into a unique cuisine which, according to Sokolov (1993), is the richest expression of Caribbean cooking. It is thus no surprise that Puerto Ricans annually consume about 0.7 kg of arracacha per capita (calculated from data provided in Valle *et al.* 1989 and assuming a total population of 3.3 million for Puerto Rico in the same year).

According to Cook and Collins (1903), *apio* has been grown in Puerto Rico at least since 1903 when it was found planted extensively "in the mountains behind Ponce." Today it continues to be grown commercially in the central mountains near Barranquitas and Orocovis, in deep clay soils at altitudes less than 900 m and comparatively high mean temperatures (over 23°C). Although not ranked as a major root crop, *apio* is "very popular and in great demand when available" (Valle *et al.* 1989). Total insular production in 1985-86 was 2295 t, with a total farm value of US\$1.05 million; hence, the farm-gate value was \$0.46/kg. Valle *et al.* (1989) report the results of sensory evaluations of four clones introduced to Puerto Rico from Colombia. Interestingly, yellow-fleshed clones received higher ratings than a white clone which was moderately acceptable in appearance, flavour and texture.

2.3.3 Cuba

Arracacha, or *afió*, is believed to have been introduced to Cuba by French immigrants from Santo Domingo, Dominican Republic, and Haiti (Esquivel and Hammer 1992) and is used in Guantánamo for certain desserts. However, arracacha is rarely offered on markets and Cubans are usually unaware of this crop (Dr Lianne Fernández, 1996, pers. comm.). According to several authors reviewed by Esquivel *et al.* (1992), the

name *afió* has an African origin. The same authors report the use of arracacha leaves and stems in fritters, a popular food across the Caribbean.

2.4 Old World

Several documents from the late 19th century testify to attempts by the British colonial government to introduce arracacha from Jamaica via the Kew Botanical Garden to India and what is today Sri Lanka. Some of the shipments survived the long sea journey to Sri Lanka and were apparently bulked up for distribution of planting material “to the headmen of villages at 2000 feet or more elevation, in the hope of its culture being taken up by the villagers” (Anonymous 1887, quoting colonial administrative correspondence). We do not know whether these efforts ever succeeded and what the status of arracacha in Sri Lanka is today.

Similarly, L'Heureux and Bastin (1936) state that arracacha was introduced to Central Africa (Burundi, Rwanda), but the authors do not say to what extent the crop spread, if at all.

3 Vernacular names

*“No nos hemos atrevido, por no salir con alguna arracachada” ... “Fíjese, Eloy, en el compañero que le va a tocar, para que no le haga case cuando le salga con alguna arracachada”*²

Idiomatic expressions using the derivative ‘arracachada’ as a synonym of ‘nonsense’, ‘blunder’ or ‘silliness’, used in the Cauca valley, Colombia (Jaramillo 1952)

‘Arracacha’ is derived from the Quechua word *racacha* (Alvarez 1990) and is widely understood in the Andes, except in Ecuador and Venezuela. Even Aymará-speaking people in Bolivia often use it instead of their own word *lacachu* (Hermann, 1989, field notes in Larejaca). Arracacha has also been accepted as the standard term in the English literature. Terms such as ‘Peruvian carrot’ or ‘Peruvian parsnip’ are confusing and their use in the literature should be discontinued.

Peru undoubtedly has the greatest variety of vernacular names for arracacha (Table 2). The term *racacha* is widespread in Arequipa, Puno and Tacna, but in Cusco and Apurímac, *virraca* seems to be preferred, whilst *ricacha* is popular in the north of the country (Amazonas, Cajamarca).

The Quechua language spread in the late 15th century from a limited area in the Cusco valley to become the lingua franca of the Inca empire that came to comprise the Andes from Ecuador to northern Chile. In the course of this cultural expansion, many indigenous languages perished and *racacha* supplanted previously used names. As Table 2 shows, indigenous words denoting arracacha are reported from Colombia and Venezuela, specifically from areas that were hardly ever controlled by the Incas, and only then for a few decades before the Spanish arrived. The record of words like *aricachi* (Ayomán language, Venezuela) or *arocueche* (in the extinct Muzo language, middle Magdalena, Colombia) raises the interesting question as to whether these terms are derived from *racacha* and, if so, whether the derivation occurred during and after the Inca conquest, or in archaic times, when arracacha spread across the Andes. Patiña (1964) presents some linguistic evidence for *arocueche* being an autochthonous Muzo word and considers it unlikely to have been merely a late deformation of *racacha*. Arracacha, he argues, might well be of northern Andean origin, and it might in remote times have been taken to the central Andes where the original term evolved into *racacha* only to return to replace its linguistic precursors. We can conclude with Patiña that “these are issues to be proposed but not to be resolved”.

² “We have dared not, in order to not say something foolish” ... “Pay attention, Eloy, to the mate you are going to have, so that you don’t pay any attention to him when he does something foolish” (Translation by Bill Hardy).

Table 2. Vernacular names of arracacha

Vernacular name	Language	Country/Region	Source
Afió	“from an African language”	Cuba	Esquivel and Hammer 1992
Apio	Spanish	Puerto Rico	Cook and Collins 1903
Apio	Spanish	Venezuela	Mathias and Constance 1971
Apio criollo	Spanish	Venezuela	Reyes 1970
Aricachi	Ayomán	Venezuela	Jahn 1927
Arocueche	Muzo	Colombia/ Middle Magdalena	Patiño 1964
Arracacha	Quechua/ Spanish	Bolivia/ Colombia/ Peru	Patiño 1964; Soukup 1970
Arrecate, arecate	?	Venezuela	Pittier 1926
Batata-aipo	Portuguese	Brazil	Zanin and Casali 1984a
Batata-baroa	Portuguese	Brazil/ Rio de J.	Zanin and Casali 1984a
Batata-cenoura	Portuguese	Brazil	Zanin and Casali 1984a
Batata-fiusa	Portuguese	Brazil	Zanin and Casali 1984a
Batata-jujuba	Portuguese/?	Brazil	Zanin and Casali 1984a
Batata-salsa	Portuguese	Brazil	Zanin and Casali 1984a
Batata-suiça	Portuguese	Brazil	Zanin and Casali 1984a
Batata-tupinambá	Portuguese/ Tupí	Brazil	Zanin and Casali 1984a
Cenoura amarela	Portuguese	Brazil	Zanin and Casali 1984a
Gnaud, Huahué	Páez-Coconuco	Colombia ?	Rivet 1941
Huisampilla	Quechua	Peru	Meza <i>et al.</i> 1996
Kiu-titsí	Timote	Venezuela	Jahn 1927
Lacache	Aymarará	Chile/ Iquique	Hermann, field notes, 1993
Lacachu	Aymarará	Bolivia/ Camacho	Hermann, field notes, 1991
Mandioquinha-salsa	Portuguese	Brazil/ São Paulo	Zanin and Casali 1984a
Pacucarrá	“Chocó indians”	Colombia/ Chocó	Jaramillo 1952
Pastinaca	Portuguese	Brazil/ Rio Grande do Sul	F.F. Santos, 1996, pers. comm.
Racacha	Quechua	Peru/ Arequipa, Cusco, Puno, Tacna	Arbizu and Robles 1986
Racacham	Quechua?	Bolivia/ La Paz	Rea 1995
Ricacha	Quechua	Peru/ Cajamarca, Amazonas	Arbizu and Robles 1986
Sacarracacha	?	Colombia/ Pasto, Quindío	Pérez-Arbeláez 1978

Vernacular name	Language	Country/Region	Source
Virraca	Quechua	Peru/ Apurímac, Cusco	Arbizu and Robles 1986
Yengó	Kamsá	Colombia/ Sibundoy	Bristol 1988
Zanahoria	Spanish	Colombia/ Nariño	Jaramillo 1952
Zanahoria	Spanish	Ecuador/ Loja	Hermann, field notes, 1994
Zanahoria blanca	Spanish	Ecuador	Castillo 1984
Zanahoria blanca	Spanish	Peru/ Cajamarca	Arbizu and Robles 1986
Zanahoria del país	Spanish	Peru/ Amazonas	Arbizu and Robles 1986
Zanahoria morada	Spanish	Peru/ Cajamarca	Arbizu and Robles 1986

In Spanish, the term *arracachal* (plural: *arracachales*) denotes an arracacha field. In the Cauca Department, Colombia, another derivative, *arracachada*, is synonymous in vernacular language with ‘nonsense’, blunder’ or ‘silliness’ (see epigraph).

As shown in Table 2, outside South America, names for arracacha are derived predominantly from Spanish and Portuguese. Simple or compound terms involving *apio* (= celery), *zanahoria* and *cenoura* (= carrot), *pastinaca* (= parsnip) and *salsa* (= parsley) were coined by European immigrants and their folk taxonomy correctly identifies arracacha as closely related to these plants (they all belong to the umbelliferous subfamily Apioideae).

Brazil has a great variety of common names for arracacha. In Rio de Janeiro, for example, *batata-baroa* or the ‘Baron’s potato’ is used. This name alludes to the alleged introduction of arracacha to Brazil by Baron de Friburgo, a nobleman from the state of Rio de Janeiro (Zanin and Casali 1984a). A São Paulo vegetable vendor, however, will not understand the term and may, eager to please the foreign customer as it happened to me, search for especially immaculate potatoes. To resolve the confusion arising from the wide range of terms for arracacha in Brazil, *mandioquinha-salsa* from the state of São Paulo was adopted as the official Brazilian word and it is now widely used in science and commerce. *Mandioquinha* is the Portuguese diminutive for cassava and *salsa* means parsley, so the official word nicely describes the similarity of arracacha with root and leaf shapes of these plants.

Cultivar names in Spanish refer to root colour, as in *arracacha amarilla* (yellow arracacha) or *arracacha blanca* (white arracacha), or denote a supposed origin, as in *Salamineña* (from Salamina), but there is not a great wealth of such names. In Peruvian Quechua, cultivar names are also mostly descriptive of colour and do not suggest great genetic variability as the rich folk taxonomy of the potato does. For example, in Cusco, an arracacha variety with pinkish pigmentation in the vascular ring, vaguely resembling make-up on an eyelid, is referred to as *pasña racacha* (= girl’s arracacha). Then, there is *qu’ello racacha* (= yellow), *yurac racacha* (= white) and *qu’ulli racacha* (= deep purple). However, the same name is often applied to different cultivars (Hermann, field notes, 1990). Meza (1995) reports the following Quechua

varietal names for arracacha: *ñut'u racacha* (= small arracacha), *toctoccha* and *walla* (= cordillera arracacha). Herrera (1942) says that four types of arracacha are distinguished in southern Peru: *r'umur'accacha* (= cassava arracacha), *arros-r'accacha*, *huaisampilla* and *morada*. A good source for Peruvian varietal names of arracacha is Arbizu and Robles (1986). Among the many names listed in this germplasm catalogue, *chaucha amarilla* (= early yellow) and *chaucha blanca* (= early white) are perhaps the most remarkable since they indicate the existence of arracacha varieties with shorter crop duration. Bristol (1988) lists several varietal names in the Kamsá language of the Sibundoy (southern Colombia).

4 Biology and agronomy

4.1 Life form

Arracacha is a perennial plant. In the absence of vigorously competing weeds, arracacha will survive in a state of minimal growth for many years even without human intervention. This is of significance to the germplasm collector since the plant, in contrast to the tuber crops potato, oca and ulluco, may still be found where people have abandoned its cultivation but provide a niche for its survival such as in backyard gardens or fruit groves. Cultivation practices seek to maintain planting stocks vegetative; however, arracacha flowers occasionally. Certain conditions, especially dehydration, may induce very strong flowering responses that exhaust the plant and lead to its death (Section 4.3.1). This phenomenon presumably has led some authors to believe that arracacha is a biennial plant (for example, León 1964); Generally, however, the development of generative structures does not intervene with its continued vegetative growth.

4.2 Plant architecture, morphology and development

4.2.1 The vegetative plant

Figure 3 shows a mature vegetative arracacha plant from highland Ecuador, 20 months after the vegetative propagule was planted in sandy soil. Although this plant shows an undesirably large aboveground plant mass (which also results from the abnormally long crop duration of 20 months), the picture serves to illustrate arracacha's unique architecture, and its implications for plant development and propagation. The plant has four distinctive fractions: the storage roots, the central rootstock, the aerial stems and the leaves (for terms in Spanish and other languages, see Table 3).

The conical to cylindrical storage root (Fig. 3A) constitutes the principal economic product. A storage root can reach a weight of around 1 kg, but, more typically, individual roots weigh between 100 and 300 g. The root is proximally constricted and connected to the rootstock through 'necks' which break easily at harvest. Like the cassava or yacón (*Polymnia sonchifolia*) storage root, it does not regenerate shoots. The storage root can therefore not be used as a propagule.

The central rootstock (Fig. 3B) is a highly swollen and compressed stem structure. In the cultivar shown, the rootstock is comparatively large. In other cultivars, the rootstock may be less prominent. Although genetically determined to some extent, shape and size of the rootstock depend greatly on the propagule used and cultivation practices (especially hilling).

The aerial stems or offshoots (Fig. 3C) are very peculiar structures unique to arracacha and several authors have struggled to find an appropriate term for them (e.g. Hodge 1954). For the sake of convenience, we will call them 'cormels', although these are normally more compressed structures as, for example, in *Gladiolus* species. However, the arracacha cormels are also derived from stem tissue and are composed of internodes, nodes and scars left by shed leaves. The cormels therefore have a segmented structure.

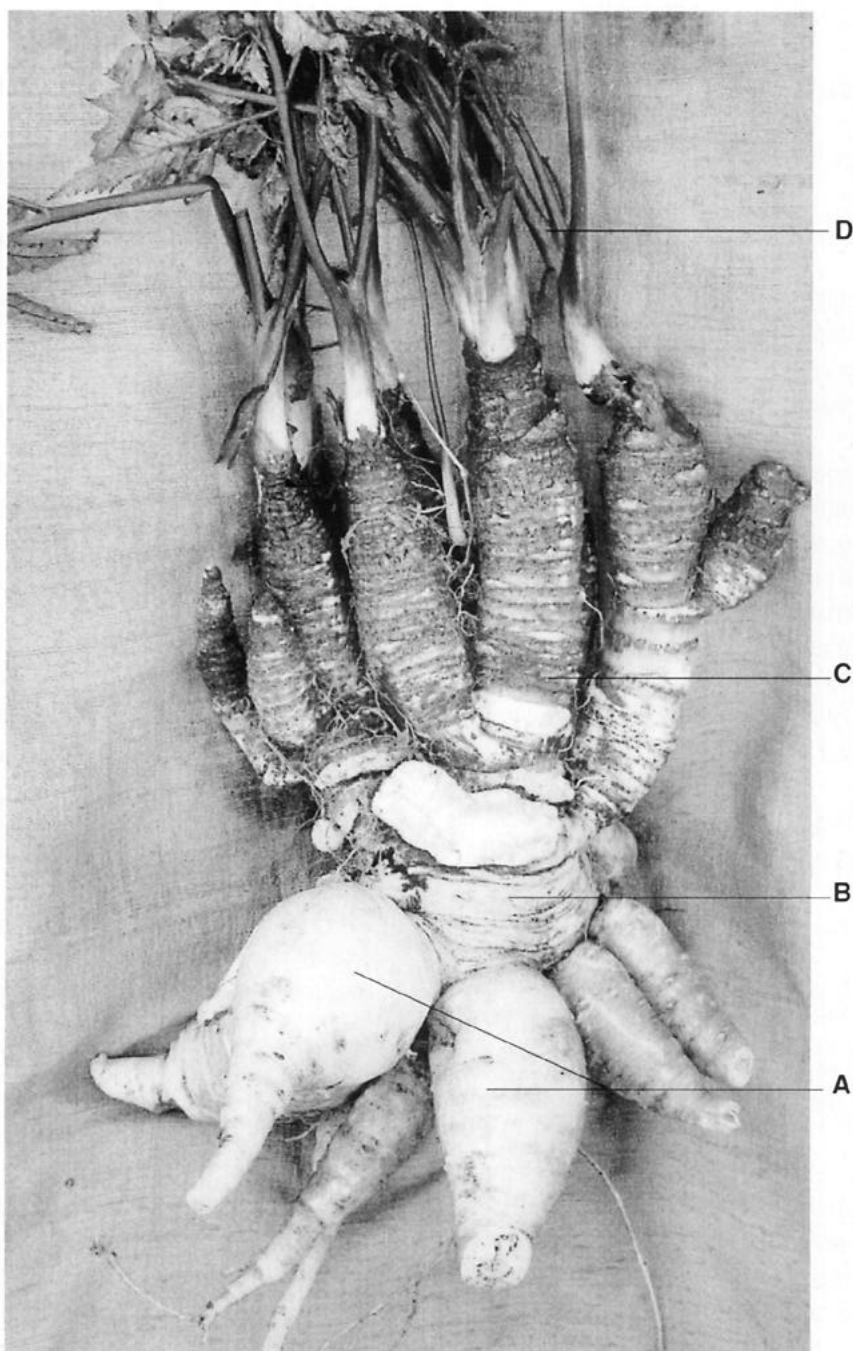


Fig. 3. Mature 20-month-old arracacha plant grown in the equatorial Andes (Ecuador) at 2400 m altitude (accession ECU1161, planted in July 1994, harvested in March 1996, density 15 000 plants/ha, propagated from entire cormels). **A:** storage roots; **B:** rootstock; **C:** stems or cormels; **D:** leaves. In this specimen, roots, rootstock, cormels and leaves accounted for 38, 17, 41 and 4% of a total dry matter of 702 g (fresh weight 3674 g).

Table 3. Terms applied to arracacha plant parts

Plant part	English	Quechua	Kamsá [†]	Spanish	Portuguese
Storage roots	arracacha, arracacha root	racacha, virraca	lengó, ingó	raíz	raíz
The entity of aerial parts and rootstock (which remain after removing the storage roots)	crown	n.a.	n.a.	partes aéreas	touceira
The central enlarged stem developing from propagule tissue; carries shoots and has storage roots inserted beneath soil surface	rootstock	n.a.	lengó, ingó	cepa, tronco	coroa, cepa
Entity of cormel and attached leaves	shoots	n.a.	n.a.	hijuelo	filhote, rebento
Apical part of cormel serving as propagule	stem cutting, sucker	k'ullucha, [‡] malqui [§]	jenashq, jenaviá, ingoshá [¶]	colino	muda
Buds inserted on cormels	eye, bud	ñahui		yema	gema

[†] The Kamsá language is spoken in the Sibundoy valley, southern Colombia; all terms are taken from Bristol (1988).

[‡] Used in Cusco, source: Hermann, unpublished field notes.

[§] Quoted in Bristol (1988) as Quechua.

[¶] Also used for the arracacha plant as a whole.

n.a. = not available.

Apical sections of the cormels with the basal part of the petioles serve as propagules; these develop over the crop's duration by growth and enlargement into the rootstock.

Each cormel carries on its apical nodes 3-5 petioled leaves which are of comparatively short duration (Fig. 3D). The leaf consists of a long petiole with a weakly developed basal sheath and the characteristically bipinnate blade. The leaves are 30-60 cm long; leaf size and dissection vary considerably within a plant and with the conditions of cultivation (Fig. 4).

The storage root formation of arracacha has been painstakingly studied by Roth (1977) in her microscopic investigation of a yellow-rooted cultivar in Venezuela (Fig. 5).

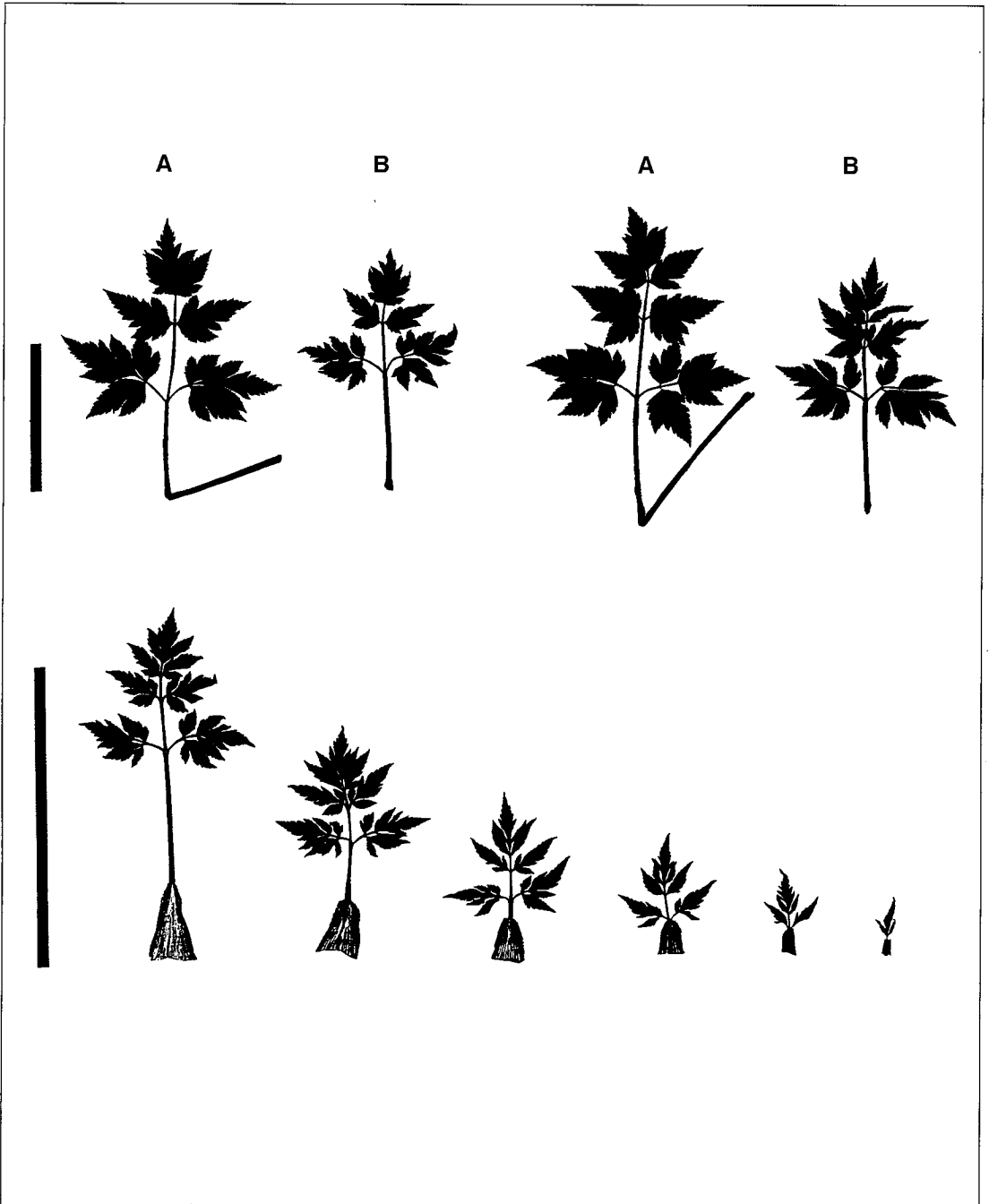


Fig. 4. Plasticity of leaf shape and size of cultivated arracacha. Leaves in the upper row show the influence of nutrient supply on two accessions (left pair: MH800; right pair MH548): **A:** field-grown plants with abundant nutrient supply; **B:** starving greenhouse plants. In the lower row, a succession of leaves along a generative shoot is shown (accession ECU1224). Scales: 20 cm.

Storage roots can be differentiated from filamentous roots by the naked eye about 2-3 months after planting. Initially, the filamentous root enlarges mainly owing to the growth of phloem parenchyma (Fig. 5A). When the root diameter has reached 2-3 cm, the xylem (the inner part of the root enclosed by the vascular ring) begins to develop starchy parenchymatic tissue which makes up most of the root at maturity. Starchy parenchyma in the (outer) cortex contain numerous longitudinal oil ducts, which are lined with secretory cells (Fig. 5B, C). In open-cut roots, the ducts exude a yellow, resinous oil with a typical umbelliferous odour. In wild *Arracacia* species, these oil ducts are more numerous and cause the astringent taste. Owing to root enlargement the rhizodermis experiences enormous dilation and a special mechanism of cork formation ('Etagenkork'), which is typical rather of monocotyledons, has evolved to allow for the continuous renewal of the root skin. Rhizodermic cork is formed in tangential layers separated by several layers of periclinally dividing cells. As new layers are formed from the underlying phloem tissue, the outer (= older) layers scale off (Fig. 5D, E, F).

4.2.2 The generative plant

The generative structures of arracacha and the factors inducing their emergence are poorly studied. Arracacha inflorescences and fruits are also conspicuously absent from most herbarium specimens. In most arracacha-growing regions, the plant rarely flowers. As will be seen later (Section 4.3.1), this is the result of cultivation practices and prevailing climatic conditions. Given appropriate flowering stimuli, however, all arracacha genotypes studied so far can reproduce sexually (Hermann, unpublished results).

Each well-developed cormel has the capacity to develop one generative shoot bearing several inflorescences. Therefore, flowering responses in a given arracacha plant range gradually from one generative shoot to as many generative shoots as there are cormels (see Fig. 6). Spontaneously flowering plants in the Andes seldom have more than 2-3 generative shoots. Figure 7 presents schematically a vigorous generative shoot (actually a ramified shoot system) of about 1.20 m height (the only generative shoot spontaneously developed on a greenhouse plant). It carried 38 umbels, none of which was found to be fruiting. Fruiting specimens have a more restricted shoot growth and a lower number of umbels. The umbels appear to be terminal. Sheathed nodes below each umbel continue shoot growth and the formation of new umbels until a certain size (and carrying capacity ?) is reached. Because of this growth pattern, the proximal umbels flower first and the peripheral ones last. The flowering period of any given shoot is between 1 and 2 months.

Leaf size and thus the photosynthetic capacity are largely restricted along the generative shoots (Fig. 4). Farmers remove these sinks as soon as they become visible, knowing that their undisturbed development can reduce root yields. Usually the 'generative' cormel develops a basal vegetative shoot which ensures the survival of vigorously flowering plants (those with generative shoots developing from all cormels).

The arracacha inflorescence is a compound umbel as shown in the schematic drawing (Fig. 8). This figure also gives the terms used to describe the inflorescence

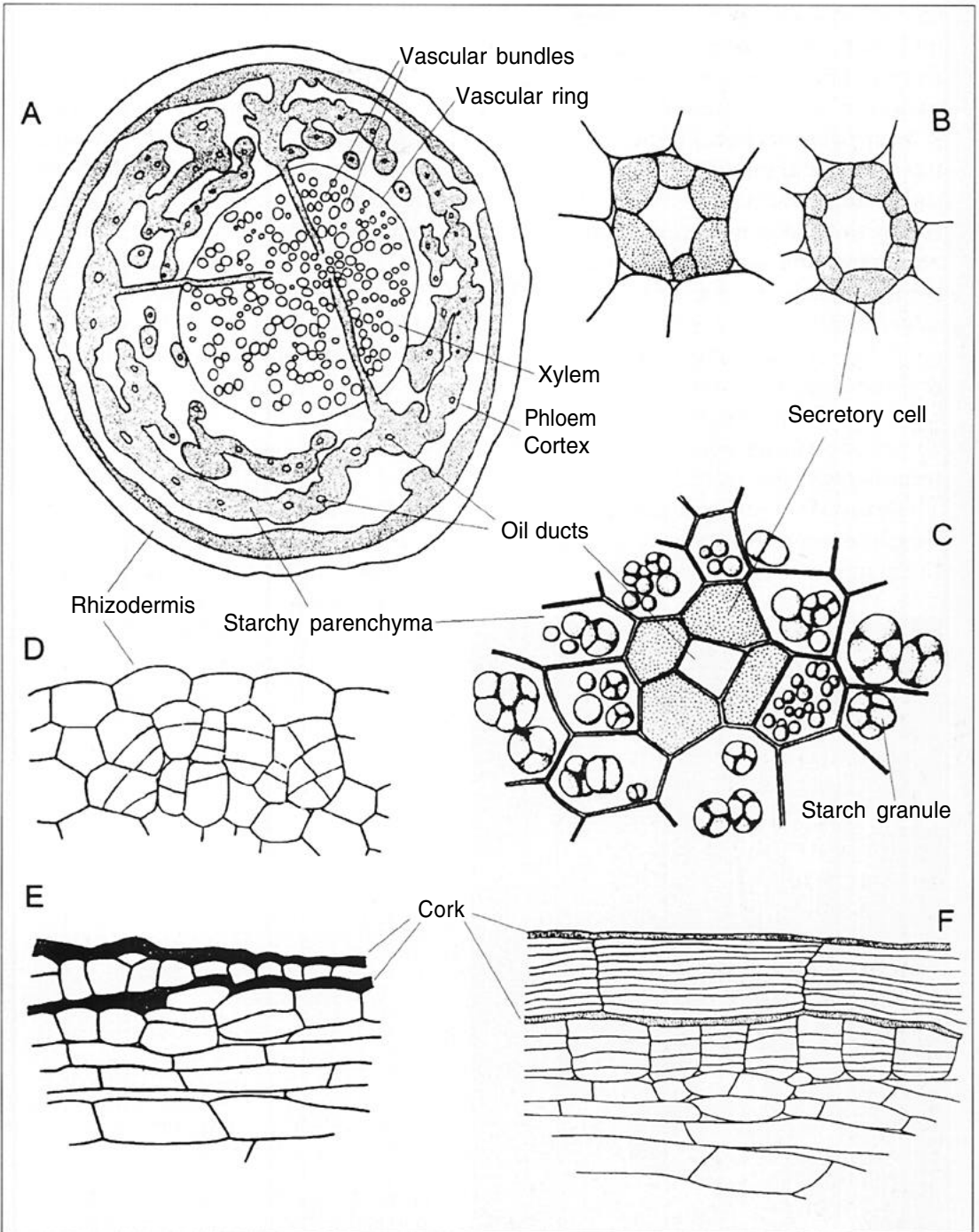


Fig. 5. Storage root development in arracacha. **A:** cross-section of a root with 4 mm diameter; **B:** mature oil ducts surrounded by secretory cells; **C:** developing oil duct within starchy parenchyma; **D, E, F:** progressive stages of 'Etagenkork' formation in rhizodermis (Source: Roth 1977).

of *Arracacia* species. The umbel has 8-14 rays, which carry the 10-25-flowered umbellets. The outer rays are stronger and carry more flowers than the inner ones. Hermaphrodite or perfect flowers, that is flowers with stamens and functional gynoecia, are found mostly on the outer umbellets; there are typically 3-5 perfect flowers per umbellet. The number of perfect flowers per umbellet decreases toward the centre of the umbel and the inner umbellets consist almost always of male or staminate flowers only. However, there are arracacha accessions, such as CA5026 (Peru, Yauyos), which deviate from this common pattern in that almost all flowers are perfect irrespective of the umbellet position. In such cases, the number of flowers per umbellet is lower and ranges from 5 to 20. Clearly, such genotypes have potential as seed parents as the possible seed yield per umbel and plant is greatly increased.

Across a wide range of genotypes, perfect flowers account typically for 15-25% of all flowers, except in a few accessions such as the aforementioned CA5026 with 85-90% perfect flowers. A distinctive feature of the arracacha umbel within genus *Arracacia* is the absence or reduction of the involucre to one lanceolate bractlet (for terminology see Fig. 8).

Arracacha flowers are actinomorphic (= radially symmetric) and with 2-5 mm length comparatively small (see Fig. 9). The epigynous, perfect flower has five petals, five stamens and two carpels, each with only one ovule; hence only one seed develops

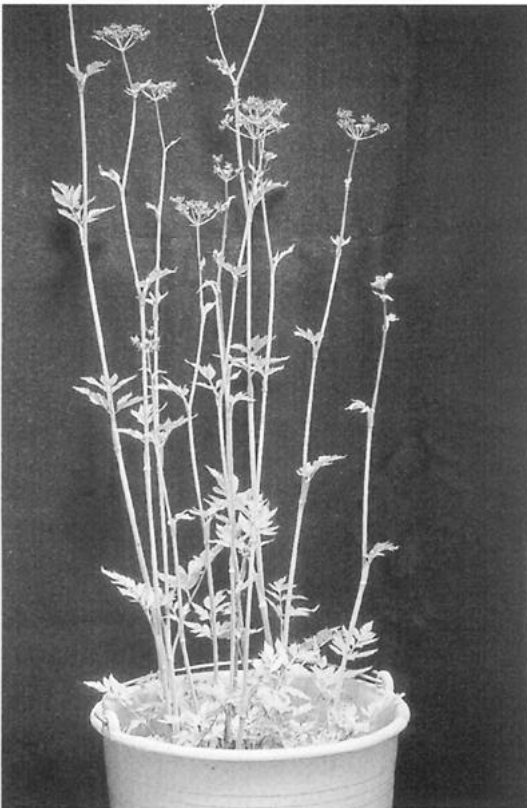


Fig. 6. Flowering arracacha plant (clone JJV-006 from San José de Minas). In this plant, flowering was induced by dehydrating the rootstock until 35% weight loss. Note that owing to this treatment, several generative shoots developed.

per carpel, and two seeds per flower and fruit. The styles emerge from an epigynous disk which functions as a nectary. The styles are basally enlarged to form the more or less conical stylopodium (Fig. 9). The stylopodium varies little between genotypes of cultivated arracacha, but its variable shape between wild *Arracacia* species is of diagnostic value (see Section 6.2.1). The formation of aberrant perfect flowers with 3 or 4 styles is characteristic of certain arracacha genotypes.

The male or staminate flower is similar to the perfect flower as far as petals, stamens and the basal disk is concerned, but it lacks functional female organs. In most genotypes, sepals are normally absent from both perfect and male flowers (asepalous flowers; see Fig. 9A-D, F). There are, however, genotypes with sepalous flowers, although these seem to be rare (Fig. 9E, G, H). The petals of immature flowers are green but they always turn maroon at anthesis. Other flower parts, such as petals, anthers, filaments, carpels and styles, are either free of the purple-maroon pigment or have it at varying intensities and combinations. Pollen from green anthers is white and pink in the more common maroon anthers. In the Ecuadorean accession JJV06, anthers with either pink or white pollen can occasionally be found within the same flower. It is obvious that the pigmentation of the various parts of the arracacha flower would lend itself for use in germplasm characterization.

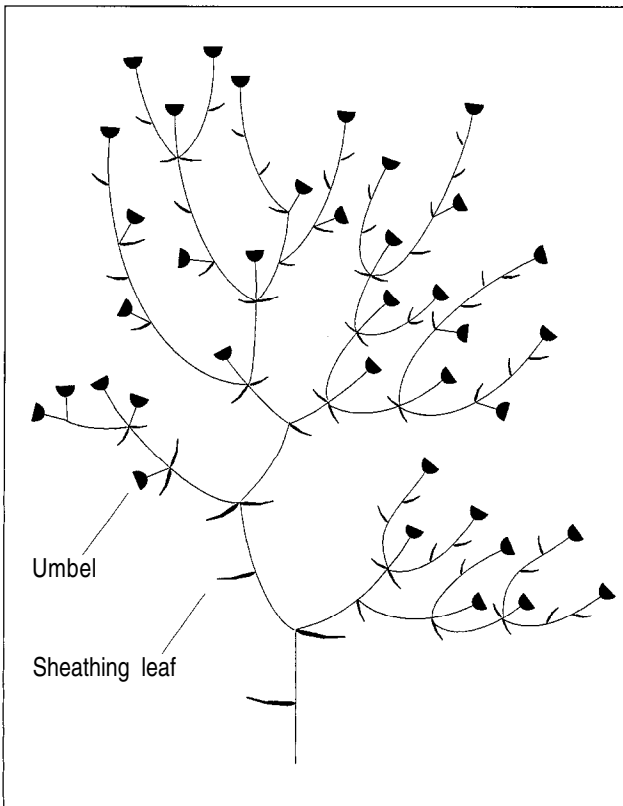


Fig. 7. Ramification of a (non-fruiting) generative shoot of *Arracacia xanthorrhiza* (schematic drawing of clone ECU-1223).

The first flowers of an umbel to commence anthesis are the perfect flowers of the outer umbellets. The development of such a flower is illustrated in Figure 9A-D. In the embryonic flower (Fig. 9A) the styles barely protrude from the perianth and their stigmatic surfaces lean against each other. Carpels and styles expand greatly until anthesis. Recent pollination experiments (Hermann, unpublished results) have shown that the stigma becomes receptive when the styles separate and display the stigmata as seen in Fig. 9B, C. At this stage, the stamens are still curled underneath the petals. Three to four days later, the stamens straighten, expand and project through the perianth, dehisce and release pollen (Fig. 9D). Anther dehiscence concurs with the peak of nectar production from nectaries on the epigynous disk. Anthers and petals now become caducous. During the entire flower development the petals remain curled.

Flowering progresses gradually from the periphery of the umbellet to the central staminate flowers and from outer to inner umbellets. Total flowering time of an umbel is about 15 days.

Generative characters of the arracacha plant show a certain variation that offers potential for the morphological differentiation of genotypes, a circumstance which is overlooked in arracacha germplasm characterization.

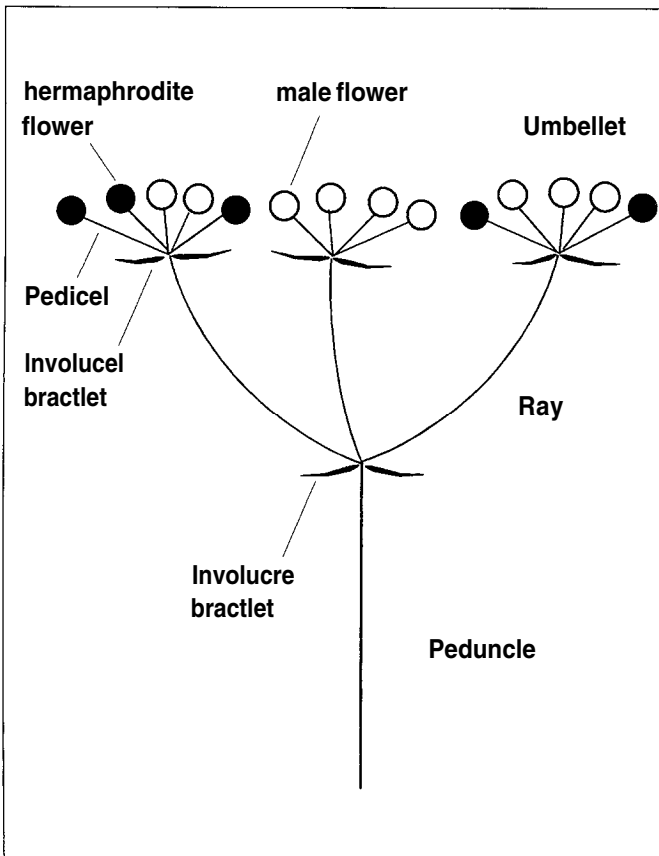


Fig. 8. Schematic drawing of the inflorescence (compound umbel) in genus *Arracacia* and terms to describe it.

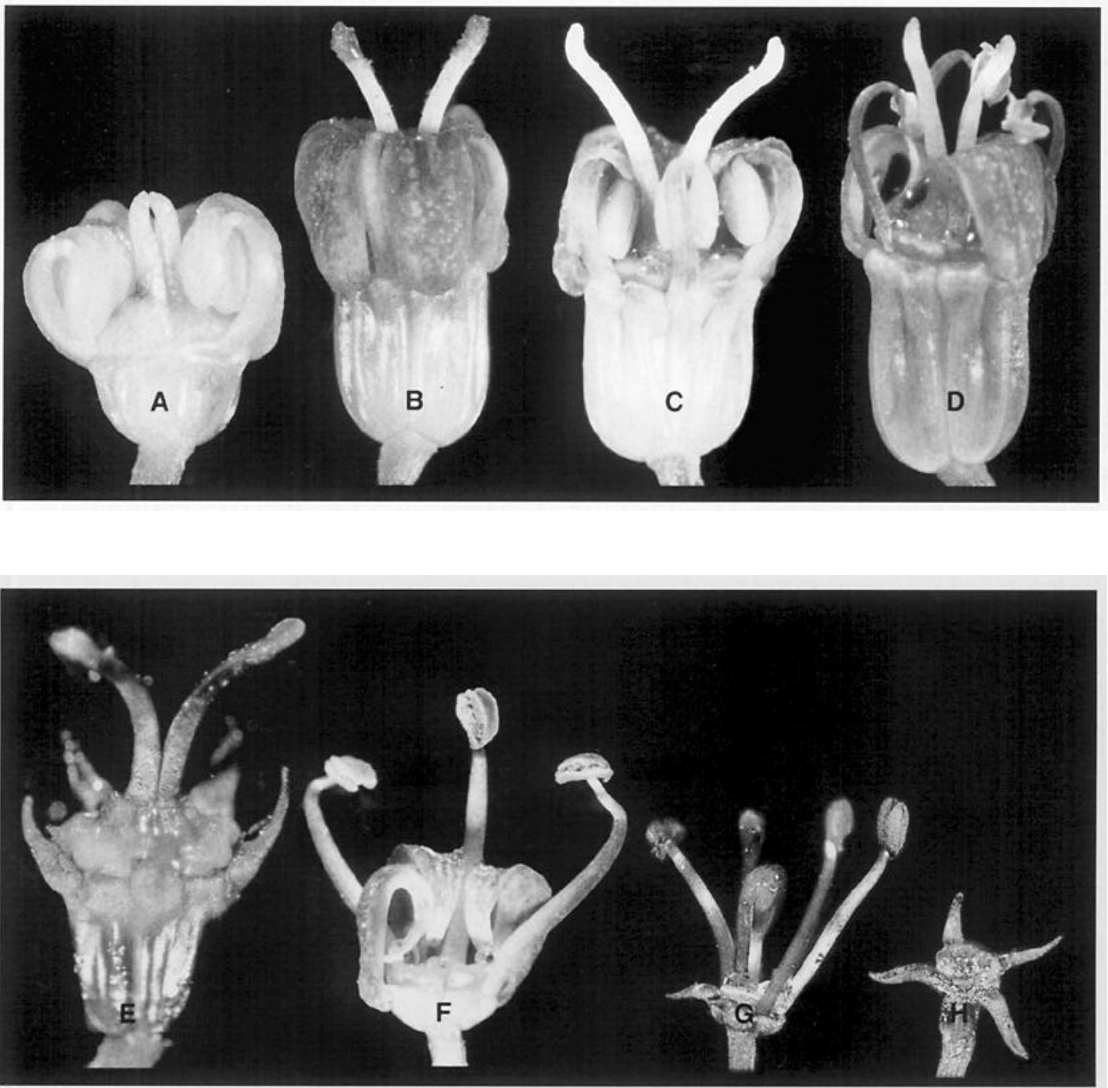


Fig. 9. Flower morphology and phenology of cultivated *Arracacia xanthorrhiza*. **A:** hermaphrodite flower a week before displaying stigmata (front petals and stamens removed); **B:** receptive hermaphrodite flower; **C:** receptive hermaphrodite flower with 2 front petals removed; **D:** hermaphrodite flower toward end of anthesis; note nectar production, dehiscent anthers and caducous petals; **E:** sepalous hermaphrodite flower, petals and stamens removed (length 4 mm); **F:** male asepalous flowers (2 petals removed); **G, H:** male sepalous flowers with dehiscent anthers, stamens and sepals partially removed. Length of hermaphrodite flowers from carpel base to stamen tips in B, C, D, E and A is 4-4.5 mm and 2 mm, respectively. Male flowers are 2-4 mm wide. Accessions JJV06 (A, B, C, D, F) and ECU1154 (E, G, H).

4.3 Reproductive biology

4.3.1 Flower induction

Whereas flowering arracacha can be observed only occasionally in the Andes (Bukasov 1930; Hodge 1954; Higuita 1970; Bristol 1988), flowering is frequent in Brazil, especially in the southern states of Minas Gerais, São Paulo and Paraná over 900 m altitude (Zanin and Casali 1984b). It is important to remember that arracacha production in this region is south of the 20th parallel, that is, south of the latitudinal range of Andean arracacha production. Seasonal variations in temperature and daylength in southern Brazil are therefore much more pronounced, and have been related to the seasonal pattern of arracacha flowering. Zanin and Casali (1984b) proposed that the low temperatures and/or short days at midyear induce flowering in commercial plantings from July to October. (Higuita (1970) also briefly mentions "low temperatures" as the cause for occasional flowering in Colombia.)

To test this hypothesis, Bajaña (1994) conducted a two-factorial greenhouse trial varying night temperatures (5-8°C vs. 12-15°C) and photoperiod (10 hours vs. 15 hours). Of the 10 genotypes used, only three flowered. Flowering responses were in general weak (only 15 out of a total of 160 plants). The treatments with short days and low night temperatures did not have statistically significant effects on flowering. In a collateral experiment, the same author removed the storage roots from mature plants and left the crowns to dry until they lost about half of their weight. Eighty percent of the replanted crowns flowered. Recent experiments with the same clone (from San José de Minas, Ecuador) showed that dehydration of mature plant crowns (20-30% weight loss) and subsequent culturing of the crowns induces, in over 90% of plants tested, the formation of nearly as many inflorescences as there are cormels in a plant (Hermann, 1996, unpublished results; see Fig. 6). These results confirm observations of Dr F.F. Santos in Brazil (1994, pers. comm.), who has repeatedly seen vigorous flowering responses in arracacha plantations that were subjected to drought, such as in abandoned fields in Goiás. Farmers in Ecuador also report increased flowering after spells of dry weather. Since drought (in Brazil) is often associated with short photoperiods and low temperatures, the effects of these factors cannot be separated. On the basis of present evidence, however, it is dehydration rather than vernalization that induces flowering in arracacha. In this context, it is perhaps noteworthy that the recently found putative ancestor of arracacha flowers after extended periods of drought (in the Ecuadorean Andes; see Section 6.2.1.5). By contrast, flowering in Old World apioid cultigens such as celery, carrots and parsley is induced by vernalization.

Flowering also seems to depend on genotype, as shown by Bajaña (1994) and observed by Plasencia and Huertas (1986) and in field collections in Brasilia by Dr F.F. Santos (1994, pers. comm.). The preliminary conclusion from these observations is that flowering is more easily induced in Ecuadorean accessions than in Peruvian and Brazilian cultivars.

4.3.2 Breeding system

As described in Section 4.2.2, the styles of the perfect flowers in a given umbel become receptive several days before the first stamens shed pollen. This phenomenon, known as protogyny, hinders self-fertilization and thus promotes outcrossing. Seed progenies of arracacha have been found to segregate considerably (Dr V. Casali, 1991, pers. comm.), which suggests a high degree of heterozygosity of arracacha cultivars and is consistent with the putative outbreeding nature of the species. The fact that spontaneous seed set can also be observed where only one clone is grown, as in Brazil, or in commercial plantations elsewhere, indicates that arracacha is sexually self-compatible, or at least is so for certain cultivars. In light of this preliminary evidence, arracacha appears most likely to be a facultative outbreeder.

4.3.3 Seed formation, storage and germination

The 'seed' of arracacha is shown in Figure 10. It is an achene or mericarp, a dry one-seeded fruit resulting from a schizocarp. At maturity, which is reached 8-10 weeks after pollination, the fruits are not shed but remain connected to a carpophore. Seed set is impaired or absent in sites that have comparatively high temperatures (Tacna, Peru; Brasilia) (Hermann, unpublished field observations). This is possibly due to the heat-induced internal breakdown of anther tissue which prevents the thecae from dehiscing and releasing pollen. During periods of daily peak temperatures above

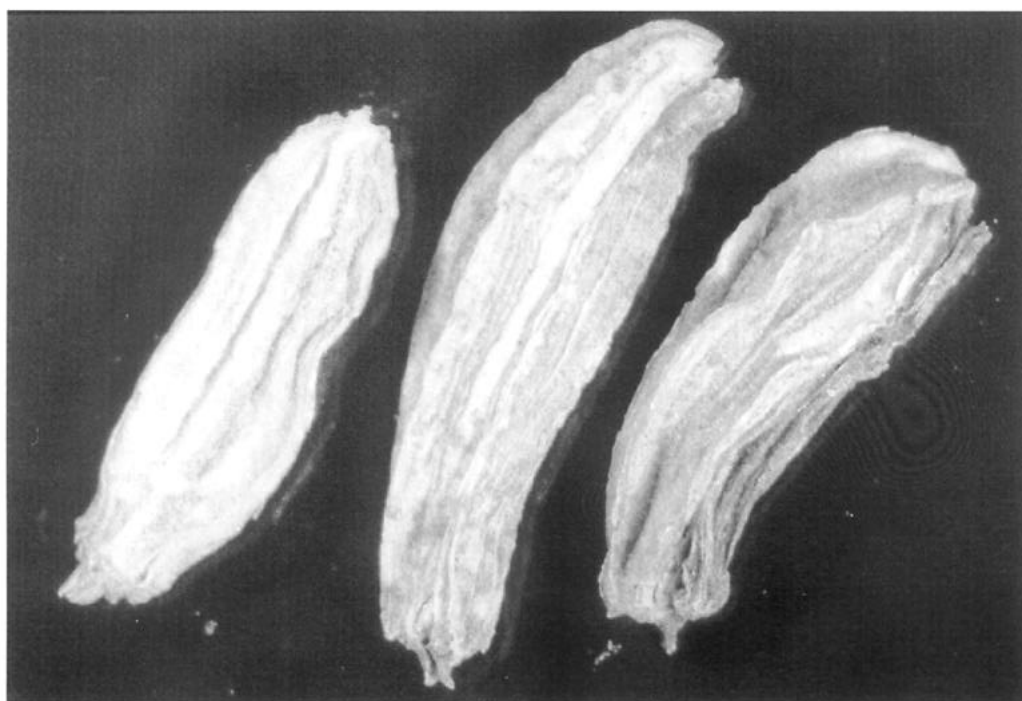


Fig. 10. Mature arracacha fruits (accession AMM5161). Length: 8-10 mm.

35°C and less than 30% relative humidity (as observed in Quito greenhouses), the anthers shrivel before they can shed pollen.

The seed of arracacha and other *Arracacia* species is orthodox, meaning that it can be dried to a low moisture content, which allows storage at temperatures below freezing point. Germination of recently harvested seed is rarely higher than 30%. The effects of plant origin, vernalization and seed treatment with chemicals and fungicides on germination have been studied to some extent, but no conclusive treatment to enhance germination has been identified (Sediyama 1988; Sediyama *et al.* 1990a, 1990b, 1991a). Larger seed, though, has significantly higher germination (Sediyama *et al.* 1991b).

4.4 Plant propagation

Plant propagation is the single most important issue in growing arracacha profitably. First, this is because the propagules can be produced on-farm, year after year, without degeneration of stocks. This, combined with robustness and nutrient efficiency, makes arracacha quite attractive to small farmers, who do not need to obtain credit to buy seed. Second, as will be seen below, root productivity depends greatly on the preparation of the propagule.

As outlined in Section 4.2.1, the cormel is used traditionally, and exclusively, as the propagule. Depending on age and development, the cormel has a few to several dozen buds, each of which has the capacity to sprout and form a new shoot, which

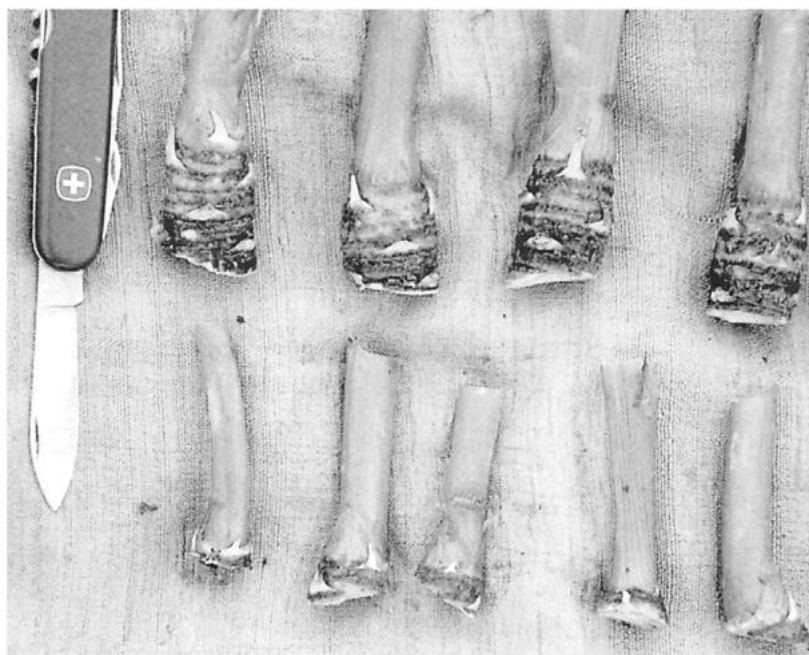


Fig. 11. Arracacha propagules. Propagules in lower row develop into more productive plants (with higher harvest index).

will swell at its base into a new cormel. A large or entire cormel, if used as the propagule, will therefore grow into a plant with many shoots (as in Fig. 3), whereas a propagule consisting of only the apical part of a cormel will result in a plant with fewer shoots, less foliage, smaller aerial parts and a higher proportion of total dry matter being allocated to the economic product, the storage roots (Casali *et al.* 1984). This relationship, which is rarely appreciated in the literature, is of the utmost importance for growing arracacha successfully.

Arracacha propagules can be taken at any stage of plant development. Senescent crowns from a mature crop are not really dormant (unlike those of *Arracacia andina*; see Section 6.2.1) and cormels taken from them will immediately root and sprout given appropriate conditions of temperature and moisture. To prepare the propagule, the cormel-offshoot is detached from the rootstock, and its leaves are trimmed back to leave only a few centimetres length of the petiole. Then the proximal two-thirds or three-quarters of the cormel are cut off in a slant cut, as seen in the upper row of Fig. 11. In the Andes, it is customary to cut a cross into the surface of the cut. This is believed to result in better spacing and a more equal lateral distribution of the storage roots. Before the propagules are planted, they are left for a few days to permit the cut surface to dry.

The more observant farmers are acutely aware of the importance of a good propagule with a minimum of eyes, yet one that has sufficient reserves to support post-planting dehydration and stress. As can be seen in Fig. 12, plants resulting from



Fig. 12. Mature 14-month-old arracacha plant from a commercial plantation in San José de Minas, Ecuador (1960 m altitude, 0°08'58"N, 78°24'15"W, annual precipitation 1000-1400 mm).

the right propagule can be tremendously productive. Such plants have as few as 10 shoots but no more than about 20, whereas more than 40 shoots (and cormels) are normally found on unproductive plants with 'hypertrophic' rootstocks. Table 4 provides data on dry matter partitioning of arracacha in three locations in highland Ecuador. Ironically, it is the small farmers of San José de Minas without access to 'technology' and 'advice' from research institutes who raise the most productive plants, with a harvest index of 82%. This is most remarkable for a root crop, especially for one that has never been 'improved' by plant breeding.

Table 4 also shows the extreme variation in dry matter partitioning of arracacha that can occur in different sites under different practices. This aspect must be observed in germplasm evaluation trials to ensure that genetic differences in plant architecture are measured and not phenomena that result from poor propagation techniques.

The multiplication rate of arracacha, that is, the number of propagules obtained from a mature plant through the conventional field method, depends on the number of cormels. In the Brazilian clone, the number of cormels per plant varies between 15 and 40 (Zanin 1985). Briceño (1977), evaluating 10 Bolivian, 12 Colombian and 4 Ecuadorean accessions, found the multiplication rates of this diverse material to range between 9 and 48 after one year of crop duration (mean and standard deviation: 27 ± 11 ; calculated from data in Briceño 1977). This rate, however, can be greatly increased by common horticultural methods such as bud cuttings, removal and rooting of sprouts from the planted cormel and other methods.

Table 4. Yield and relative dry matter partitioning (DMP) of mature arracacha plants in three locations in the Equatorial Andes

Variable	San José de Minas	Tumbaco	Cumbayá
Fresh root yield (t/ha)	35-52	n.d.	18-24
Total DM yield (t/ha)	6.9 - 10.2	n.d.	12-13
Single plant DM yield (g/plant)	345-1181	284 - 901	280-294
DMP rootstock (%)	0.03 ± 0.01	0.15 ± 0.08	n.d.
DMP cormels (%)	0.07 ± 0.01	0.49 ± 0.09	n.d.
DMP leaves (blades and petioles) (%)	0.07 ± 0.08	0.10 ± 0.08	n.d.
DMP rootstock + cormels + leaves (%)	0.18 ± 0.04	0.73 ± 0.23	0.55 - 0.68
DMP storage roots (%) (=harvest index)	0.82 ± 0.02	0.27 ± 0.12	0.32 - 0.45

Conditions of cultivation: *San José de Minas*: from commercial production by small farmers at 1960 m asl, crop 14 months old (source: Hermann, unpublished data); *Tumbaco*: germplasm field collection (accessions ECU1161, ECU1179, ECU1181), 2400 m asl, crop 20 months old (source: Hermann, unpublished data); *Cumbayá* Nestlé experimental station, 2500 m asl, crop 10 months old, derived from data in Raffauf and Izquierdo 1994; all localities near equator. (Example: "DMP rootstock (%) is the fraction of total plant dry matter accounted for by the rootstock.) n.d.= no data.

Tissue culture of arracacha from meristems or protoplasts has been pioneered by Brazilian authors (Reis *et al.* 1989; Pessôa and Esquibel 1991; Pessôa *et al.* 1991a, 1991b, 1994) but it is of no commercial relevance to date. Recent research (Landázuri 1996) identified promising culture media for shoot-tip culture and micropropagation. A protocol is now available to propagate the plant *in vitro* at a rate of six to one per 8-week cycle by using an MS medium supplemented with 3% sucrose, 56 ppm BAP (6-benzylamino purine) and 0.05 ppm ANA (α-naphthaleneacetic acid).

4.5 Crop husbandry

4.5.1 Planting

Generally, the unrooted propagule is planted at the onset of the rainy season. A very promising development in Brazil, promoted by extensionists and increasingly adopted by farmers, is the rooting of propagules and subsequent transplanting to the field. This improves early plant development and, as a classical horticultural technique, brings about a number of benefits, the most significant being more homogeneous plant canopies, reduced crop duration and higher yields (Câmara 1992, 1993). According to farmers in Goiás I have interviewed recently, pre-rooting of propagules takes about 45-50 days. It is conveniently achieved on small plots with improved soil substrate. At planting, transplants can be selected and subsequent crop establishment is rapid. As a consequence, the crop can be harvested 6-7 months after planting compared with a crop duration of 8-10 months for unrooted planting material. Planting densities vary between 15 000 and 30 000 plants/ha (Higuita 1970; Santos *et al.* 1993). Santos *et al.* recommend a spacing of 0.8 m between rows and 0.4 m within rows. This seems to be a common practice for growers in Brazil.

Popular belief in Northern Peru has it that during the planting season one should avoid sleeping with crossed legs as this will cause the storage roots to become twisted and result in deformed arracachas at harvest.

The reason for the slow initial plant development of arracacha is unknown, but possibly the early allocation of dry matter to storage structures (cormels and rootstock) causes reduced leaf area replication. Because initial plant growth is slow, arracacha is, in the traditional cropping systems of the Andes, often intercropped with maize, which matures after 5-6 months. Weeding, either mechanical or chemical (in Brazil), is needed during early crop development. Once the arracacha canopy closes, however, arracacha can form high leaf area indices and thus suppress weed growth.

Hilling is traditionally done in the Andes and in parts of Brazil. Farmers believe that this stimulates storage root formation. A recent experiment, however, has shown that hilled plants have reduced harvest indices and lower yields (Raffauf and Izquierdo 1994). Hilling (as well as deep planting) can lead to elongated and hypertrophic rootstocks. Farmers in Brazil are discouraged from continuing this practice because of doubtful benefits and the labour costs involved (Dr F.F. Santos, 1996, pers. comm.). Some caution is perhaps indicated to not prematurely dismiss hilling as inappropriate.

4.5.2 Fertilization

In the Andes, fertilizers are often not or only sparingly applied to arracacha. Higuita (1970) probably has Andean soils of poor fertility in mind when he recommends for Colombia 500-600 kg of compound fertilizer (N-P-K = 10-30-10 or 12-24-10). It is not clear whether this recommendation is based on experiments, but the suggested quantities do not emphasize nitrogen. In Brazil, arracacha is typically grown from residual nutrients left over from a preceding potato crop (Santos 1993). Santos *et al.* (1991) recommend, for the cerrado latosols (poor in P and K), 600 kg/ha of compound fertilizers (N-P-K = 4-14-8) and an additional 20 kg/ha of borax every second year. However, Mesquita-Filho *et al.* (1996), who investigated the effects of borax fertilization on loamy latosols, found that borax dressings of 60 kg/ha (in a range of 0-90 kg/ha) gave the highest arracacha yields. With nitrogen supplies higher than those indicated above, arracacha produces exuberant foliage, harvest indices drop and crop duration is prolonged.

4.5.3 Harvest

Root bulking is notoriously late in arracacha. Therefore, the crop is harvested, in general, not earlier than 10 months after planting, especially if unrooted propagules were used. Farmers, however, are compensated for the inconvenience of long crop duration by the possibility of leaving the crop in the ground for later harvest, either to profit from rising prices or to take advantage of seasonally changing availability of family labour. Typically, harvest takes place after 12 months but can be delayed up to 16 months after planting. Harvesting begins with completely pulling up the plants with the roots. The roots are easily broken away from the plant and the remaining crown is divided into rootstock (mostly for feed) and cormels. Often the entire crowns are left in a heap for a few days or weeks until needed for the preparation of propagules. To maintain a given area of arracacha, only one cormel per harvested plant is needed and the remaining aerial plant mass is used for feed or left to rot.

A continuous range of yields from 3 to 63 t/ha has been reported in a collection of Ecuadorean germplasm (Nieto 1993), but it is not clear how much of this variation is genetic. Yield figures usually include the storage roots as the only marketable product, but because of the highly variable dry matter partitioning of the plant, the total of roots and rootstocks would be a more appropriate measure for the capacity of the plant to build up starchy dry matter. For example, in varietal trials in the Sabana de Bogota comprising nine varieties, average yields of 20.1 ± 4.2 t/ha were reported, of which only 3.22 ± 1.78 t/ha were storage roots and the remainder were rootstocks (calculated from data in Higuita 1969). As will be seen in Section 5, the chemical composition of the rootstock is very similar to that of the storage root and could therefore have potential for processing.

In general, root yields are below 20 t/ha and reflect growth under residual nutrient availability. According to a nation-wide survey conducted by Santos (1993), average yields in Brazil are 8 t/ha. Where adequate care is provided to the crop through irrigation, fertilization and the use of appropriate propagules, arracacha

yields are well above the national average (>20 t/ha), even in the arid cerrado uplands of Goiás (1000 m altitude, 16° S), hitherto considered unsuitable for arracacha culture (Santos 1993).

4.5.4 Pests and diseases

Arracacha is generally regarded as a robust crop with few disease or pest problems if it is appropriately rotated. But insects, bacteria and fungi can cause significant damage.

According to my field observations, acari (*Tetranychus urticae*) harm the crop frequently and are the most widespread and serious arracacha pest (Normanha and Silva 1963; Higuaita 1969; Fornazier 1996). A beetle pest locally called 'chisa' is increasingly limiting arracacha culture in Tolima, Colombia (Mr J. Rivera Varón, 1996, pers. comm.; Sánchez and Vásquez 1996). 'Chisa' larvae mine the root and up to 40% of yield losses are reported. They belong to several genera of the subfamily Melolonthinae of the Scarabaeidae (*Cyclocephala*, *Ancognata*, *Phyllophaga*, *Serica*, *Macroductylus*, *Plectris*, *Issonychus*, *Anomala*). Sánchez and Vásquez (1996) claim that excessive use of pesticides occurs in Colombia to combat the pest. Other minor pests in Brazil include the moth *Agrotis ipsilon* and the mining larvae of the beetle *Conotrachelus cristatus* (Fornazier 1996). In Brazil, nematodes of genus *Meloidogyne* have become a problem, but they can be controlled readily by long rotations (Santos *et al.* 1991; Ventura and Costa 1996).

Among bacteria, *Erwinia* species are widely considered to be the most harmful to storage roots both in the field and in the store (Ventura and Costa 1996). *Erwinia* occurs especially at high temperatures. It infects the plant systemically and the disease is thus distributed via the propagules (Reyes 1970; Camino and Díaz 1972; Zapata and Pardo 1974).

A number of fungi attack different plant organs of arracacha. The most important disease in Brazil, especially in conditions of high soil moisture, is *Sclerotinia sclerotiorum*. It causes the plant and roots to rot and may lead to total crop losses. Rotation is recommended to combat the disease. Other fungi damaging the roots in the field and during storage include *Sclerotium rolfsii*, *Fusarium* sp., *Phoma* sp. and *Rhizopus* sp. (Normanha and Silva 1963; Ventura and Costa 1996). Leaf spot diseases in arracacha are caused by *Septoria* sp., *Cercospora* sp. and *Xanthomonas campestris* pv. *arracaciae* (Ventura and Costa 1996).

Several arracacha viruses and their features have been described (Jones and Kenten 1978, 1981; Kenten and Jones 1979), but it is not clear how they affect plant performance and yield. No degeneration of arracacha seed stocks has been observed as it occurs in the case of virus-infested potatoes. To date, five viruses infecting arracacha are known: AVA (arracacha virus A, nepovirus), AVB (arracacha virus B, nepovirus), the potyvirus AP-1, the carlavirus AV-3 and PBRV/A, a recently found variant of the potato black ring spot virus. PBRV/A was found to infect a range of potato cultivars (Lizárraga *et al.* 1994). Recently, simple and multiple virus infections were found in a sample of 40 plants belonging to 10 Ecuadorean arracacha accessions.

Only 23% of the plants were free of the five arracacha viruses tested. AP-1 and AV-3 were found in 53 and 38% of the plants, respectively (Mr L.M. Duque, 1996, pers. comm.). These two viruses also accounted for most of the infections found in a sample of Peruvian arracacha accessions (Lizárraga 1997).

4.5.5 Post-harvest

For a root, arracacha must be considered highly perishable and this constrains the commercial exploitation of the crop. Within a few days after harvest, and before the roots actually start to deteriorate, they develop brown spots, lose their brilliance and become unattractive in market displays. Also, large roots frequently crack at harvest even when carefully handled. The marketable life of arracacha at 25°C extends barely a week, the main cause for deterioration being rapid weight loss and subsequent rotting (Czyhrinciw and Jaffé 1951; Thompson 1980). Thompson observed that roots, at 18.5°C and 69% relative humidity, had lost 10.6% weight in 7 days. Under these conditions infections with *Rhizopus*, *Penicillium*, *Aspergillum*, *Nigrospora*, *Mucor* and *Syncephalastrum* occurred after 4 days. Arracacha is much more susceptible than carrot to mechanical damage which causes soft lesions and subsequent infections with opportunistic parasites (Henz 1995).

Deterioration, however, can be delayed over several weeks, either by reducing storage temperatures (3°C or 12°C; Czyhrinciw and Jaffé 1951), or, more economically, by measures that prevent root desiccation. A promising approach involves the application of plastic wrappings to individual roots. Using PVC cling or shrink films, Thompson reports a reduction of daily weight loss rate to less than 1 g/kg compared with about 17 g/kg for unwrapped roots. Likewise, Casali *et al.* (1988) found minimal weight loss (<1%) of roots “stored in polyethylene film” during 90 days at 5°C.

Leaving arracacha roots unwashed has also proved to enhance shelf-life (Thompson 1980; Câmara 1984b), but markets usually require washed roots. In this context, it is interesting to note that the Sibundoy Indians in Colombia used to bury harvested arracachas to keep them fresh for up to three weeks (Bristol 1988). Washing itself does not cause deterioration but rather the small wounds inflicted on the root surface during handling. These provide entry points for bacteria (Henz 1995). In Brazil, the most common post-harvest diseases are caused by the bacterium *Erwinia* and by the fungus *Rhizopus* (Henz 1995). Revetti (1967) reports doubled shelf-life after gamma-irradiation of arracacha.

Arracacha plant crowns discarded at harvest and often left near fields may survive for several months and this demonstrates that the storability of these parts is much better than that of the storage roots, despite the fact that they closely resemble the roots in chemical composition.

4.6 Crop ecology

No experimental data on the ecological requirements of crop growth of arracacha are available, but a number of conclusions can be drawn from the analysis of

temperature and rainfall patterns at arracacha-growing sites, which display enormously varying ecological conditions (Fig. 13). Altitudes range from 900 m (coastal Peru) to 3300 m (Peru, Bolivia) and annual rainfall varies from 0-30 mm (coastal Peru) to 5000 mm (Sibundoy, southern Colombia). Near the equator, arracacha is grown in the diurnal climate of tropical highlands, usually above 2000 m altitude. Farther away from the equator, such as in the subtropical climates of southern Brazil (not south of 26° S) the seasonal variation of temperature (and daylength) is much more pronounced and the crop is confined to lower altitudes where mean daily minimum temperatures during the cold season are above 5°C. Because frost kills the plant, plantations at high altitudes in southern Brazil (>1000 m) are at risk in the three coldest months of the year. If cultivars with reduced crop duration became available, arracacha could possibly be cultivated in the 7-8 frost-free months of many climates at higher latitudes and altitudes. It is not clear why the plant is not cultivated in the tropical lowlands, but there is some evidence from Florida that arracacha does not produce storage roots in hot and wet environments (Hodge 1954). On the other hand, I have recently seen well-developed arracacha plantings with precocious storage root bulking in the hot, albeit semi-arid, conditions of the upper São Francisco valley (northern Minas Gerais, Brazil; locality: Mocambinho, 14°55' S, 43°57' W, 450 m altitude; mean daily minimum (maximum) temperatures: 15-20 (30-33)°C). It remains to be seen whether arracacha can be cropped sustainably in the hot tropics where pests and diseases, particularly bacteria afflicting storage roots, are often more of a problem than in cooler environments. Mean monthly temperatures in arracacha-growing sites vary mostly between 15 and 20°C; they rarely exceed 20°C (see Fig. 13).

Although the formidable storage tissues of arracacha may confer some resistance against temporary drought, the plant thrives best when soil moisture is available throughout the cropping cycle. This may partly explain the widespread cultivation of arracacha in the humid Venezuelan and Colombian Andes with their bimodal rainfall patterns (see climate diagrams for Mérida, Bogotá and Pasto in Fig. 13). Also the rather wet conditions of Paraná, southern Brazil (exemplified by the diagram of Curitiba, Fig. 13), and of the Amazonian slopes of the Andes (no diagrams shown) allow its rain-fed cultivation with annual precipitations well over 1000 mm. However, root yields can double in southern Brazil when supplementary irrigation is provided (Dr F.F. Santos, 1995, pers. comm.). At sites with pronounced dry seasons (usually with less than 1000 mm precipitation) or in arid environments, however, arracacha needs to be irrigated; examples include the inter-Andean valleys, which lie in the rain shade of the Eastern Cordillera (see diagrams for Ambato and Cochabamba in Fig. 13) and the oases of the Peruvian and Chilean coastal desert (for example Tacna; see Fig. 13).

In conclusion, arracacha is largely restricted to relatively cool, but frost-free, montane tropical environments; it thus resembles arabica coffee in ecological requirements although the latter crop might be somewhat less cold tolerant. It should be possible to crop arracacha where arabica coffee has been successfully grown.

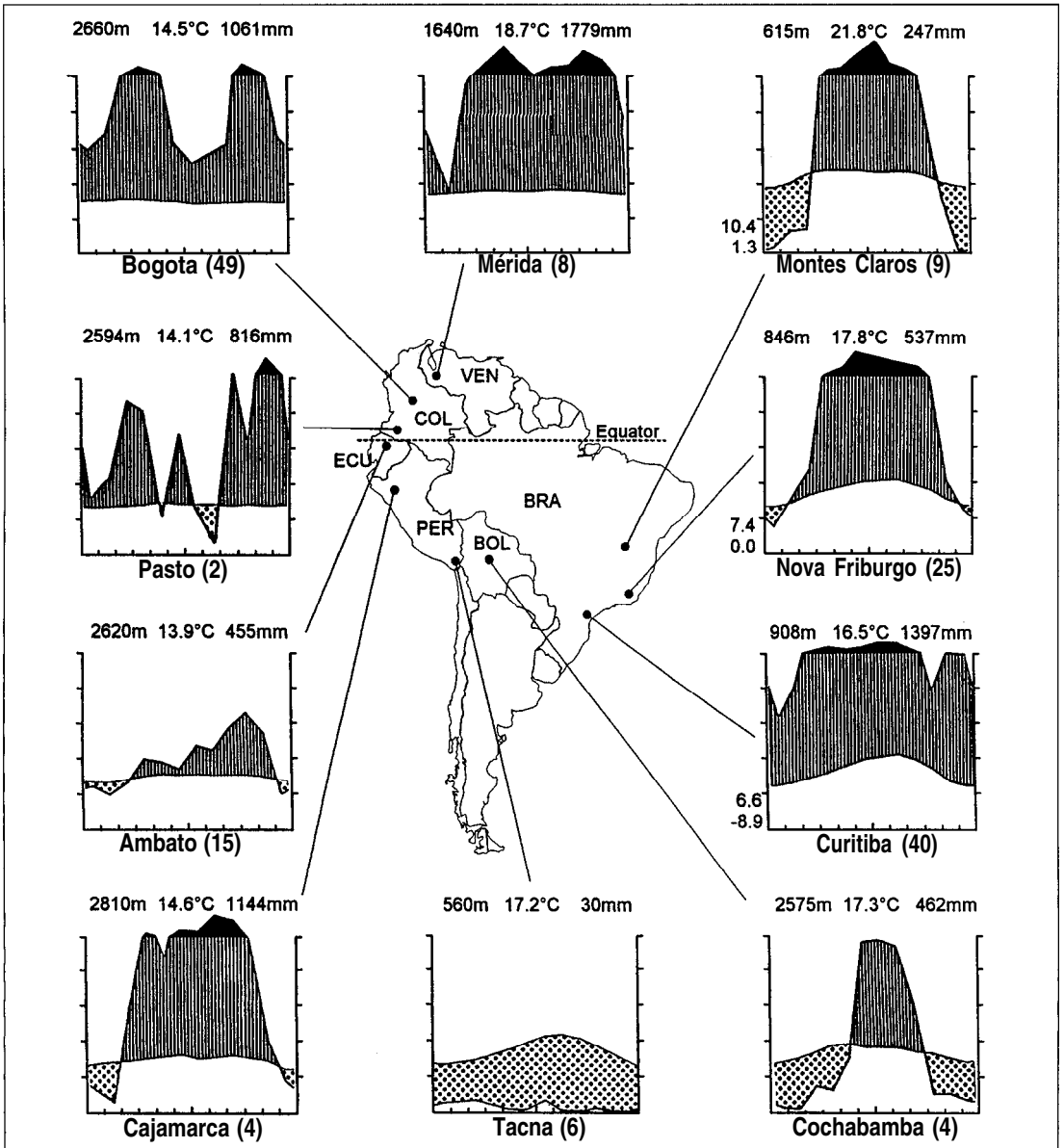


Fig. 13. Climates of arracacha growing sites. The lines in each diagram provide mean monthly temperature and precipitation data; units on left and right vertical axes are 10°C and 20 mm precipitation, respectively. Arid periods are represented by dotted areas (when the precipitation goes below the temperature curve). Humid periods are indicated by hatched areas. Periods with monthly precipitation above 100 mm are in solid black and reduced in scale by 1 : 10. Altitude (m), yearly mean temperature ($^{\circ}\text{C}$) and yearly mean precipitation (mm) are given on top of each diagram; numbers to lower left indicate (where available) the mean daily minimum temperature of the coldest month (Curitiba: 6.6°C) and the lowest temperature ever measured (Curitiba: -8.9°C). Numbers following the location name are years of meteorological observations. Source of diagrams: Walter and Lieth (1960).

Indeed, arracacha culture often provides an alternative for small producers abandoning coffee cultivation for lack of profit or because of phytosanitary problems (Colombia, Brazil).

Little else can be said about the crop ecology of arracacha, except perhaps that the susceptibility of its storage root formation to environmental conditions deserves further study. For example, storage root initiation and bulking of arracacha are retarded by conditions that induce lush foliage growth as observed in fields of high nitrogen availability or excessive irrigation (Dr F.F. Santos, 1995, pers. comm.). Arracacha forms only minute storage roots in container culture as various trials under a variety of nutrient and temperature conditions in Quito greenhouses have shown. Clearly, this sets arracacha apart from other crop plants including sweetpotato, potato and the other species discussed in this volume, which readily form tubers or storage roots in pots.

Daylength effects on root formation of arracacha have not been reported yet. Daylength appears to have no influence on flower induction (Bajaña 1994; see also Section 4.3.1).

5 Utilization

"The root yields a food, which is prepared in the same manner as potatoes, is grateful to the palate, and so easy of digestion, that it frequently constitutes the chief aliment of the sick. Starch and pastry are made from its fecula; and the root, reduced to pulp, enters into the composition of certain liquors, supposed to be efficacious as tonics. In the city of Santa Fé, and, indeed, wherever it can be produced, the arracacha is as universally used as the potato is in England."

M. Vargas describing in 1805 the use of arracacha in his native Colombia, especially in Bogotá (as quoted in Hooker 1831).

Arracacha is grown for its storage roots and, overwhelmingly, these constitute the principal economic product. However, all harvestable plant parts can be used for human and animal nutrition. The texture and chemical composition of the rootstock and cormel are similar to those of the storage root, but the rootstock is somewhat more fibrous (Higueta 1969). The rootstock is even superior in nutritional quality, as it has elevated protein (1.3 times) and mineral contents (e.g. calcium 2.1 times) compared with the roots (calculated from data in Camara 1984a; data from Brazilian commercial clone only). Table 5 compares dry matter content and its variation of the root, rootstock and other harvestable plant parts for different clones and growing sites. According to this table, dry matter of the rootstock varies more than that of other plant parts. Cormels always have lower dry matter content than either roots or rootstocks.

Table 5. Variation in dry matter content (%) of arracacha by plant part

Plant part	Commercial Brazilian clone (1)	Ecuadorean clones (2)	Commercial crop, Ecuador (3)
Storage roots	24.5 ± 0.8	19.4 ± 1.4	19.6 ± 0.3
Rootstock	23.5 ± 1.0	20.4 ± 4.5	15.4 ± 1.6
Cormels	n.d.	15.7 ± 1.6	13.9 ± 1.0
Leaves (including petioles)	n.d.	11.2 ± 0.8	9.6 ± 0.6
Leaf blades	18.0 ± 1.8	n.d.	n.d.
Petioles	8.2 ± 0.6	n.d.	n.d.

Source and growth conditions: (1) Calculated from data presented in Câmara 1984a, experiments in Viçosa, Minas Gerais (Brazil), only values for plants harvested between 8 and 11 months are taken into account; (2) Hermann, unpublished data, clones ECU1161, ECU1179, ECU1181, germplasm field collection, 2400 m asl, plants 20 months old; (3) Hermann, unpublished data, from commercial production by small farmers in San José de Minas, Pichincha, 1960 m altitude, crop 14 months old.

n.d. = no data.

In the Kamsá language of the Sibundoy Indians of southern Colombia, the same words denote both arracacha roots and rootstock (Bristol 1988; see Table 3). Indiscriminate use and preparation of both parts for food and lumping them in one pile during harvest, as observed by Bristol in 1962-63, corroborates that the Sibundoy indeed have no concept for roots as opposed to rootstock in arracacha. In his noteworthy review on the ethnobotany of arracacha in Colombia, Hodge (1954) pictures a Bogota vegetable vendor selling arracacha rootstocks, presumably for human consumption. Fifteen years later, presenting yield responses in nine Colombian genotypes, Higuira (1969) pooled root and rootstock weights to give "total yields". This probably indicates widespread commercial use of the rootstock in Colombia at the time of publication of the article. According to Mr J.J. Rivera (1996, pers. comm.), the use of arracacha rootstocks is still common in the Colombian department of Boyacá.

Usually, however, the rootstock and aerial plant parts (cormels, petioles and leaf blades), which can account for a considerable part of total biomass, are fed to domestic animals, especially pigs. The tender petioles and leaves have been reported to be eaten in Cuba (see Section 2.3.3), but I have never encountered this practice during extensive travel in South America nor references to it. Non-food uses of cultivated arracacha or its processed products have, to my awareness, not been recorded. (See, however, the medicinal uses of wild *Arracacia* species described in Section 6.2.1.5).

5.1 Chemical composition and its variation

Root dry matter of arracacha can range from 17 to 34% of the fresh weight according to data in the literature (reviewed in Pereira 1995; see Table 6). Values beyond 30%, however, occur only in genotypes which were recently selected by Brazilian researchers (Santos and Pereira 1994). Relatively high dry matter values have been reported from commercial ware in Venezuela (27%; Czyhrinciw and Jaffé 1951) and Colombia (24-28%; Higuira 1968, 1969) and from trials in Brazil (22-25%; Câmara 1984a). In Ecuador, a lesser range of 16-20% has consistently been found (Mazón *et al.* 1996; Hermann, unpublished data). The overwhelming part of arracacha root dry matter is carbohydrates, of which about 95% is starch and 5% is sugars (mainly sucrose) (Câmara 1984a).

Data in Table 6 show that arracacha is also a good source for ascorbic acid, vitamin A and minerals, especially calcium. The daily requirements for these nutrients can be met by consumption of comparatively small amounts of arracacha. The root, however, is a poor source for protein, with an average of about 1% protein in the fresh matter or 4% protein in the dry matter. There are conflicting reports as to the most limiting amino acid in arracacha protein: analyses reported in Câmara (1984a) identify lysine, whereas Pereira (1995) concludes from independent results that isoleucine is in the minimum compared with the FAO standard protein.

As can be seen in Table 6, vitamin A or carotenoids are by far the most variable nutrients, with the maximum value being 27 times the minimum observed. Carotene

is a pigment and its varying concentrations cause the wide range of root colours from white over cream to yellow and orange in arracacha germplasm collections. Studies by Almeida and Penteadó (1987) showed that b-carotene is the principal carotenoid present in the commercial Brazilian clone (86 mg/100 mg edible portion) and that 30% of it is lost by cooking roots for 10 minutes.

Table 6. Variation in chemical composition of arracacha roots (per 100 g edible portion)[†]

Component	Unit	Mean	Range	Max./Min. [‡]
Total solids	g	26.0	16.8 - 34.1	2.0
Carbohydrates	g	24.9	19.3 - 29.9	1.5
Starch	g	23.5	16.9 - 25.5	1.5
Total sugars	g	1.66	0.65 - 1.98	3.1
Proteins	g	0.96	0.60 - 1.85	3.1
Lipids	g	0.26	0.19 - 0.35	1.8
Fibre	g	0.85	0.60 - 1.24	2.1
Ashes	g	1.30	1.05 - 1.38	1.3
Ascorbic acid	mg	23.0	18.3 - 28.4	1.5
Vitamin A (carotenoids)	I.U. [§]	1760	255 - 6879	27.0
Thiamine	mg	0.08	0.02 - 0.12	6.0
Riboflavin	mg	0.04	0.01 - 0.09	9.0
Niacin	mg	3.45	1.00 - 4.50	4.5
Pyridoxine	mg	0.03	0.01 - 0.07	7.0
Calcium	mg	65	45 - 128	2.8
Magnesium	mg	64	55 - 98	1.8
Phosphorus	mg	55	33 - 159	4.8
Iron	mg	9.5	3.6 - 15.4	4.3
Potassium	mg	2.40	1.86 - 3.04	1.6

† Adapted from Pereira 1995 (based on a literature review and the author's results).

‡ Author's calculations.

§ International units.

5.2 Food uses

The use of arracacha in food, whether for direct consumption or for processed products, can be explained in terms of three characteristics: starch content and quality, colour and flavour. Particular, and not yet understood, functional properties of arracacha starch are of crucial importance for most dishes and processed products. There is also a widespread belief that arracacha (or its starch) is easily digested and

therefore an ideal food for children and the ailing. Hodge (1954) claims that arracacha starch is less flatulent than the starch of potato (*Solanum tuberosum*). In Loja, southern Ecuador, a strict 40-day diet commonly followed by women after giving birth includes arracacha to the exclusion of potatoes (Mrs Joy Horton de Hofmann, 1997, pers. comm.). Arracacha adds unique colours to dishes and processed products, especially the yellow-rooted clones, which assume a vivid orange colour after heat treatment. Opinion as to the umbelliferous aroma of arracacha, however, is divided. Some people are fond of it, and others loathe it. It is a unique aroma, but it is clearly reminiscent of parsley, celery and other umbelliferous vegetables.

Unlike many other roots, arracacha is not unpleasant to eat raw, but cooking is required to soften its tissue and gelatinize its starch, thus rendering it more digestible. This is why arracacha roots are never eaten raw. Even thinly sliced, arracacha does not hold much promise for applications in salads or other raw food, as it lacks the acid or sweet compounds present in oca (*Oxalis turbeuosa*) and ahipa (*Pachyrhizus ahipa*) which, combined with special textures, provide interesting new tastes.

5.3 Direct consumption

Traditionally, arracacha is used in soups, purées and especially stews locally called *chupe* (Peru), *locro* (Peru, Ecuador), *sancocho* (Colombia) and *cocido* (Venezuela). The classical sancocho and the closely related cocido include meat, pork, potato (*S. tuberosum*), cassava, plantains, arracacha, optional pork sausages, onions and the indispensable leaf coriander (*Coriandrum sativum*). Variations of this dish include *viudo de pescado* from the Magdalena valley (Tolima, Colombia), in which fish replaces meat and pork, and the *mondongo* from Antioquia, a stew with arracacha, potatoes, sausages and beef tripe as the characteristic ingredients.

Soups and purées having arracacha as their main starchy ingredient are deliciously creamy and light food. Frying arracacha also gives interesting results; however, it reduces the typical arracacha aroma and deep-fried arracacha strips are, especially when made from the white-rooted, less aromatic clones, virtually indistinguishable from (potato) french fries. Frying also compromises reducing sugars in the Maillard reaction, and produces dark and undesirable colours in some arracacha genotypes that are presumably high in reducing sugars.

Modern Brazilian cuisine has added quite a few creative arracacha recipes. *Soufflé de mandioquinha-salsa* requires cooked and hot arracachas to be mashed and mixed with butter and egg yolks. After stiffly beaten egg-whites are folded into this mixture, it is baked to expand greatly in volume (Sangirardi 1988). Rio de Janeiro has invented *batata baroa em calda* (arracacha compote), which involves blanched arracacha pieces being cooked in dissolved sugar (Weiss 1995) as is also done with a variety of fruits. Another popular arracacha dessert comes from the northern Andes. Called *pasteles* in Ecuador or *buñuelos de apio* in Venezuela, this recipe calls for the cooked and mashed arracacha roots to be mixed with butter, eggs and sugar. This mass is shaped and fried in oil. A salty version of this dish is equally popular in Venezuela (Dr Maria L. García, 1996, pers. comm.).

In Minas Gerais, Brazil, descendants of Italian immigrants use arracacha instead of potato in the well-known gnocchi dish. This gives a special and light consistency and arracacha is thus preferred over the original ingredient. Sokolov (1993) mentions the use of arracacha in the *alcapurrius* of Puerto Rico. This is a fritter whose dough is a mixture of purees from arracacha, glutinous plantain and starchy yautía (*Xanthosoma sagittifolium*). This dough is stuffed with a meat filling, shaped into fritters and deep-fried.

In Costa Rica, arracacha is used finely chopped and fried with minced meat and onions as a filler in *tortillas de maiz*. This traditional dish is called *picadillos*; it is served during church celebrations on patron saint's day (Drs J. León and N. Mateo, 1996, pers. comm.). In conclusion, arracacha offers a great variety of culinary uses, which is unsurpassed by other starchy roots and tubers.

5.4 Processing

Arracacha is overwhelmingly used for direct consumption, but several processed products would almost certainly be produced in higher volumes were it not for the elevated raw material prices that result from the popular esteem of the root for direct consumption. The almost complete absence of processed arracacha in the Andes, however, can only be explained in terms of a lack of entrepreneurial initiative since the crop can be produced with great ease and is relatively inexpensive. On the other hand, Brazil has a wide range of processed products, but its companies struggle with high raw material costs that limit the proportion of arracacha in processed products (Hermann 1995).

5.4.1 Instant food

In its processing plant in San José de Rio Pardo, São Paulo state, Nestle-Brazil uses arracacha as an ingredient in both wet and dry formulae of instant soups and baby food. In fact, all non-sweet Nestlé products in Brazil contain some arracacha, but only up to about 15% of total product dry weight. The particular flavour and food consistency achieved by using arracacha are considered decisive for its use. The company processed about 300 t of arracacha annually between 1985 and 1993.

Nutrimental, a company in Curitiba, Paraná, Brazil, specializes in the production of dehydrated vegetables, which are sold to other food-processing companies such as Knorr for use in dry formulations of purees and soups (Fig. 2D). Nutritional produces flour and flakes from arracacha. The bright orange colour of dehydrated arracacha flakes is particularly attractive and not found in other vegetables (dehydrated carrots are deep red). Processing involves abrasive peeling, slicing, blanching and drying flakes batch-wise in forced-ventilated ovens. Nutritional processed 400 t of arracacha in 1991. Nutritional managers are considering the development of an instant purée for infants based on arracacha because of the good reputation this dish enjoys with the population (Hermann 1995).

5.4.2 Chips

Arracacha chips have been available for several years in Quito supermarkets from production by the Quiteña company in Calderón, near Quito. This company processed 50 t of fresh roots in 1994. Although the quality of these chips leaves room for improvement, they sell well, and with a better supply of raw material, the company could sell more. Arracacha processed in Quiteña comes from San José de Minas in Pichincha province. It is comparatively low in dry matter (up to 20%) and darkens after frying, as do a few other Ecuadorean clones tested so far (Hermann 1996).

Promising results with arracacha chips have been achieved in pilot trials at the Krebauer company, Brasilia, using the traditional Brazilian clone. Experiments yielded arracacha chips of excellent quality and acceptance. Crispness was similar to that of potato chips, but a trained panel consistently rated the appearance of arracacha chips superior to that of potato chips. Panelists emphasized the light sweetness of arracacha chips as an attractive and distinctive feature. Additional advantages included lower fat absorption, the possibility of direct packing and reduced frying temperatures (Santos and Hermann 1994).

5.4.3 Starch

Arracacha starch was widely used for pastry in Colombia during the first half of the 19th century. In 1831, Hooker wrote: “The root [of arracacha] rasped and macerated in water, deposits a fecula, which is in very general use at Bogotá, as a light nourishment for the sick, in the same manner as the fecula of the *Maranta arundinacea* is in Jamaica” (Hooker 1831; see also epigraph in Section 5). Today, arracacha starch is sporadically extracted in Colombia, but this is no longer of commercial significance. In 1994, I observed rural women in Huila use the starch for small spongy cakes called *bizcochuelos* (for example Doña Lucila Jiménez, El Grifo, Municipio Altamira). In Manta, Cundinamarca, arracacha starch has been used in the past for *bocadillos* (cookies); however, the industry is about to disappear and only one starch processor has remained (Mr Gómez; Dr Isabel Hernández, 1994, pers. comm.). The extraction of starch from arracacha (and other roots and tubers, such as *Canna edulis*, cassava and *Maranta arundinacea*) is basically the same in rural households throughout Colombia. The roots are washed, peeled and grated over a metal sheet, which is perforated with a nail to provide an abrasive surface. The resulting pulp is suspended in water and subjected to several cycles of washing and settling until a white and clean starch sediment is obtained. Households produce hardly more than a few pounds for home consumption or *para el gasto* as people in the northern Andes say.

The only evidence for commercial arracacha starch use comes from the Bogotá-based Ramo company, whose production philosophy is to systematically retrieve traditional cookie recipes and turn them into modern products. The company has offered for decades a successful product line, called *colaciones*, which is a traditional Colombian assortment of cookies. To achieve particular textures in this product, Ramo employs a number of starches, mainly from cassava and achira (*Canna edulis*), but also small amounts of arracacha starch, which was found to enhance crunchiness

in the baked product. The company does not reveal product compositions, but annual use of arracacha starch in 1994 was said to be 5 t, all derived from a company-owned extraction plant. Research at Ramo's laboratories resulted in the development of several pastry products with elevated arracacha starch contents (up to 30%), such as *bocadillos* and *bizcochitos*, but because of problems with arracacha starch supply these products can not be launched yet (Hermann 1994).

Arracacha starch is of a brilliant white colour and has comparatively small granules. In a given sample, the granules between 5 and 35 μm diameter, generally account for 80-95% of total starch volume (as determined with a laser diffraction counter). The granule size distributions for storage roots, rootstocks and cormels (of an Ecuadorean clone) are quite different (Fig. 14). With an average diameter of 17.2 μm , starch granules in roots are bigger than those found in cormels (11.1 μm) or rootstocks (13.3 μm). The size range of cormel and rootstock starch granules, both absolutely and in relation to average size, is narrower than the size range of root starch.

However, viscoamylography shows that during gelatinization there are no significant differences between the starches from different plant fractions. Peak viscosity of arracacha starch measured with a rapid viscoanalyzer (RVA) was lower than that of potato, oca (*Oxalis tuberosa*), achira (*Canna edulis*) and ulluco (*Ullucus tuberosus*) starches (concentration: 2 g/25 ml). Initial, peak and final gelatinization temperatures recently measured by differential scanning calorimetry (DSC) were found to be 50, 58 and 67°C, respectively. The gelatinization enthalpy as revealed by DSC is 2.9 J/g dry starch (Hermann, unpublished results). Amylose content was determined by Dufour *et al.* (1996) in Colombian material (18.5%) and by Villacrés and Espín (1996) in six Ecuadorean clones (average: 20%). Raffauf and Izquierdo (1994) give a range of 10-12% of amylose obtained in different plant parts and under different growth conditions of one Ecuadorean clone. Amylose-free arracacha cultivars have recently been found in Colombia (Dr D. Dufour, 1997, pers. comm.).

The opportunity for arracacha starch on the market lies perhaps with its exceptionally low syneresis³ (Raffauf and Izquierdo 1994), even at low acidity (pH = 2.4; Dufour *et al.* 1996). Usually, syneresis in food products is minimized by the use of modified starches. These, however, are increasingly perceived as 'unnatural' ingredients and replaced with native starches to give 'ecological' appeal to processed food. Moreover, native starches are considered food ingredients rather than additives and their proportion in processed food is not subject to regulations. This prompted Raffauf and Izquierdo (1994) of Nestlé's Latin American Research & Development Center near Quito to explore yield potential, extractability and production economics of arracacha starch. It is not clear whether Nestlé contemplates product development involving arracacha starch.

Starch use could add considerable value to the conventional production of arracacha for the fresh market, as starch is also contained at high levels in rootstocks

³ Exudation of a liquid from a starch gel, for example in food products subject to freeze-thaw cycles.

and cormels. These account usually for much of the total biomass (see Table 4) and are often left to rot in the field. The costs of starch manufacture from harvest residues and non-commercial roots would essentially be those for transport and processing.

Starch from arracacha roots, by contrast, would be much costlier to produce as the raw material is highly valued on the fresh market. It remains to be seen whether root starch can be produced at competitive prices and/or whether niche markets can be identified, for example in the food industry, where specific starch qualities are required (see above). Cost estimates based on different scenarios range from US\$1.33/kg of arracacha starch in Colombia (Hurtado *et al.* 1997) to US\$2.57/kg in Ecuador (Raffauf and Izquierdo 1994). These estimates do not take into account the possibility to reduce costs by selecting clones high in starch content. Likewise the potential for improving extraction efficiencies was not considered by Hurtado *et al.* (1997) who report starch yields of only 6-11% per root fresh matter and extraction efficiencies as low as 24-50% of starch per root dry matter, which may have resulted from the use of inadequate equipment. Although data provided by Raffauf and Izquierdo (1994) were from 10-month-old (and prematurely harvested?) plants, their experiment shows that arracacha can be an interesting starch source when roots and

Fraction of total starch volume

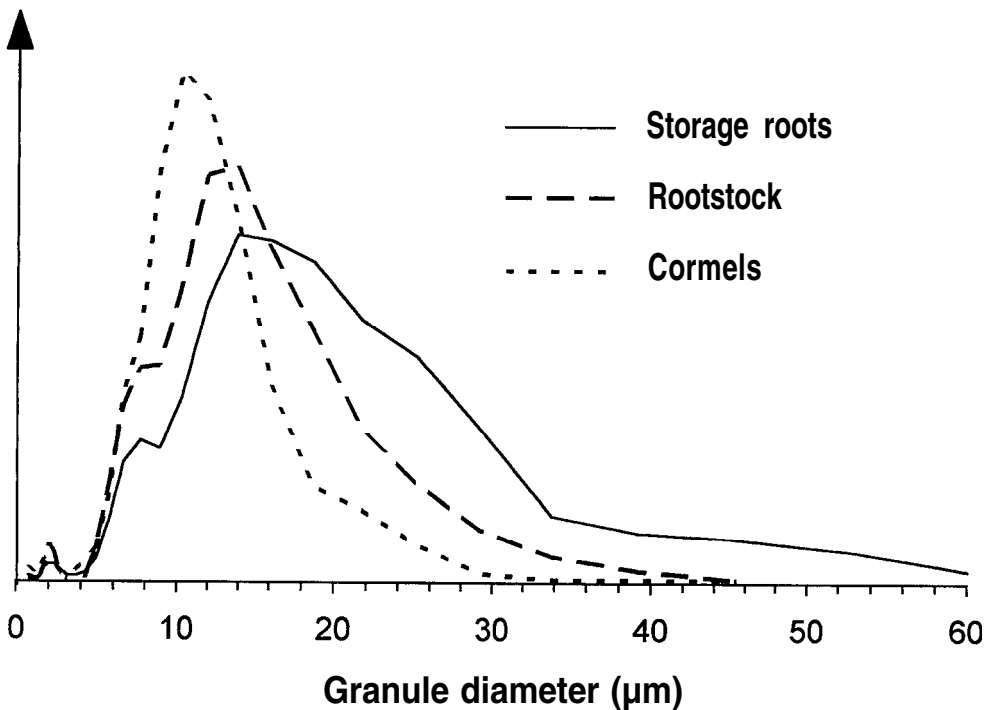


Fig. 14. Granule size distribution of arracacha starch from different plant parts (determined with a Malvern Laser diffraction counter). Accession ECU1181; culture conditions: plants grown in Tumbaco, 2400 m asl; planted July 20, 1994, density 1.00 x 0.80 m, harvested March 20, 1996.

crowns are processed: starch yields were between 4.7 and 8.0 t/ha and 14-18% of fresh matter and the extraction efficiency varied between 64 and 68%.

5.4.4 Fermentation

During field work in Quetame, Cundinamarca, I recorded a use of arracacha that still seems to be common in that part of Colombia. *Guarapo de arracacha* or *chicha de arracacha* is a mildly alcoholic beverage.⁴ Its preparation is similar to that of the Amazonian *masato*, which is made from cassava. To prepare *guarapo*, boiled arracacha roots are ground and allowed to cool for a night. Then the ground mass is passed through a cloth or screen, water and raw sugar are added and the mixture is left to ferment for 3 days (information from José Vicente Rojas Torres, Finca Mermejil, Estaquecá, 1994) (Hermann 1994). Bristol (1988) mentions the former use of arracacha for chicha-making among the Sibundoy Indians (southern Colombia) and there is a reference to it for the Colombian Orinoco and Amazonas (Duque 1994). It has also been reported from Peru (Hermann, 1988, field notes).

⁴ The term 'guarapo' in general is reserved for fresh and fermented sugar cane juice: 'chicha' denotes maize beer.

6 Taxonomy and biosystematics

6.1 Umbelliferae

There are an estimated 300 genera and between 2500 and 3000 species in this family, which is also called Apiaceae. The Umbelliferae are cosmopolitan but rare in lower latitudes. A little less than one-third of the umbelliferous species occur in the New World, a figure approximating the proportional land mass (Mathias 1971). Umbelliferae are frequent in temperate highland areas and particularly diverse in moderate climates and in the Mediterranean (Heywood 1978). In the tropics, many species occur at high altitudes (Friedberg 1978), some well above the tree limit (Maas and Westra 1993).

Chemically, the Umbelliferae are characterized by high contents of essential oils, coumarins, polyacetylenic constituents and flavonoid compounds. The seeds contain aleurone grains (reserve store of proteins) but are free of starch. Sucrose is the main sugar in subterraneous storage organs (Hegnauer 1978).

The Umbelliferae is a family of eminent economic importance. Its uses involve storage roots (*Bunium bulbocastanum*, *Daucus caudata*, *Lomatium* sp., *Pastinaca sativa*), vegetables (*Apium graveolens*, *Foeniculum vulgare*), kitchen herbs (*Anethum graveolens*, *Anthriscus cerefolium*, *Petroselinum crispum*, *Levisticum officinale*), aromatic seed (*Carum carvi*, *Coriandrum sativum*, *Cuminum cyminum*), numerous medicinal and poisonous plants (*Conium maculatum*, *Ferula* spp., *Oenanthe* spp.) and ornamentals (*Eryngium giganteum*, *Ferula* spp., *Heracleum* spp.) (Heywood 1978; Kunkel 1984).

6.2 Genus *Arracacia* Bancroft

Arracacia BANCROFT, Trans. Agr. Hort. Soc. Jamaica 1825: 5 (1825).

Perennial or biennial, stout to slender, glabrous or pubescent, erect, caulescent, branched or simple herbs from taproots or tubers. Leaves petiolate, alternate or some opposite, pinnately or ternately divided with large leaflets, to decompose with linear to filiform ultimate divisions. Petioles sheathing at base. Inflorescence of lax to compact, usually pedunculate compound umbels. Involucre usually 0. Rays numerous to few, spreading-ascending to divaricate and reflexed. Involucel bractlets few, narrow, longer or shorter than the flowers and fruit, or 0. Calyx teeth 0; petals oblanceolate to obovate with a narrower inflexed apex, yellow, purple (maroon), or white; styles slender to short, erect, spreading or reflexed. Stylopodium conic and conspicuous or depressed and indistinct. Carpophore bifid to deeply 2-parted, flat or terete. Fruit lanceolate or oblong to ovoid, compressed laterally, usually narrowed toward apex, rounded at base; mericarps subterete, glabrous or pubescent; ribs prominent, acute or obtuse, or filiform and indistinct; vittae 1 to several in the intervals, 2 to several on the commissure; seed face usually sulcate or concave.

Arracacia Bancroft is a genus of about 30 species, extending from Mexico and Central America to Peru and Bolivia (Mathias and Constance 1976). The Mexican species are described in Mathias and Constance (1944, 1968, 1973) and Constance and Affolter (1995a, 1995b). *Arracacia xanthorrhiza* is the only cultivated species.

According to Constance and Affolter (1995b), the genus occupies a position central to a number of New World apioid genera, such as *Tauschia*, *Coaxana*, *Coulterophytum*, *Myrrhidendron* and *Neonelsonia*, all of which have been confused with it. The authors conclude that “unsuccessful attempts to define *Arracacia* to the complete exclusion of all these other genera” are more than a century old and that the generic delimitation of *Arracacia* has not been solved yet.

Efforts to properly define species within *Arracacia* have been hampered by the lack of appropriate herbarium material and cytological and field studies. The inadequacy of this situation has changed little since Constance wrote in 1949: “Many of the collections are immature or lack significant structures; others are not readily referable to any described entity but are scarcely adequate for the typification of a new one” (Constance 1949). Mature fruits, which are important in the systematics of the Umbelliferae, are often lacking in herbarium material. Germplasm collectors should therefore seek to include such material in their collections. From the viewpoint of the present paper, it is particularly regrettable that, with few exceptions, botanists have not included root material in their voucher specimens, a problem that greatly impairs the analysis of biosystematic relationships to the cultivated arracacha. On the other hand, germplasm collectors have seldom made herbarium vouchers, so that only fragmentary cultivated material is available in herbaria (Castillo and Hermann 1995).

6.2.1 South American species of genus *Arracacia* Bancroft

We consider now nine *Arracacia* species for South America. The geographical distribution of these species is given in Figure 1. The following account of their taxonomy attempts to synthesize the work of Dr Lincoln Constance and the late Dr Mildred E. Mathias, expert taxonomists for the Umbelliferae who published together from the University of California for almost 40 years (Constance 1949; Mathias and Constance 1941, 1955, 1962, 1976). Their work is being continued at Berkeley by Constance and Affolter (1995a, 1995b). Although a revision of *Arracacia* is overdue (especially in those entities that show close affinities with the cultivated arracacha), the species descriptions and localities of voucher specimens provided in the literature are compiled here and discussed. Access to these data is difficult in South America and this compilation should provide a useful tool for explorers of the genepool of *Arracacia*. Exsiccatae resulting from recent collections also have been included.

The following species descriptions define all South American *Arracacia* species as caulescent herbs. According to the definition used here, ‘caulescent’ is a condition where the flowers and fruits arise from a leafy stem with distinct internodes, as opposed to the ‘acaulescent’ condition, where the flowers and fruits emerge directly from a basal leaf rosette (Dr L. Constance, 1996, pers. comm.). In that sense, all South American taxa of *Arracacia* are indeed caulescent. However, this definition obscures significant differences in growth habit and phenology in this genus and current taxonomies do not take into account the diagnostic value of these differences which will be briefly explained.

The shoots of South American *Arracacia* species grow from perennial roots that are either woody, wide-ranging and rarely surpassing 1-2 cm in diameter, or tuberous, tapering and often more than 4 cm thick at their base. The shoot systems of species with woody roots, such as those of *A. elata* and *A. moschata*, are of indeterminate growth. Consequently, their shoots are often over 3 m long and can be seen sprawling over (disturbed) roadside vegetation. The habitats of these species are mostly in temporarily moist or perhumid montane forests (>3000 m altitude; Fig. 15). The inflorescences are borne laterally on distal shoot sections. The plants resprout from basal nodes and they will display synchronously vegetative, flowering and fruiting shoots throughout the year (except for extremely dry periods).

The plant habits and phenologies of tuberous species (*A. xanthorrhiza*, *A. andina*, *A. equatorialis*) are quite distinct. They result from adaptation to warmer and seasonally arid habitats at lower altitudes (below 3000 m). A rootstock consisting of the greatly enlarged and starchy root and compressed stem structures attached to it at soil surface serves as a storage organ allowing the plant to survive rainless periods of up to 8 months during which all aerial plant parts perish. During the rainy season 'rosettes' of large and petioled leaves emerge from the rootstock. In



Fig. 15. *Arracacia elata* in páramo vegetation in Ecuador (western slopes of Mount Atacazo, Pichincha; 3550 m altitude, 0°19'57"S, 78°37'31"W, Hermann, Vásquez & Montalvo 1451; photograph: 30 October 1996).

plants beyond a certain size, also one to several generative shoots of determinate growth can develop. Each of them bears several inflorescences (umbels). Leaves on the generative shoot are much smaller and have reduced petioles. The development of vegetative leaf rosettes and generative shoots is synchronous in *A. andina* and *A. xanthorrhiza*. In greenhouse material of *A. equatorialis*, the formation of the generative shoot often precedes vegetative growth. This species and *A. andina* display pronounced dormancy of the rootstock, a trait which is absent in cultivated arracacha.

6.2.1.1 *Arracacia colombiana* Constance & Affolter, Brittonia 47: 322-323 (1995)

Rather slender, caulescent, branching, herbaceous, the foliage and inflorescence sparsely scaberulous to hispidulous, to 1 m tall, from woody roots; leaves ovate, 10-15 cm diameter, biternate or ternate-pinnate, the leaflets ovate, 2-5 cm long, 1-3 cm broad, acute to obtuse, rounded or cuneate at base, mucronulate-serrate, scaberulous to hispidulous on the veins beneath; petiole 10-15 cm long, the petiole and petiolules without definite callous thickenings but usually papillose at the main junctures; cauline leaves reduced upward with somewhat dilated oblong to oval scarious sheaths, the upper leaves wholly sheathing; umbels pedunculate, the peduncles 5-12 cm long, scaberulous-hispidulous at apex; involucre absent or of 1 or 2 foliaceous bracts; rays 10-25, the 3-5 fertile rays 3.5-7 cm long, the staminate filiform, much shorter, all spreading-ascending; umbellets about 20-flowered, only 2 or 3 flowers perfect, the mature pedicels (3) 8-20 mm long, filiform, spreading; involucl of about 5 linear, entire, unequal bractlets 3-8 mm long, shorter than flowers and fruit; flowers yellow; calyx absent; petals oblong to obovate, 1-veined, vein sometimes branched below apex, with a narrow inflexed apex; stylopodium low conical, the styles about 1 mm long, spreading or reflexed; carpophore bipartite, the halves slender, erect; fruit ovoid-cordate, 3-5 mm long, 4-5 mm broad; little narrowed at apex, cordate at base, the mericarps subterete, glabrous, the ribs low, filiform; vittae rather large, 2 or 3 in the intervals, 4-6 on commissure; seed face deeply sulcate.

List of exsiccatae: **COLOMBIA. Cundinamarca:** En areas abiertas y en monte muy denso, suelos ricos, arenosos, Cordillera Oriental, entre Bogotá y La Calera, 2650-3000 m, 27 Nov 1947, *Barkley, García-Barriga & Vanegas 17C752* (Holotype: COL!; Isotypes: UC!, US!). — **Sibaté** (2-4 mi S), 13-15 Oct 1917, *Pennell 2452* (paratype, F, K, MO, NY, UC, US and US photo # 230). — **Meta:** Río Arroz well above confluence of Quebrada Pedregal, 29 Aug 1943, *Fosberg 20915* (US).

This recently described species from a limited geographic range in Colombia is similar to *Neonelsonia acuminata* and the Mexican *Arracacia filipis*. Whether this is a 'good' species will be seen when more material and especially fully mature specimens become available.

6.2.1.2 *Arracacia tillettii* Constance & Affolter, Brittonia 47: 324-327 (1995)

Stout, caulescent, branching, parsley-scented, the foliage and inflorescence sparsely tomentulous, to 1 m tall, from a thick taproot; leaves thick membranous, triangular-

ovate, 10-25 cm diameter, 2-3 ternate or ternate-pinnate, the leaflets lanceolate to ovate-lanceolate, 5-8 cm long, 1-3.5 cm broad, acute or acuminate, cuneate, rather coarsely serrate and occasionally lobed or incised, paler and prominently reticulate-veined and scaberulous beneath; petiole 20-35 cm long, both petioles and petiolules papillose at the main junctures, sheathing, the lower third of sheath lustrous near-white; cauline leaves reduced upward with somewhat dilated oblong scarious sheaths, the upper wholly sheathing; umbels pedunculate (or umbels sometimes sessile), the peduncles 5-15 (20) cm long, tomentulous at apex; involucre of 3-5 linear to ovate-lanceolate entire to 3-lobed bracts 5-20 mm long; rays 15-20, the 8-10 fertile rays 4-10 cm long, the staminate filiform and much shorter, all spreading-ascending; umbellets 15-25-flowered, the mature pedicels to 10 mm long, spreading; involucre of about 5 linear to lanceolate, entire or few-lobed bractlets 2-5 mm long, shorter than flowers and fruit; flowers light yellowish green, the petals oblong-oval; stylopodium low conical, the styles spreading, about 1 mm long; carpophore bipartite; immature fruit ovoid-elliptical, 4-5 mm long, 3-4 mm broad, obtuse at apex, rounded at base, glabrous, the ribs narrowly winged (?); vittae and seed face not seen.

List of exsiccatae: **COLOMBIA. Guajira:** Sierra de Perijá, Cerro Pintada, 3200 m, 26 Apr 1987, *Cuadros & Gentry 3543* (paratype, JBG, MO, UC). — **VENEZUELA. Zulia:** Distr. Maracaibo, Campamento 'Monte Viruela' (10°25' ca. 13" N, 72° 52' ca. 42" W), on tepuí-like limestone massif 5 x 2.5 km on international boundary, Serranía de Valledupar, Sierra de Perijá, ca. 3100 m, 21-28 Jul 1974, *Tillett 747-1194* (Holotype: VEN!; Isotypes: COL!, MO!, NY!, UC!).

This species has recently been described on the basis of two collections from an inaccessible area in the Serranía de Perijá near the border between Venezuela and Colombia. According to Constance and Affolter (1995b), it is difficult to assign generically, partly because of a lack of mature fruit. *Arracacia tillettii* has affinities with *Myrrhidendron* and its isodiametric fruit recalls *Neonelsonia*. Carpologically, *A. tillettii* is very similar to *A. colombiana*.

6.2.1.3 *Arracacia moschata* (Kunth) DC., Prodr. 4: 244 (1830)

Conium moschatum Kunth in H.B.K., Nov. Gen & Sp. 5: 12, pl. 430 (1821).

Plants stout, caulescent, branching, 0.5-2 m tall, the foliage glabrous, the inflorescence scaberulous, from tuberous roots. Leaves ovate, 10-30 cm long, 8-15 cm broad, bipinnate or ternate-pinnate, the leaflets ovate-oblong to ovate, acute, 2-5 cm long, 1-3 cm broad, spinulose-serrate and incised to pinnatifid toward base, paler beneath, squamulose-tufted on the rachis above. Petioles 10-20 cm long. Cauline leaves with oblong inflated sheaths. Inflorescence branching, the peduncles axillary. Involucre usually 0. Rays 10-25, rather stout, spreading-ascending or spreading, scaberulous, 5-13 cm long. Involucre of 3-8 linear to lanceolate, entire or few-toothed bractlets 6-15 mm long. Petals maroon (rarely yellow), oval; styles slender, the stylopodium conical. Pedicels 10-30 mm long, scaberulous. Carpophore bifid ca. half its length.

Fruit lance-ovoid, 6-8 mm long, 3-4 mm broad, the ribs prominent, acute; vittae solitary to several in the intervals, usually 4 on the commissure. (Description taken from Mathias and Constance 1976.)

List of exsiccatae: **ECUADOR.** — **Azuay:** “Crescit in frigidis Provinciae de los Patos, prope Teindala, 1400 hex. “, *Humboldt & Bonpland* 2163 (P. holotype). — **Bolívar:** Canton Guaranda, parroquia Salinas, en Las Tres Mercedes, a 4.8 km desde Salinas hacia Guanjo, 3200 m, 10 May 1994, *Tapia & Cazar* 33 (UC). — **Carchi:** 10 km de El Angel hacia Tulcán en la Panamericana antigua, antes de llegar a los frailejones, 3000-3300 m, 3 Feb 1995, *Hermann & Korntheuer* 1373 (UC) — El Frailejón on road Tulcán-El Carmelo, 3300 m, 6 Mar 1974, *Harling & Andersson* 12518 (NY). — Julio Andrade-Playón de San Francisco road, Cochaseca, 6 July 1978, *Boeke & Jaramillo* 2363 (NY). — Las Peñas, between la Rinconada and San Gabriel, 3150 m, *Asplund* 7182 (S, UC). — “Hauca & Tusa”, 2700-3000 m, *Lehmann* 4675 (K). - Ca. 8 km S of Tulcán, 2500 m, *Hitchcock* 21005 (GH, NY, US). — Páramo del Angel, 3400 m, *Sparre* 14241 (S). — Road Tulcán-El Pun, 3500 m, *Mexía* 7580 (UC, US). — **Cotopaxi:** Road Quevedo-Latacunga, Zumbagua, 3500 m, *Harling, Storm & Ström* 8906 (GB). — **Imbabura:** Mojanda, ca. 10 km SSW of Otavalo, 2900-3150 m, *Sparre* 13462 (S). — Mojanda, on road Otavalo-Minas, 3200 m, *Sparre* 16823 (S). — Cerro Cotacachi above Lago Cuicocha, ca. 3300 m, *Asplund* 20247 (S). — Sine loco, *Sodiño* 80, 80/17 (Q). — **Napo:** Near Archidona, *Jameson* 724 (BM). — **Pichincha:** Quito, *Jameson* 30 (BM, W). — Quitensian Andes, *Jameson s.n.* (K). — Cerro Pichincha, *Jameson s.n.* (US); *Hall* 40 (K); *Benoist* 2423 (P, UC). — Cráter de Pululahua, N of Quito, ca. 2800 m, *Barclay, Juajibioy & Tinajero* 7901 (UC). — Road Quito-Santo Domingo de los Colorados, km 46, 2000 m, *Dodson & Thien* 1064 (LA, WIS). — **Tungurahua:** Road Paso-Ambato, near Río Ambato, 2850 m, *Heinrichs* 71 (G, M, NY). — San Fernando, Ambato-Guaranda, km 12, 3300 m, *Sparre* 18410 (S). — **Prov. unknown:** Sine loco, *Spruce* 5794 (BM, NY); *Jameson* 30 (K).

This species is, with *Arracacia xanthorrhiza*, one of the two properly referred classical species in the genus. *Arracacia moschata* is a well-defined taxonomical entity and can be easily recognized because of its distinctive (spinulose-serrate) leaf and seed shape (Fig. 16). The seeds, and to a lesser extent the leaves, have a pleasant umbelliferous fragrance, somewhat reminiscent of the resinous odour of certain conifers and *Citrus*.

It is common in the páramos of central and especially northern Ecuador, on both sides of the Cordillera, between 3000 and 3300 m altitude. However, it has not yet been collected in Loja and it seems to be absent from Peru. *Arracacia moschata* might also occur in southern Colombia, in habitats similar to the ones in which the species is common in northern Ecuador.

I have seen large populations of this species in Carchi (*Hermann & Korntheuer* 1373) (Fig. 16), where it occurs in wet habitats regularly exposed to fog and mist. In these situations, *A. moschata* is associated with *Coriaria*, Ericaceae and *Espeletium*.



Fig. 16. Herbarium specimen of *Arracacia moschata* collected in Carchi, Ecuador. (Lot.: 10 km de El Angel hacia Tulcán en la Panamericana antigua, 0°40' N, 77°53' W, 3300 m asl, 3 February 1995, vern. 'sacha zanahoria', Hermann & Korntheuer 1373, UC.) Scale: 10 cm.

Its shoots, which emerge from a lignified and compact rootstock, reach several meters in length and sprawl over roadside thickets. The woody roots can surpass 1 m in length but rarely exceed 2 cm in thickness (*Tapia & Cazav 33*).

6.2.1.4 *Arracacia elata* Wolff, Bot. Jahrb. 40: 304 (1908)

Arracacia Pennellii Constance, Bull. Torrey Bot. Club 76: 71 (1949).

Arracacia Wigginsii Constance, *ibid.* 43.

Plants stout, caulescent, branching, vining or scrambling, 1-8 m long, the foliage glabrous, minutely scaberulous in the inflorescence, from tuberous roots. Leaves triangular-ovate to ovate, 8-30 cm long, 10-25 cm broad, ternate or 1- or 2-pinnate, the leaflets lanceolate to ovate-lanceolate, acute or acuminate, 2-6 cm long, 0.8-4 cm broad, spinulose-serrate and usually incised or lobed towards base, paler beneath, squamulose-tufted on the rachis above. Petioles 15-45 cm long. Cauline leaves with oblong inflated sheaths. Inflorescence branching, the peduncles terminal and axillary. Involucre usually 0. Rays 15-30, slender, spreading-ascending, scaberulous, 3-7.5 cm long. Involucel of 3-10 linear to lanceolate, entire to toothed bractlets 2-15 mm long. Petals greenish-yellow, oval to obovate; styles slender, the stylopodium conical. Pedicels 3-8 mm long, scaberulous. Carpophore bifid, ca. 1/4 its length. Fruit ovoid to oblong-ovoid, tapering at apex, 4-8 mm long, 3-5 mm broad, the ribs prominent, obtuse; vittae solitary to several in the intervals, usually 2 or 4 on commissure.

List of exsiccatae: **COLOMBIA. Cundinamarca:** Río San Francisco, above Bogotá, 13 Sep 1917, *Pennell 1932* (NY type of *A. pennellii* Constance, GH, US). - Macizo de Bogotá, Quebrada del Rosal, 3000 m, 29 June 1939, Cuatrecasas 5700 (US). - **Norte de Santander:** Between Mutiscua and Pamplona, 3400 m, 23 Feb 1927, *Killip & Smith 19728* (GH, NY, US). - **Santander:** Cordillera Oriental, páramo de Santurbán, entre Cuesta Boba y el extremo oeste, 3400 m, 27 July 1940 *Cuatrecasas & Barriga 10314* (US). - Páramo de Romeral, 3800-4100 m, 29-30 Jan 1927, *Killip & Smith 18541* (GH, NY, US). - Vicinity of Vetás, thickets along stream, 3100-3200 m, 16 Jan 1927, *Killip & Smith 17347* (GH, MO, NY, US). — Quebrada de País, north of La Baja, dense forest, ca. 3200 m, 31 Jan 1927, *Killip & Smith 18781* (GH, MO, NY, US). — **ECUADOR. Azuay:** Cruz Pampa region above Baños (ca. 15 km SW of Cuenca), 9000-10000 ft. elev., 29-30 June 1945, *Camp E-3934* (NY). - Panamerican Highway, 65-70 km S of Cuenca, shrubby páramo and roadbanks, 3300-3400 m, 3 Jan 1981, *Balslev 1426* (NY). - Canton Cuenca, Zurucucho, forest edge, 3200 m, 11 Aug 1978, *Boeke, Jaramillo & Narvaez 2631* (NY). - Road Cuenca-Angas, roadside, 3050 m, 28 Dec 1976, *Boeke 664* (NY). — Cerro Soldados (W of Sayausid) below Quinoas, 3400 m, *Harling, Storm & Ström 8762* (GB, UC). — Laguna de Surucuchu, 3100-3200 m, *Sparre 18855* (S). — Pan American Highway 40 km S of Cuenca, 3300 m, *Wiggins 10769* (UC, holotype of *A. wigginsii*; US). — Cruz Pamba region above Baños (ca. 15 km SW of Cuenca), 2750-3050 m, *Giler & Prieto (=Camp E-3934)* (BM, G, K, MO, P, UC, US). — 10 km S of Cumbe, 3000 m, *Harling, Storm & Ström 8013* (GB). — **Cañar:** Road Biblián—Cañar *Harling, Storm & Ström 8621* (GB). — Vicinity of Cañar *Rose & Rose 22715* (US). — Headwaters of

Río Mangán, 20-22 km ENE of Azogues, 3300 m, *Fosberg & Prieto 22818* (UC, US). — **Cotopaxi**: Road Toacazo-Sigchos, 3350 m, 9 July 1996, *Vásconez & Vacas 11*. — Road above Pilaló toward Zumbahua, 3525 m, 11 July 1996, *Vásconez & Vacas 14*. — Western slopes of Cordillera along road Zumbahua-Pilaló, 3400 m, 10 Nov 1996, *Hermann, Vásconez & Jarrín 1471*. — **Pichincha**: 4.5 km de San Juan de Chillogallo a lo largo de la carretera hacia la cumbre del Atacazo, 3500 m, 16 Dec 1990, *Hermann 647*. — 10.7 km from San Juan de Chillogallo on road toward Martínez hacienda, 3550 m, 30 Oct 1996, *Hermann, Vásconez & Montalvo 1451*. — Pichincha, SE slope on road to N antenna, roadside, very ashy soil, 3500-3700 m, 21 July 1982, *Clemants, Boeke, Holmgren & Crisafulli 2064* (NY). — San Juan, 3500-3700 m, *Fagerlind & Wibom 1557* (UC). — “Crescit in umbrosis humidis montes Pichincha” 3350 m, *Jameson 281* (Sodiro 610) (Q) — Valle de Lloa (Unguí), *Benoist 2709* (P). — **Prov. unknown**: “In coll. apric. interand. Sanlagua”, *Sodiro (2574) 609* (G). **PERU. Amazonas**: “A Chachapoyas orientem versus, inter Tambo Ventillas et Piscohuañuma”, 3600 m, *Weberbauer 4423* (type photos: F, GH, UC, US). — Province Chachapoyas, Cerros Calla Calla, west side, 45 km above Balsas, midway on the road to Leimebamba, 3100 m, 19 June 1964, *Hutchison & Wright 5748* (UC, USM, F, NY, MO). — Chachapoyas, uppermost slopes and summit of Cerros de Calla Calla, near km 403-407 of Balsas-Leimebamba road, 3400-3550 m, 18 Aug 1962, *Wurdack 1718* (NY). — **Ayacucho**: Choimacota Valley, 3000 m, *Weberbauer 7584* (F, GH, US). — **Cajamarca**: 3500-3800 m, *Vargas 10369*. — Province Hualgayoc, Hacienda Taulis, Río La Quinoa above La Playa, vining 2-3 m, streamsides, 2900 m, 4 Sep 1964, *Hutchison & Von Bismarck 6506* (UC, USM, US, F, NY, MO, K, MICH). — **Cusco**: Province Urubamba, woods, 3000 m, *Rauh & Hirsch 1049* (UC). — **Huánuco**: Province Pachitea, Tambo de Vaca, ca. 12,000 feet, *MacBride 4456* (F, US). — **La Libertad**: Provincia Otuzco, Chilte, Hacienda Llaguén, en quebrada pedregosa, López 615. — **Piura**: In summit area on road to Canchaque, 30-38 km above and west of Huancabamba, 3200-3300 m, vining 4 m through trees, 17 Sep 1964, *Hutchison & Wright 6651* (UC, USM, US, F, NY, MO, K, MICH). — **Puno**: Provincia Carabaya, entre Ayapata y Kahualluyoc, 3595-3800 m, *Vargas 10747*. — **VENEZUELA. Mérida**: La Mucuy, valle del río Loro, entre la estación forestal y la laguna, sobre el camino a la Laguna Coromoto, 3200 m y más, *Barclay & Juajibioy 9940* (UC). — Entre las rocas de la quebrada Monte Zerpa, 2700 m, *Bernardi 657* (NY). — Distrito Libertador, Parque Nacional Simón Bolívar, La Mucuy, formaciones leñosas al S y al E de la Laguna Coromoto, 3400 m, 22 Dec 1983, *Pipoly & Aymard 6558* (NY). — Mérida, 16 Feb 1957, *Bernardi s.n.* (NY).

This vining species is very similar to the preceding one in general aspect and habitat (bushy páramos), but it is of much wider distribution (Venezuela, Colombia, Ecuador, Peru). It also reaches higher altitudes, especially farther away from the equator as in southern Peru. Its greenish-yellow petals, acuminate leaflets, more ovoid fruits, obtuse fruit ribs as well as the lack of a pronounced fragrance set it apart from *A. moschata*. The woody roots are up to 2 cm thick and spread over large areas (Figs. 17 and 18).

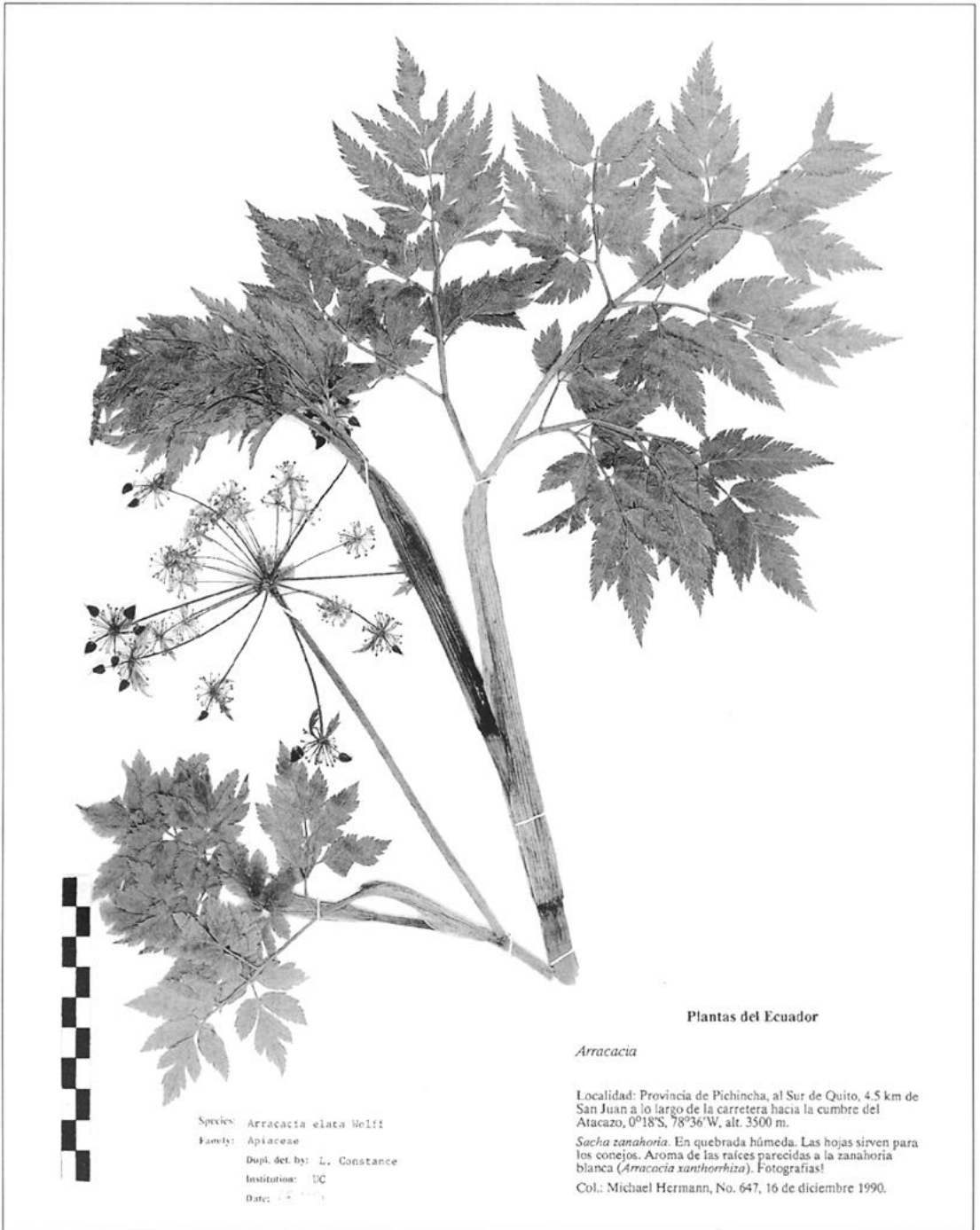


Fig. 17. Herbarium specimen of *Arracacia elata* collected in Pichincha, Ecuador. (Loc.: 4.5 km de San Juan a lo largo de la carretera hacia la cumbre del Atacazo, 0°18' S, 78°36' W, 3500 m asl, 16 December 1990, vern. 'sacha zanahoria', Hermann 647, UC.) Scale: 10 cm.

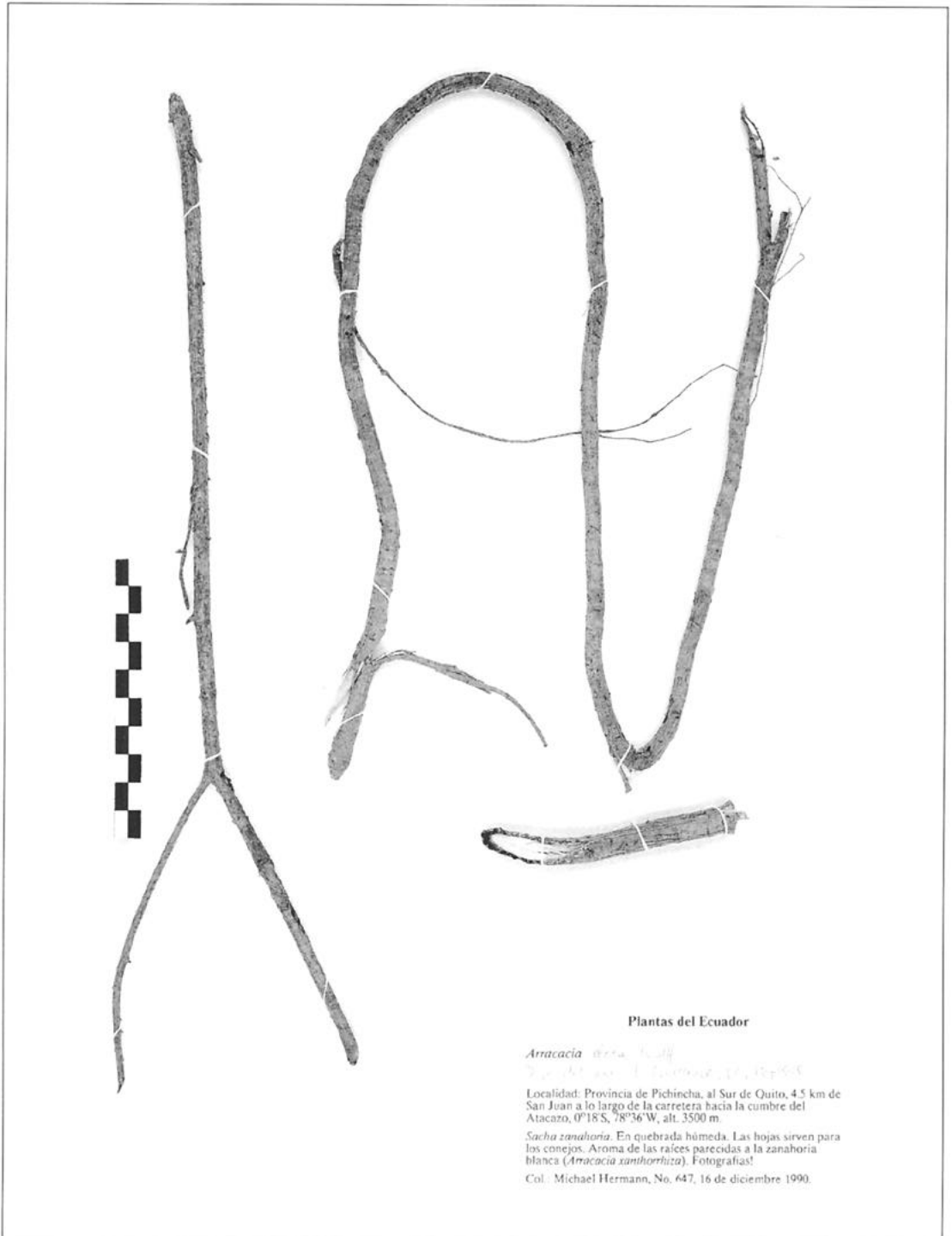


Fig. 18. Roots of *Arracacia elata* (for locality and specimen, see Fig. 17). Scale: 10 cm.

Near Quito, *A. elata* is a very common plant on the western slope of the Atacazo volcano between 3300 and 3550 m altitude, where it is associated with terrestrial orchids, Melastomataceae, Ericaceae, *Vaccinium* spp., *Ottoa oenanthoides* (Umbelliferae), *Lycopodium*, *Oxalis* spp., *Gunnera* sp., ferns and other plants that indicate high atmospheric humidity (Fig. 15). Here *A. elata* often trails over páramo bush and develops long shoots, often measuring 4 m and more. However, in open sites the plant assumes a bushy habit, as seen in Fig. 15, and is up to 2 m high. The plant is especially frequent in creeks and in other wet soil conditions.

6.2.1.5 *Arracacia xanthorrhiza* Bancroft, Trans. Agr. Hort. Soc. Jamaica 1825: 5 (1825)
Conium Arracacha Hook., Exot. Pl. pl. 152 (1825).

Arracacia esculenta DC., Bibl. Univ. Sci. & Arts 40: 78 (1829).

Bancroftia xanthorrhiza Billb. Linn. Samf. Handl. 1: 40 (1833).

Plants stout, caulescent, 0.5-1.2 m tall, minutely squamulose and scaberulous, from greatly swollen tuberous roots. Leaves broadly ovate, 1-3 cm long and broad, biternate or bipinnate, the leaflets ovate-lanceolate to ovate, 4-12 cm long, 1.5-6.5 cm broad, acuminate, mucronate-serrate and coarsely incised or lobed, squamulose or scaberulous. Petioles 8-45 cm long. Cauline leaves with narrow sheaths. Inflorescence branching, the peduncles alternate or whorled; scaberulous at apex. Involucre 0. Rays 5-15, spreading-ascending, 1.5-4 cm long, scaberulous. Involucel of 5-8 setaceous entire bractlets 2-5 mm long. Petals purple or greenish, oval; styles slender, the stylopodium depressed. Pedicels 2-4 mm long. Carpophore 2-parted. Fruit oblong, 10 mm long, 2-3 mm broad, constricted below apex, the ribs prominent, acute; vittae solitary in the intervals, 2 on the commissure.

List of exsiccatae of cultivated or presumably cultivated material: **BOLIVIA. La Paz:** Provincia Larecaja, cultivated near Quiabaya, 55 km de Sorata hacia Consata, 3120-3280 m, 9 Sep 1989, *Hermann* 285,289 (NY, LPB-foilage, roots). –Provincia Camacho, Comunidad Queñe, 15 km de Mocomoco hacia Chuma, 3000 m, 13 June 1991, *Hermann, Morales & García* 835,836. – Sorata, 9 Jan 1958, 2697 m, *Mandon* 595 (GH), 22 Apr 1940, *Holway & Holway* 563 (US-foilage). – Sirupaya, 1800 m, 27 July 1906, *Buchtien* 5971 (US-foilage). – **BRAZIL. São Paulo:** São José do Rio Preto, 1150 m, *Hermann* 800. – **COLOMBIA. Antioquia:** Cordillera Central, alrededores de Medellín, 1560 m, 1 May 1946, *Hodge* 6861 (GH). – **Cauca:** Popayán, *Lehmann* 407 (GH-flowers). – Cuesta de Tocatá, road from Buenaventura to Cali, Western Cordillera, 1500-1900 m, *Pittier* 714 (US). – **Putumayo:** Valle de Sibundoy, ca. 2250 m, 18 Feb 1942, *Schultes* 3267 (GH-foilage). **ECUADOR. Loja:** Vicinity of Las Juntas, *Rose, Pachano & Rose* 23215 (US-foilage). – Cultivated, West Indies to Peru, and possibly Bolivia. – **Tungurahua:** Ambato, 1918, *Rose* 38 (GH, US-photo of foliage). – **PERU. Cusco:** Paruro, Hacienda Araypallpa, 3100 m, 28 July 1937, *Vargas* 411 (GH, CUZ). – Colinas del Laxaihuamán, 3600 m, Dec 1928, *Herrera* 858 (F). – Ollantaytambo, ca. 3000 m, 24 June 1915, *Cook & Gilbert* 282 (US-foilage). – San Miguel, Urubamba valley, ca. 1800 m, 26 May 1915, *Cook & Gilbert* 934, 935 (US-

foliage). — Cultivated in chacra of Félix Huamán Zúñiga, Nogal Niyoc, Provincia de Calca, 22 km de Paucarpata hacia Colca, 2050 m, 23 Sep 1990, *Hermann, Cruz & Meza 546,547,549* (NY, MOL-foliage, roots).

List of exsiccatae of recently collected wild material (identified by L. Constance): **ECUADOR. Chimborazo:** Cantón Colta, 30 minutos a pie desde Cañihacia Corralpamba, 11 May 1994, *Tapia & Cazar 43* (UC). — 8 km from Capzol toward Huigra, 1600 m, 17 May 1996, *Hermann & Santos 1410* (UC). — **PERU. Cusco:** Provincia Cusco, bajando de Fierroccata hacia la Granja K'ayra, 3300-3400 m, 12-13 Feb 1991, *Hermann 747, Hermann & Cruz 749,750* (UC, MOL). — Ak'o Moqo, Granja K'ayra, San Jerónimo, camino a Paruro, 3500 m, 10 Dec 1990, *Cruz 108* (MOL). — Provincia Anta, 22 km de Ancahuasi hacia Limatambo, 2900-3100 m, 14 Feb 1991, *Hermann, Cortés & Alvarez 764* (UC, MOL).

This species is the cultivated arracacha. It is grown all across the Andes (except Argentina) and some mountain ranges in Central America, the Caribbean and southeastern Brazil (Hermann 1991, 1995). According to Friedberg (1978), arracacha is the only umbelliferous domesticate in Peru; no other native umbellifer has been domesticated or used for aromatic properties in this country.

Herbarium specimens used to describe the species are notoriously insufficient, and published descriptions are correspondingly inadequate (Constance 1949). Arracacha is vegetatively propagated and rarely flowers in the Andes, so most herbarium specimens are sterile. None of the older material used by systematists is unquestionably from the wild (see list of exsiccatae) and the species has so far been known only from cultivated material.

The specific epithet *xanthorrhiza* is Greek for 'yellow-rooted' and thus refers to the clones with yellow to yellowish orange flesh preferred in most countries. However, arracacha also has white or ivory-coloured roots; sometimes these show purplish variegations in the tissue surrounding the vascular bundles. Notably, *Arracacia* species with close affinities to arracacha (*A. andina*, *A. equatorialis*) have white roots only.

Undoubtedly wild collections identified by L. Constance as *A. xanthorrhiza* were only recently made, both in Peru and Ecuador. The Peruvian material (vouchers *Hermann 747; Hermann & Cruz 749,750; Cruz 10; Hermann, Cortés & Alvarez 764*) comes from two provinces in the department of Cusco (Cusco and Anta), where it is locally abundant between 2900 and 3500 m altitude in open or disturbed sites (Figs. 19 and 20). Local people refer to this material in their native tongue (Quechua) as *k'ita racacha*, *k'ita virraca* (= wild arracacha) or *orko racacha* (= mountain arracacha, = high-altitude arracacha). I have grown this plant from original seed in Quito greenhouses and it has invariably shown its biennial nature. After initial slow development, the plant grows into a simple herb with basal leaves that emerge from a rootstock. After about 7-9 months of vegetative growth, true senescence sets in, that is, the leaves will die even under favourable growth conditions. The storage roots are about 4 cm thick



Fig. 19. Herbarium specimen of wild *Arracacia xanthorrhiza* collected in Cusco, Peru. (Lot.: Provincia Anta, 22 km de Ancahuasi hacia Limatambo, 13°28' S, 72°23' W, 2900-3100 m asl, *Hermann, Cortés & Alvarez 764*, MOL, UC.) Scale: 10 cm. This species is the same as vouchers *Hermann 747, 749, 750* and *Cruz 108* from Granja K'ayra, San Jeronimo, near Cusco. In Quechua, this biennial species is referred to as *k'ita racacha* (= wild arracacha) or *orko racacha* (= mountain arracacha, = high-altitude arracacha). Its tuberous and fetid roots are 4 cm thick and 10-20 cm long (see Fig. 21).

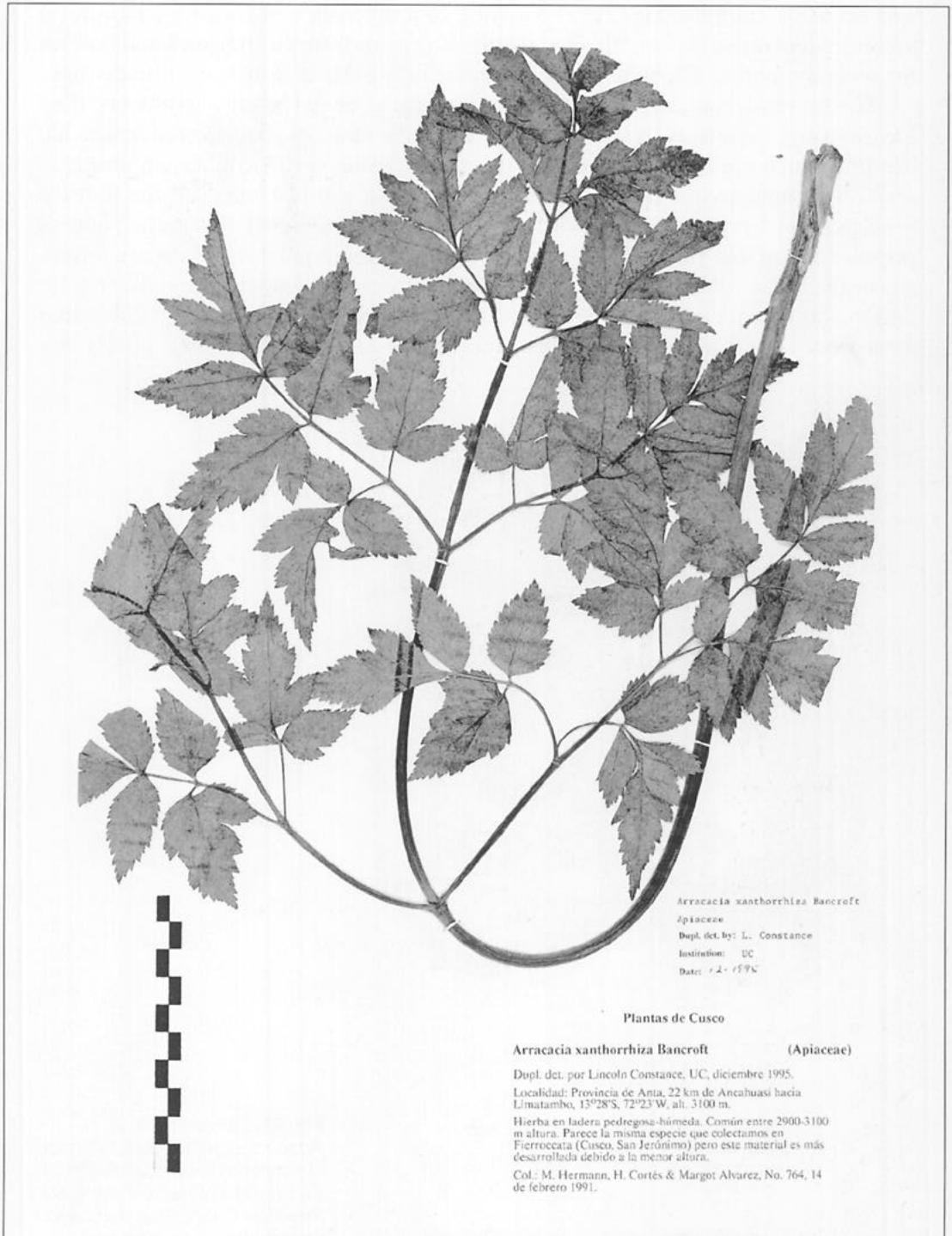


Fig. 20. Leaf of wild *Arracacia xanthorrhiza* (for locality and specimen, see Fig. 19). Scale: 10 cm.

and up to 20 cm long (Fig. 21). Following root dormancy of about 2-3 months, a vigorous generative shoot with several umbels appears from the rootstock and flowers for several months. Then the whole plant, including the rootstock, eventually dies.

The tuberous roots are yellowish and are said to be fed to pigs. However, they have a strong flavour and remain astringent after cooking. As in cultivated arracacha, but to a much higher extent, numerous vessels in the cortex contain an aromatic resin. It is hard to imagine how prehistoric people would have used the root for food, perhaps by roasting it in hot ashes to get rid of the outer and fetid cortex. Unless populations of this variant of *A. xanthorrhiza* with more palatable roots are found, it is unlikely the wild ancestor of the cultivated arracacha. Also its biennial character and the occurrence of this wild species at high altitudes set it apart from cultivated arracacha. Neither Herrera in his *Sinopsis de la Flora de l Cusco* (1941) nor

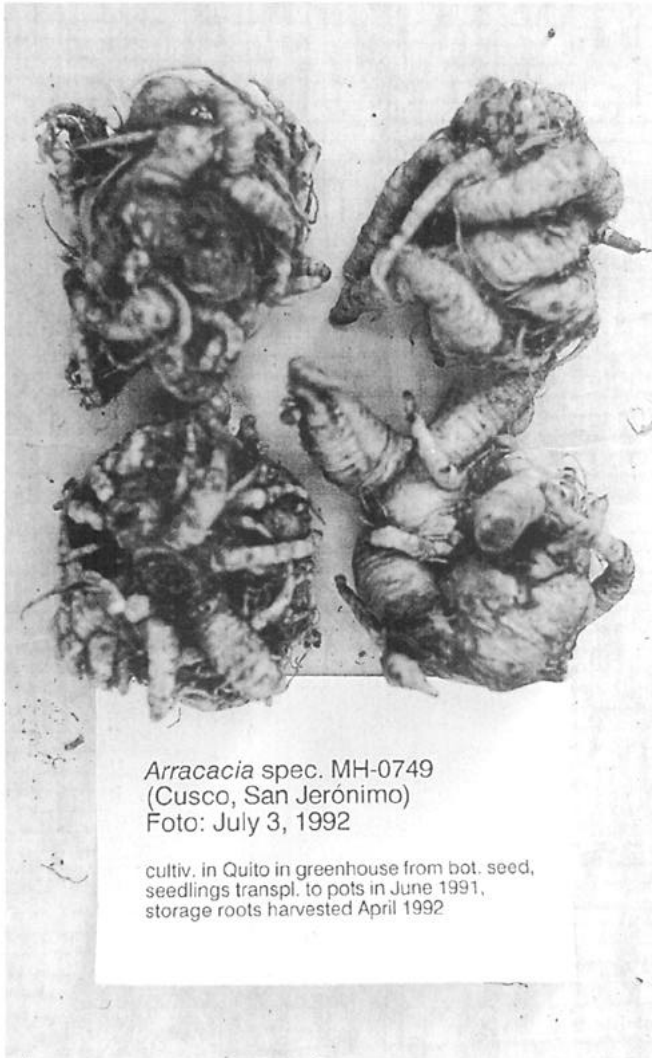


Fig. 21. Storage roots of *Arracacia xanthorrhiza* cultivated in pots from seed collected from wild plants in Cusco, Peru. (Loc.: Provincia Cusco, San Jerónimo, bajando de Fierroccata a la Granja K'ayra, 13°33' S, 71°55' W, 3300 m asl, Hermann 747)

Weberbauer in his classic monograph on the Peruvian flora mention this species (Weberbauer 1911). Because of its absence (or dearth) in herbaria, we must conclude that this material is rarer than the situation in Cusco would suggest.

A more likely candidate for the ancestral race from which arracacha might have been domesticated was recently found near Cañi, Chimborazo, Ecuador (voucher *Tapia & Cazar 43*). This material was identified by Dr Constance as *A. xanthorrhiza*. Material with identical root and fruit characteristics is now also available from Huigra and Sibambe in Chimborazo Province (*Hermann & Santos 1410*), and from Bolívar Province. Specimens from the Huigra and Sibambe populations (vouchers *Asplund 15452*, *Fosberg & Giller 22581*), however, have previously been assigned to *Arracacia andina* (Mathias and Constance 1976). This illustrates the difficulty of differentiating *A. andina* from *A. xanthorrhiza*. Indeed, Dr Constance, in a pers. comm. to me (1995), wrote: "Since publication of the Flora of Ecuador, I concluded that *Arracacia andina* Rusby is too similar to *A. xanthorrhiza* Bancroft to be regarded as specifically distinct".

Figure 22 shows a herbarium voucher of the recently made collection from the Sibambe-Huigra population (*Hermann & Santos 1410*). This population is distributed between 1450 and 2500 m altitude in the canyons of the Chanchán River and its affluent Río Sibambe. Near Chanchán, at 1600 m altitude, it is a frequent plant on road banks or other disturbed sites with sandy or stony soils of high alkalinity (pH = 8-8.8). Annual rainfall is around 500 mm, of which only 100 mm falls during the dry season from June to November. The resulting xerophytic vegetation (Fig. 23A) is classified as 'monte espinoso pre-montano' in the modified Holdridge system (Cañadas 1983). It is characterized by thorny bushes, *Agave*, *Opuntia* and some columnar cacti. Wild crop relatives of this vegetation include *Cyclanthera*, *Phaseolus vulgaris* and *Psidium*. In the cantons of San Miguel and Guaranda in Bolívar province, the plant can be found in moister habitats and soils of neutral or slightly acid pH (6-7).

This *Arracacia* species has a striking similarity with cultivated arracacha in terms of morphology (root, leaf and generative characters), life form (perennial) and altitudinal distribution, yet it is sufficiently distinct to be recognized as wild as opposed to merely escaped from cultivation. Local informants interviewed in villages in Chimborazo and Bolívar, especially women, recognized it as a medicinal, the roots or leaves of which are commonly employed in potions to induce *post partum* placental elimination, in both humans and domestic animals.

In May 1996, this wild arracacha was found above Chanchán in a variety of growth stages ranging from single-leaved seedling plants left from the preceding rainy season to juvenile-vegetative and to mature-generative plants with tubers weighing up to 3 kg, the latter presumably being several years old (Fig. 23C). The seedling forms a thick taproot from which, in the juvenile plant, several tuberous roots emerge. These swell into storage roots which taper up to 1 m in length and can be up to 8 cm thick at their base. These are difficult to recover entirely as they break easily. Apparently, taproots and storage roots are perennial as is the plant. As in cultivated arracacha, a 'crown' of cormel-like structures develops on top of the taproot (Fig. 23D). The cormels are not as pronounced as in cultivated arracacha,

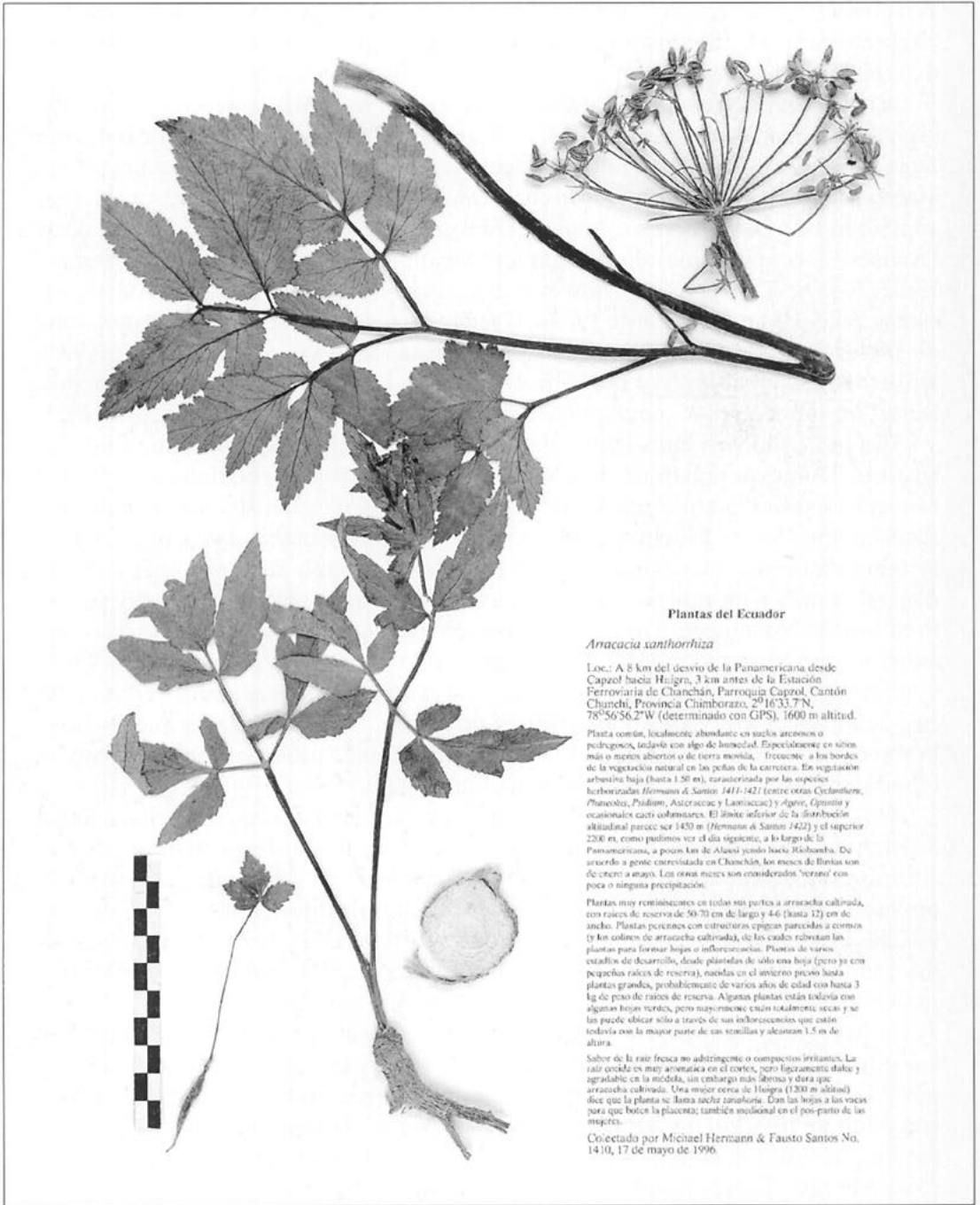
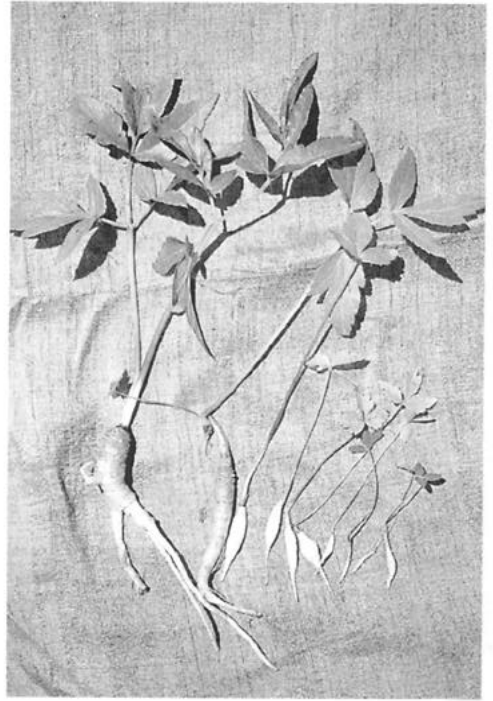


Fig. 22. Herbarium specimen of wild *Arracacia xanthorrhiza* collected in Chimborazo, Ecuador. (Loc.: Cantón Chunchi, on road Capzol-Huigra, 3 km before train station of Chanchán, 17 May 1996, vern. 'sacha zanahoria', 2°16'33.7" S, 78°56'56.2" W, 1600 m asl, *Hermann & Santos 1410*, UC.) Scale: 10 cm.



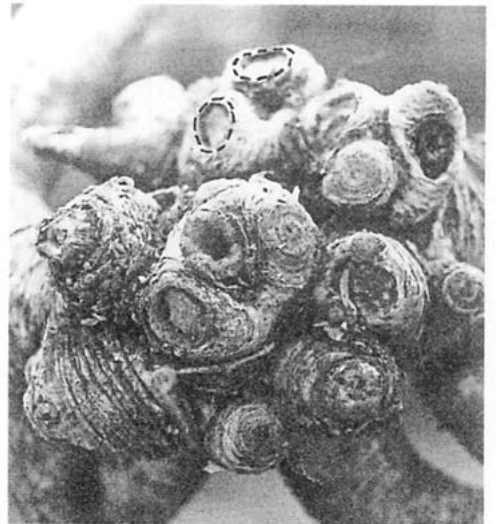
A



B



C



D

Fig. 23. Collecting site and storage root of *Arracacia xanthorrhiza* voucher *Hermann & Santos 1410*. (Loc.: Ecuador, Cantón Chunchi, on road Capzol-Huigra, 3 km before train station of Chanchán, 2°16'33.7"S, 78°56'56.2"W, 1600 m asl) **A:** collecting site on road bank, note dry bush ('estepa espinosa montano bajo'); **B:** juvenile (vegetative) plants; **C:** typical storage roots weighing 1-3 kg per plant; **D:** crown of rootstock from which the plant regenerates in the rainy season (trace drawing indicates scars left from generative shoots) (Photographs: May 1996).

but rather are depressed and rise only to the soil surface. The cormel is homologous to the propagule in cultivated arracacha, which is called *colino* or *hijuelo* in Spanish. It is a solid stem structure, consisting of starchy storage parenchyma, but it has distinct internodes and nodes at which the leaves are inserted. Some of the otherwise vegetative corms develop generative stalks, as indicated by the trace drawing (Fig. 23D), which emphasizes scars left by such stalks. Leaf shape and generative characters, such as flower and fruit morphology, as well as seed fragrance are very similar to those of cultivated arracacha.

The cooked root is fibrous, but it has a bland, slightly sweet and umbelliferous taste. The content of physically extractable starch is 14-16% of the fresh root weight. Although not as pleasant to eat as cultivated arracacha (the flesh remains firm after extended cooking and is more fibrous), this wild arracacha does not have the astringent principles of the Peruvian material described above, and it would therefore have made an attractive caloric food source for prehistoric gatherers. The plant can easily be spotted because of its conspicuous generative shoots, which are up to 1.5 m high, and, as a rule of thumb, the larger ones are associated with bigger roots. Equipped with a digging tool, a person can harvest 10-20 kg of roots in half an hour in abundant plant populations. Human intervention might have been beneficial to maintaining or even increasing plant populations as seeds shed from harvested plants would have germinated in freshly disturbed sites, where the plant occurs naturally. Thus early people might have unconsciously maintained populations for sustainable exploitation. Such people would probably not have used the crowns, which trap dead leaves and soil and account for only 10% of total root weight. Presumably, the crown would have been discarded during food preparation. It may have sprouted on garbage heaps, thus eventually leading to the discovery of the most convenient propagation method, which is the replanting of the crown or parts of it.

To my knowledge, the Huigra-Sibambe population is an entity that resembles cultivated arracacha more than any other wild *Arracacia* germplasm described so far. It might offer potential for introgressing drought resistance, desiccation resistance of the roots and improved dry-matter partitioning (into the storage roots versus the crown) into the cultivated background. Future explorations should concentrate on mesothermic and periodically dry valleys adjacent to Chimborazo and Bolivar. Such habitats occur across the northern and central Andes, and the *Arracacia* germplasm in question here might well extend northward into southern Colombia and southward into Peru. In this context, a brief mention of wild arracacha used as emergency food and for “helping women with childbirth” in Cajamarca (adjacent to Ecuador) is most noteworthy (Seminario 1995).

6.2.1.6 *Arracacia andina* Britton, Bull. Torrey Bot. Club 18: 37 (1908). Fig. 4

Plants stout, caulescent, 0.3-1.0 m tall, the foliage and inflorescence minutely squamulose or scaberulous, from a tuberous base. Leaves triangular-ovate to ovate, 10-30 cm long, 15-30 cm broad, 1-2-pinnate, the leaflets lanceolate to ovate, acute to acuminate, 2-10 cm long, 1-5 cm broad, mucronate-serrate and usually shallowly

incised or lobed, sparsely squamulose to hispidulous. Petioles 15-35 cm long. Cauline leaves with moderately inflated sheaths. Inflorescence branching, the peduncles usually whorled, scaberulous at apex. Involucre usually 0. Rays 8-25, slender, spreading-ascending, 2-8 cm long, scaberulous. Involucel of 6-9 linear entire bractlets 2-9 mm long. Petals purple, obovate; styles slender, the stylopodium depressed. Pedicels 2-10 mm long. Carpophore 2-parted. Fruit ovoid, 6-11 mm long, 4-5 mm broad, obtuse, the ribs very prominent, acute; vittae 1-3 in the intervals, 4-6 on the commissure.

List of exsiccatae: **BOLIVIA**. “Plantae Bolivianae”, *Bang* 2839 (F, GH, MO, NY, US). - Ingenio del Ovo, Rusby 776 (F, NY-TYPE, US). — **ECUADOR**. — **Cañar**: Between Tambo and Suscal, valley of Río Cañar, 2000-3000 m, *Camp E-2778* (UC). — **Chimborazo**: Sibambe, canyon of Río Sibambe, affl. of Río Chanchan, 2460-2550 m, 28 Jan 1945, *Fosberg & Giller* 22581 (NY, UC, US). — Huigra, *Asplund* 15452 (S). — **Cañar**: Between Tambo and Suscal, valley of Río Cañar, 2000-3000 m, *Camp E-2778* (UC). — **PERU**. **Cajamarca**: *Sagástegui & Mostacero* 9124 (MO) (specimen cited in Brako and Zarucchi 1993).

Constance maintained this as a separate species on the basis of its broader leaflets and fruit characteristics (Constance 1949), which differentiate it from its closest relative *A. xanthorrhiza*. However, the similarities between the two species have been discussed in the foregoing account. Perhaps what has to date been considered *A. andina* is the wild arracacha. Only a revision and more comprehensive material will show whether this entity is conspecific with *A. xanthorrhiza*, in which case the binomial *A. andina* would have to be reduced to synonymy.

6.2.1.7 *Arracacia equatorialis* Constance, Bull. Torrey Bot. Club 76: 46 (1949)

Plants slender, caulescent, 0.4-0.8 m tall, the foliage somewhat squamulose, from tuberous roots. Leaves triangular-ovate, 6-30 cm long, 7-18 cm broad, biternate or bipinnate, the leaflets ovate to lanceolate, 2-8 cm long, 0.5-3 cm broad, acute or acuminate, mucronate-serrate and usually deeply incised or lobed, squamulose to glabrate. Petioles 10-20 cm long. Cauline leaves with scarios, strongly inflated sheaths. Inflorescence branching, the peduncles usually whorled. Involucre usually 0. Rays 6-15, slender, ascending, 1.5-4 cm long, scaberulous. Involucel of 3-6 ovate-acuminate entire narrowly scarios-margined bractlets 2-6 mm long. Petals purple, obovate; styles slender, the stylopodium depressed. Pedicels 2-5 mm long. Carpophore 2-parted. Fruit ovoid-oblong, 7-9 mm long, 3-4 mm broad, obtuse, the ribs filiform, acute; vittae solitary in the intervals, 2 on the commissure.

List of exsiccatae: **ECUADOR**. **Azuay**: Cantón Cuenca, parroquia San Joaquín, barrio Parabón, 1 km W de la carretera, *Tapia & Velásquez* 58. — Cantón Cuenca, parroquia Cumbe, 28.6 km on road Cuenca-Saraguro, 3000 m, *Tapia & Velásquez* 133 — 2 km N from Chordeleg on slopes of river bed on left side of road to Cuenca, 2335 m, 7 Aug 1996, *Vásconez & Montalvo* 16 — **Loja**: Vicinity of Las Juntas, Rose, *Pachano &*

Rose 23215 (US, holotype; GH, NY). — S. Pedro-Chinchas (ca. 55 km W of Loja), 1600 m, 1 Mar 1947, *Espinosa* 1305 (UC). — Cantón Loja, parroquia San Lucas, loc. Bucashi, a 46 km de la vía Loja-Cuenca, 16 Feb 1992, *Tapia & Velásquez* 51. — Cantón Loja, 7 km on old road Loja-Catamayo, 3000 m, *Tapia & Velásquez* 140. — Above San Pedro de Vilcabamba, 2000 m, Feb 1995, *Herrmann* 1573. — **PERU.** — **Apurímac:** Provincia Andahuaylas, quebrada Posoconi, 2650 m, *Vargas* 8795. — **Cusco:** San Sebastian, grassy place on summit of bluff, 3300-3400 m, *Pennell* 13628. Prov. Cusco, Cerro Sape, frente a Sacsahuamán, cerca a la ciudad de Cusco, 3400 m, *Ferreira* 2675. Prov. Paruro, Araypallpa, 3100 m, *Vargas* 411. — **Junín:** Prov. Tarma, Huasahuasi, *Ruiz & Pavón*,

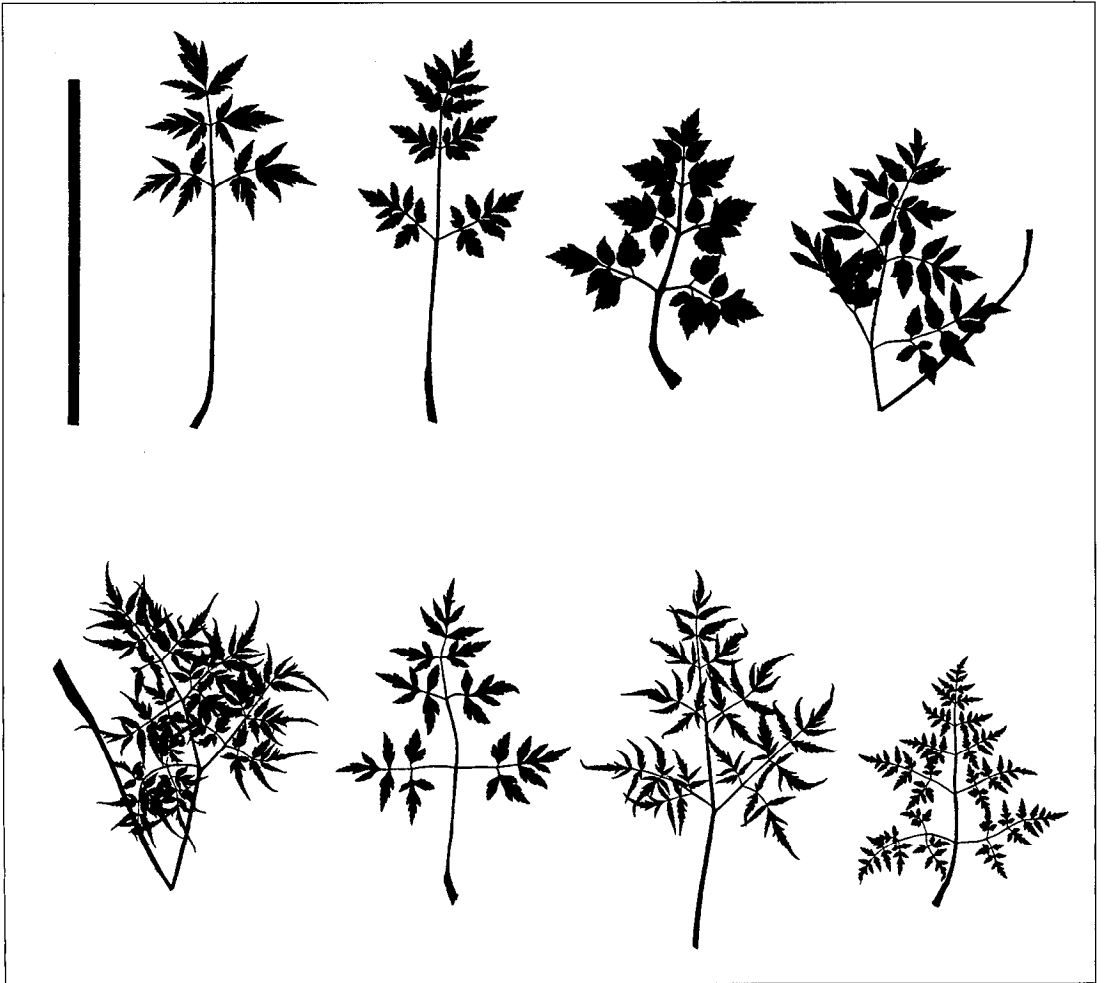


Fig. 24. Leaf variation of *Arracacia andina* (upper row) and *Arracacia equatorialis* (lower row). Herbarium specimens in upper row from left to right: *Herrmann* 1523 (Bolívar), *Vásconez & Velasco* 4 (Bolívar), *Herrmann* 1522 (Chimborazo), *Vásconez & Velasco* 1 (Chimborazo). Herbarium specimens in lower row from left to right: *Vásconez & Montalvo* 17 (Loja), *Herrmann* 1543 (Loja), *Herrmann* 1573 (Loja), *Herrmann* 1520 (Azuay). All specimens from Ecuador. Scale: 30 cm.

— Entre Palca y Huacapistana, 2400-2700 m, *Weberbauer 1745* — Entre Palca y Carpapata, 2500 m, *Cerrate 929* — Carpapata, 2500 m, *Cerrate 2806* — Quebrada pedregosa, 2300-2500 m, *López 802* — Huacapistana, Valle de Tarma, 2400 m, *Velarde 722* — Chanchamayo, *Isern (Cuatrecasas 2417)* — Prov. Huancayo, Huancayo, alrededores, *Soukup 3579*.

This species is known from southern Ecuador and Peru. It has high overall resemblance with *A. xanthorrhiza* and *A. andina* but has been maintained as a separate species because of differences in its fruit, leaf, involucler and oil tube characters (Constance 1949; Mathias and Constance 1976). Also the gracile growth habit and the highly dissected leaf sets the species apart from both *A. xanthorrhiza* and *A. andina* (see Fig. 24). I have observed material from Azuay (*Vásconez & Montalvo 16*) and from Loja (*Hermann 1573*), southern Ecuador (Fig. 25). The storage roots (diameter up to 3 cm) are smaller than those of *A. xanthorrhiza* or *A. andina*; however, the skin of the roots of this material is very thin and easily rubbed off in



Fig. 25. *Arracacia equatorialis* from Loja, cultivated in Quito greenhouse (Herbarium voucher *Hermann 1573*) (Photograph January 1997).

contrast to the paper-like skin of *A. andina* which can be peeled off entirely. This feature and proximal constrictions of the roots (the 'necks' that connect them to the rootstock) suggest close affinity of *A. equatorialis* with cultivated arracacha. There is probably too little material available to decide whether *A. equatorialis* merits species status and what its biosystematic relations with other *Arracacia* species are.

6.2.1.8 *Arracacia incisa* Wolff, Bot. Jahrb. 40: 305. 1908

Stout, caulescent, branching, 0.3-1.2 m high, the foliage squamulose; leaves triangular-ovate to ovate-lanceolate, 10-25 cm long, ternate-pinnate or bipinnate, the leaflets triangular-ovate to ovate-oblong, acute, cuneate or truncate at base, the lower distinct and short-petiolate, the upper sessile and the larger pinnately incised, squamulose on margins and along veins on both surfaces, the lower surface paler and reticulate, a squamulose tuft on the upper side of the sulcate rachis at the base of the larger leaflets; petioles 8-16 cm long, narrowly sheathing at base, the sheaths scaberulous on the veins; cauline leaves with wholly sheathing, inconspicuously inflated petioles; inflorescence branching, the peduncles arising axially and terminally, 2-12 cm long, squamulose at apex; involucre wanting, or of 1 or 2 sheathing bracts; fertile rays 4-8, stout, spreading-ascending, 1-4 cm long, scaberulous at least at apex; involucel of 4-8 obovate to lanceolate, scarious, denticulate-margined, unequal bractlets, 5-10 mm long, the green central portion projecting as an acuminate point, exceeding flowers but shorter than fruit; fertile pedicels 2-6, stout, spreading, usually 2-5 mm long, scaberulous; flowers dark purple or greenish, the petals obovate; stylopodium depressed, the styles slender, divaricate; carpophore 2-parted to base, lax; fruit ovoid, 5-8 mm long, 3.5-6 mm broad, the ribs very prominent and corky, acute; vittae small, 2-3 in the intervals, 3-6 on the commissure, frequently some accessory ones under the ribs or in the intervals; seed scarcely channeled under the intervals, the face deeply sulcate.

List of exsiccatae: **PERU. Ancash:** Prov. Bolognesi, Capillapunta, Cerro al Sur de Chiquián, 3560 m, *Ferreyra 5712*, *Cerrate 155*. — **Cusco:** Prov. Paucartambo, Paucartambo Valley, Hacienda Churu, 3500 m, *Herrera 1391* — Kencumayo 3300 m, *Woytkowski 199* — Prov. Cusco, Cusco, *Rose & Rose 19034*. — **Huánuco:** Prov. Pachitea, steep rocky open grassy slope, Huacachi, estación near Muña, 6500 ft, *Macbride 4163*. — **Lima:** Prov. Huarochirí: "in declivibus rupestribus prope Tambo, ad viam ferream inter oppida Lima et Oroya," 2650 m, *Weberbauer 165*, type — Viso, sandy hillside, 2800 m, *Goodspeed, Stork & Horton 11540* — Valley of Rio Rimac near Lima-Oroya highway at km 90 east of Lima, 3000 m, *Goodspeed & Weberbauer 33059* — Matucana, 8000 ft, *Macbride & Featherstone 326, 2949* — Rio Blanco, 12,000 ft, *Macbride & Featherstone 730* — Prov. Canta: cerca a Culluay entre Canta y La Viuda, 3600-3700 m, *Ferreyva 12964* — Pasco: Prov. Daniel Carrion, in shrub on southwestern canyon slope, Yanahuanca, 10 000 ft., *Macbride & Featherstone 1244*.

This species, which is known only from Peru, and *A. peruviana* have been generally confused, largely because of the inadequacy of the original description. The involucels of the two species are entirely distinct. *Arracacia incisa*, with its conspicuous scarious involucels, deep purple flowers, and blunt, prominently ribbed fruit, is one of the most distinctive species of the genus. The taproot is fleshy and has a fragrance of anise (Mathias and Constance 1962).

6.2.1.9 *Arracacia peruviana* (Wolff) Constance Bull. Torrey Club 76: 45 (1949)

Velaea peruviana Wolff, Bot. Jahrb. 40: 303 (1908).

Slender, branching, 0.6-0.9 m high, squamulose to scaberulous throughout, the stem base clothed with dry sheaths, from a branched taproot; leaves ovate-lanceolate, 20-30 cm long, bipinnate, the leaflets ovate to lanceolate, acute, cuneate at base, the lower distinct and short-petiolulate, the terminal sessile and confluent, 2-5 cm long, 1-4 cm broad, coarsely sinuately lobed and mucronulate-serrate, squamulose on veins and margins, the lower surface paler and reticulate; petioles 10-30 cm long, sheathing below; cauline leaves pinnate, the uppermost with short, wholly sheathing petioles; inflorescence of alternate axillary peduncles, 7-15 cm long, squamulose at apex; involucre wanting, or of a single leaf sheath; fertile rays 5-10, slender, spreading, 4-8 mm long, squamulose especially at apex; involucl of 6-10 entire linear bractlets 5-9 mm long, exceeding flowers but shorter than fruit; fertile pedicels 2-6, spreading, 5-6 mm long, squamulose or scaberulous above; flowers reddish-brown, the petals obovate; stylopodium depressed, the styles slender, spreading-erect; carpophore unknown; fruit ovoid, 4-6 mm long, 3-4 mm broad, glabrous, the ribs filiform; vittae large, solitary in the intervals, 2 on the commissure; seed face deeply and narrowly sulcate.

List of exsiccatae: **PERU. Ancash:** Prov. Cajatambo, infra Ocos, 3000-3200 m, *Weberbauer 2748*, type. – **Ayacucho:** Prov. Huanta, mountains northeast of Huanta, *Weberbauer 7513*. – **Lima:** Prov. Yauyos: Cuchapaya-pampa, cerca (arriba) a Tupe, 2830 m, *Cerrate 1027*. – **Moquegua:** Prov. Mariscal Nieto: Carumas, *Weberbauer 7269*.

This is a species from Peru separable by its conspicuous linear bractlets and reddish-brown flowers. Little is known about its distribution and roots.

7 Variation of cultivated arracacha

7.1 Morphological variation

There appears to be little morphological variation in the cultivated gene pool of arracacha. Because of the dearth of experimental data, however, this is difficult to prove. Clearly, the storage root is the most variable plant part; three horticultural forms are generally recognized: yellow-rooted and white-rooted material and cultivars with additional purplish pigmentation (probably anthocyanins) in the outer cortex or in the region of the vascular bundles. Cultivars of the latter type are particularly frequent in collections of Peru. The former classification, however, is an artificial one, and, in reality there is a continuous range between the three 'extremes'. Figure 26 shows root shapes in an Ecuadorean germplasm collection. The variation in root shape is modest compared with that of other roots and tubers. From the comparative richness of varietal names (Arbizu and Robles 1986; Meza 1995) and available descriptions, it is reasonable to assume that Peru has the greatest morphological diversity in arracacha of all countries.

The only segregating population known is one that resulted from (self-pollinated) seed progenies of the commercial Brazilian clone. This progeny shows a wide range of white to intensely yellow root colour, but purple genotypes also occur at a low frequency. The Brazilian clone is therefore highly heterozygous.



Fig. 26. Variability of arracacha storage root variability in Ecuadorean germplasm collection (Photo courtesy INIAP).

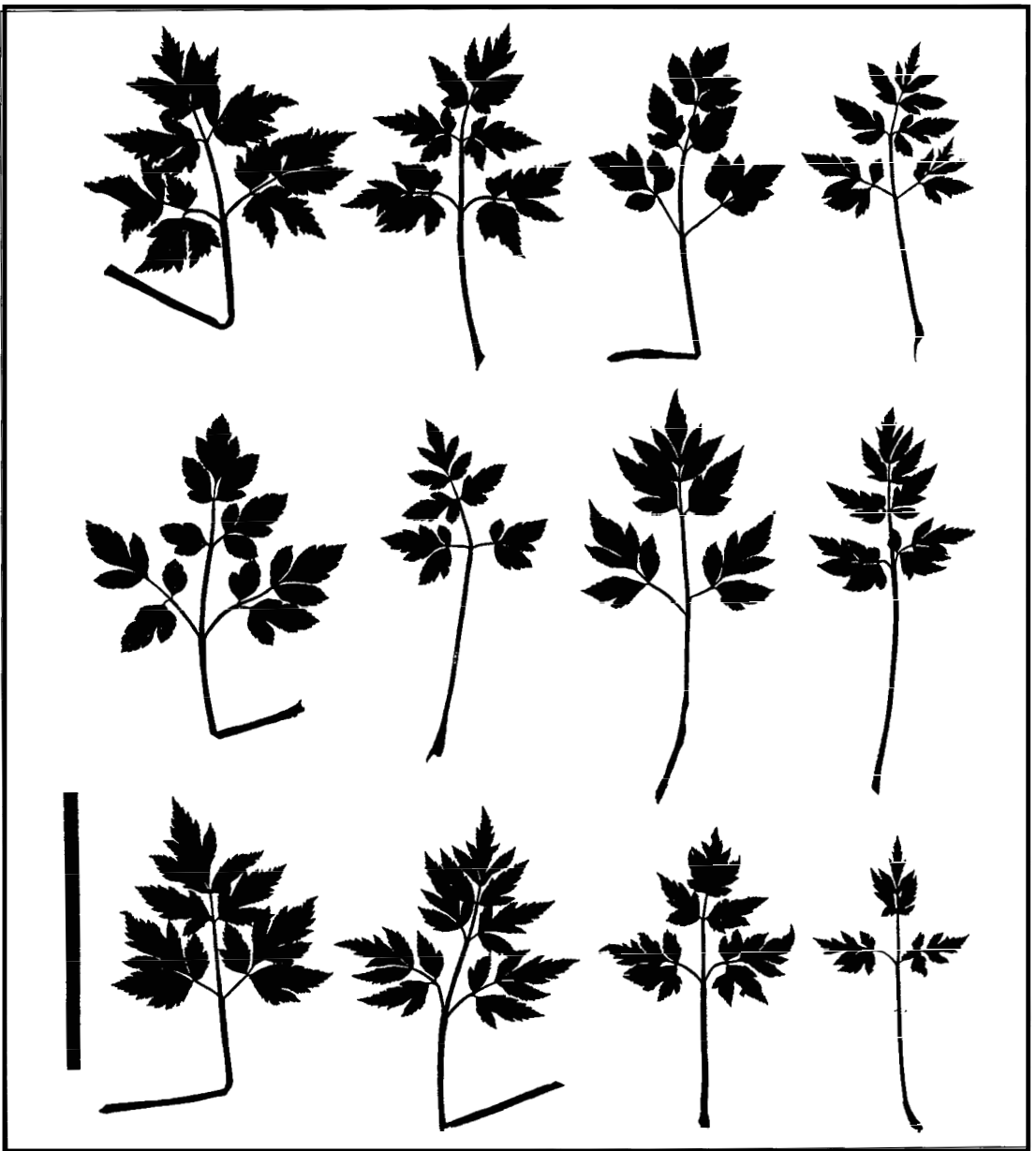


Fig. 27. Leaf variation of cultivated arracacha across species range. All leaves are from plants of the same age and growth conditions (cultivated in pots in greenhouses). Provenance of accessions used (from left to right and top to bottom): Colombia: MH1358 (Cundinamarca, 4°18'N), MHIF1342 (Huila, 2°05'N); Ecuador: ECU1155 (Imbabura, 0°13'N), ECU1232 (Cotopaxi, 0°47'S), ECU1168 (Cotopaxi, 1°04'S), ECU1206 (Bolívar, 1°32'S), ECU1186 (Cañar, 2°43'S); Peru: CA5026 (Lima, 12°20'S), MH546 (Cusco, 13°00'S); Chile MHCN1250 (Arica, 18°50'S); Brazil: MH800 (São Paulo, 20°40'S), CNPH90437 (Distrito Federal, approx. 16°S); note the leaf of MH800 shows virotic leaf deformation. This is the commercial clone used all across Brazil and CNPH90437 is an F₁ genotype resulting from selfing MH800. Scale: 30 cm.

Figure 27 presents the leaf variation found in arracacha cultivars across the species range. By comparison with Fig. 24, it becomes clear that leaf variation in wild *Arracacia* species is much greater. Leaf shape of arracacha may vary as much within one accession as between accessions of a collection. Mazón (1993) struggled to describe leaf characters but concluded that only the degree of (purple) petiole pigmentation is a suitable and consistent leaf descriptor.

Future germplasm evaluations should consider the allocation of dry matter to the rootstock, which appears to be variable (see Table 4). Also, the variation of generative plant parts holds potential for the development of germplasm descriptors (see Section 4.2.2).

7.2 Chromosome number

Chromosome counts in root tips of cultivated arracacha have consistently shown a mitotic number of 44, both in Peruvian (Blas and Arbizu 1995; Blas 1996; 65 accessions) and Ecuadorean material (Mr J.J. Vásconez, 1996, pers. comm.). Blas and Arbizu report the same number for two “wild arracacha” accessions from Peru. Apioïd genera have mostly haploid series of 11 chromosomes (Darlington and Wylie 1955) and it therefore seems likely that arracacha is a tetraploid. Tetravalent pairing in meiosis was recently observed in Ecuadorean arracacha (Mr C. Salazar, 1996, pers.

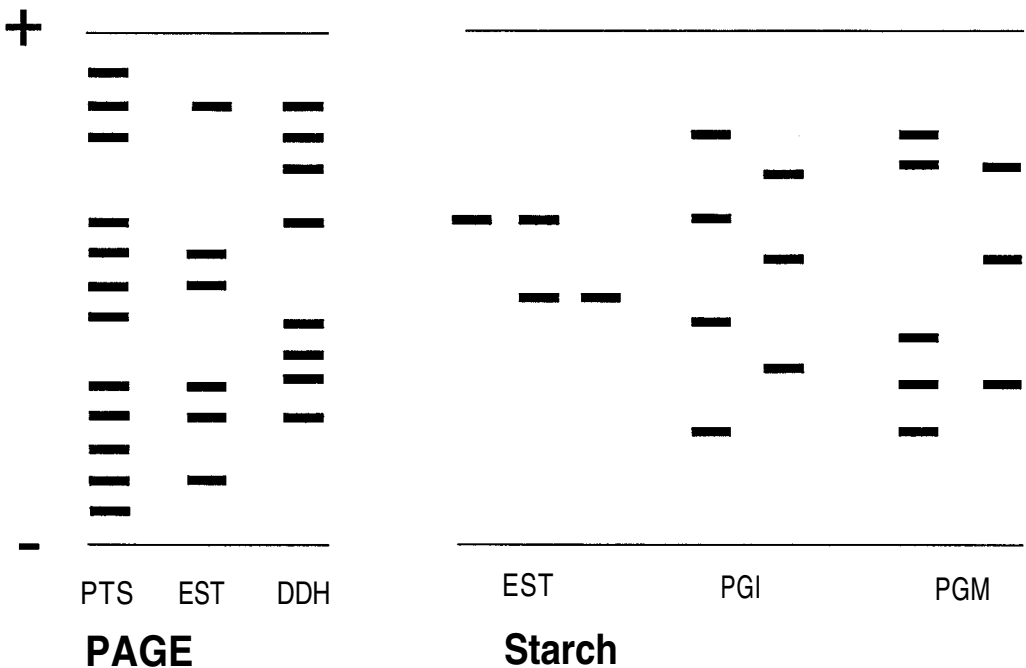


Fig. 28. Electrophoretic isozyme patterns of cultivated arracacha. (Sources: Mazón 1993 (Starch), Erazo *et al.* 1996 (PAGE)). PAGE: in polyacrylamide gels; Starch: in starch gels. EST=esterases, DDH=dihydroliipoamide dehydrogenase, PGI=phosphoglucosomerase, PGM= phosphoglucosomutase, PTS=total proteins.

comm.). Constance *et al.* (1976) report 44 chromosomes for 15 specific taxa of Mexican *Arracacia* and the same number in the closely related genus *Tauschia*.

7.3 Molecular variation

To overcome the difficulties involved in differentiating arracacha cultivars morphologically, Mazón (1993) and Erazo *et al.* (1996) conducted studies aimed at finding isozyme polymorphisms. Although both authors used a range of plant tissues, extraction procedures and buffer systems, little or no isozyme variation was found in a collection comprising Bolivian, Brazilian, Chilean, Ecuadorean and Peruvian germplasm (see Fig. 28). Of 20 isozyme systems showing enzymatic activity, only three (esterases, phosphoglucoisomerase and phosphoglucomutase) showed modest polymorphisms in starch gels (Mazón 1993).

Preliminary work using PCR-amplified DNA from random-sequence decamer primers has yielded promising results in terms of molecular polymorphisms for application in fingerprinting of arracacha cultivars. Thus Blas *et al.* (1997) and Castillo (1997) report the occurrence of DNA polymorphisms in 48% and 85% of primers assayed, respectively. Castillo (1997), however, concludes from his work that overall molecular diversity in his (Ecuadorean) material is low.

8 Conservation and use

8.1 Genetic erosion and germplasm collecting

Undoubtedly, countless generations of farmers, especially the more diversity-minded individuals who share with the modern plant collector a fascination about variation in crop plants, have brought upon us the extant diversity of arracacha and other traditional crop plants. This should not be mistaken with the recently evolving and increasingly popular belief that farmers per se are germplasm conservationists, and that crop germplasm can be conserved *in situ*, in complementarity with genebanks, as it were. Andean farmers indeed use germplasm, whether for economic, medicinal, culinary, aesthetic or other purposes, but chiefly for the diversification of diets that often cannot be supplemented, or only insufficiently so, from markets for lack of integration in the money economy. The fact that one still finds amazingly diverse crop germplasm in poor areas of the Andes is not necessarily proof of the curatorial attitude of farmers, but rather a sign of their dependence on genetic diversity in their fields as an insurance against famine and disease. As farmers are (successfully) integrated into national market economies and have access to external food sources, education and health, an objective that all Andean societies aspire to, dependence on native food sources decreases, and germplasm inevitably is lost to some extent. This is an incremental process and farmers will retain what they still consider useful. I have traveled widely across the Andes and gathered local evidence for the loss of cultivars of arracacha and other crops, particularly in those countries that have lower overall indices of poverty and seem to ‘progress’ economically faster than other countries (Argentina, Chile, Colombia, Ecuador). In light of this experience, the vigorously promoted view on *in situ* crop conservation would appear highly objectionable.

The conservation of germplasm, as opposed to its use, is a conscious effort to preserve what is today obsolete or currently not needed, in the belief that such material will be valuable at a later stage for the extraction of interesting traits from ‘undesirable’ genetic backgrounds. This is what farmers cannot and will not do.

Little is known about the disappearance of arracacha genotypes. This process is commonly referred to as genetic erosion, but strictly speaking, what is meant is the loss of genes or unique linkage groups of genes. Whether genotypes or genes, for that matter, are actually disappearing would require knowledge of the structure of genetic diversity, which, in the case of arracacha, we do not have.

There is, however, indirect evidence for the loss of genotypes in some areas. During germplasm-collecting trips, farmers interviewed often recall clones that are no longer around. Much of the production destined for commerce is from a limited number of genotypes and these tend to replace varieties that, for one reason or another, are less attractive to produce. It has been argued that potatoes and other clonally propagated tuber crops of the Andes have not suffered the extent of genetic erosion as previously thought, and that, in spite of the introduction of modern cultivars, many of the rarer genotypes are still used. This argument overlooks the

economic dimension of the problem. Even if a genotype survives in some remote location, it might become unreasonably costly to spot and collect it. It is therefore a good precautionary principle to preserve this material now, which has also been the rationale behind the collecting of arracacha germplasm in the past.

Since arracacha cannot be propagated from the storage root, which is the economic product, germplasm collections are not possible from markets, unless the rootstock is on offer which seems to be exceedingly rare and restricted to parts of Colombia (see Section 5). Collecting localities given in catalogues (Arbizu and Robles 1986; Tapia *et al.* 1996), therefore, nearly always represent actual growing sites. Cormels are available from arracacha plants in all stages of development and this in combination with the year-long crop duration ensures accessibility to cormels year-round. Even when the crop has been harvested, its crowns (aboveground plant parts) are stored and farmers are normally willing to derive cormels for the visitor. The crowns are not eaten and, since they are stored far in excess of re-planting needs, they are not as highly valued as other (edible) tubers upon which poor people rely in periods of food scarcity. Obviously, collecting at harvest time is more rewarding to germplasm collectors as they can observe root and plant morphology and record uses. Once collected, the cormels can be stored conveniently in paper bags for several weeks at ambient temperatures. On arrival at the genebank, the cormels should be cleaned and surface-sterilized. It is also possible to excise meristems or shoot-tips from the cormels for tissue culture.

Herbaria will be of virtually no help to map out promising areas for arracacha germplasm explorations because of the scarcity of herbarium specimens both in Latin America and in collections known for their New World holdings (for example Missouri and New York Botanical Gardens). Sexual seeds are rarely available from fields and they are of little significance to the germplasm collector.

8.2 Arracacha in genebanks

Efforts to collect arracacha germplasm date back to the early 1970s when both Peruvian institutions, aided financially by the Interamerican Institute for Cooperation in Agriculture (IICA), established arracacha field collections. In 1977, the first of eight international congresses on Andean crops was held and subsequently other field genebanks of arracacha and other Andean root crops were started in the Andean countries, particularly in Peru. The 'lost decade' of the 1980s brought civil strife to Peru, and much of what had been collected was lost owing to political instability, the lack of financial resources and even terrorist threats to genebank curators (Dr C. Arbizu, 1989, pers. comm.). Also, the funding of international agencies was channeled mostly to collecting, but little incentive for follow-up activities, especially for the maintenance and characterization, was provided. Ironically, germplasm scientists in the region generally derive more prestige from the size of their holdings than from a small but well-curated collection. Inflated collections and lacking financial resources proved thus to be a fatal combination that caused some of the loss that occurred. The only two collections

that have essentially kept their holdings are in Quito (INIAP) and Cajamarca (University). Unfortunately, collecting missions during recent decades did not yield herbarium material. This is a source of particular regret when germplasm collections were lost. Informative germplasm catalogues with good location data are available for Peru (Arbizu and Robles 1986) and Ecuador (Tapia *et al.* 1996).

Table 7 provides an overview on current collections as they have been reported in genebank catalogues or other documents. A total of about 700 clonal accessions of arracacha are currently available from genebanks. Ecuador, northern Peru and parts of southern Peru have been comparatively well covered by collecting missions, but there are no significant collections from Bolivia, Colombia and Venezuela.

Table 7. Reported germplasm holdings of arracacha

Institution [†]	Country	No. of accessions	Origin	Source of information	Status
University Ayacucho	Peru	88	All of Peru	Arbizu and Robles 1986	Mostly lost
University Cusco	Peru	104	Apurímac, Cusco, Puno	Ortega 1995	Recently collected
University Cajamarca	Peru	110	Cajamarca, Amazonas	Seminario 1995	Collected over the past 25 years
INIA	Peru	180	Northern Peru	C. Arbizu, 1996, pers. comm.	Characterization
INIAP	Ecuador	94	All of Ecuador	Tapia <i>et al.</i> 1996	Collected over the past 15 years, characterization
EMBRAPA-CNPB	Brazil	35 11	Brazil Ecuador	F.F. Santos, 1996, pers. comm.	Characterization, breeding
International Potato Center	Peru, Ecuador	66	Brazil, Colombia, Ecuador, Peru, Bolivia, Chile	International Potato Center, 1996, germplasm databases	In quarantine, RAPD fingerprinting

[†] INIA = Instituto Nacional de Investigaciones Agrarias, Peru; INIAP = Instituto Nacional Autónomo de Investigaciones Agropecuarias, Quito, Ecuador; EMBRAPA-CNPB=Empresa Brasileira de Pesquisa Agropecuária, Centro Nacional de Pesquisa de Hortaliças, Brasília DF, Brazil.

Most collections are well documented in terms of passport data, but from the available genebank documentation the status of characterization and evaluation is unclear except for the INIAP holdings in Quito. Yield or other plant performance data from this collection, however, are not very meaningful as they come from a field genebank at 3050 m altitude, where arracacha is poorly adapted. Even by conservative estimates, INIAP's arracacha collection is highly redundant, with 57% duplicated accessions (Mazón 1993). Based on a study involving the analysis of 75 polymorphic RAPD markers, Blas *et al.* (1997) estimated the clonal duplication of CIP's arracacha collection to be 51%. We must assume that other collections have similar degrees of duplication, although there are few data to support this.

The arracacha collection of the International Potato Center is an opportunity collection assembled during multi-tuber crop missions to Chile, Colombia, Bolivia and Peru. It is not the result of systematic explorations of the arracacha gene pool.

EMBRAPA-CNPH in Brazil currently holds some 2000 clones, of which 35 have been identified as promising material for distribution within Brazil. All this material was selected from self-set seed progeny of the only commercial Brazilian clone (see Section 8.4). In addition, CNPH conserves 11 Ecuadorean accessions donated from INIAP some years ago.

CATIE in Costa Rica had for some time a collection of 6 accessions, but it appears to have been lost because of poor adaptation to the tropical climate of Turrialba (600 m altitude, approx. 10° N) (Mr J.A. Morera, 1996, pers. comm.).

8.3 Conservation strategies

The foregoing section illustrates the effort of many institutions in the Andean countries to preserve the genetic heritage of their countries, but it also shows the infant stage of the conservation of arracacha genetic resources. Mere amassing of materials with little regard for geographical representation or conservation needs is typical for any germplasm collection in its early stages and is a product of our ignorance of the structure and geographical distribution of crop gene pools. Even the best-researched collections of global crops are plagued by this syndrome to some extent.

Arracacha, however, is a minor crop and only minor resources can justifiably be allocated to the preservation of its gene pool. Also, the clonal diversity in a vegetatively propagated crop is a finite quantity and increasing collecting efforts inevitably result in diminished increments of captured diversity in analogy to the economic law of diminishing returns. It follows then that clonal comprehensiveness of arracacha collections should not be the aim but rather 'lean' collections that encapsulate a maximum of diversity in a minimum number of accessions.

The first step to achieve this is to identify clonal duplicates by the use of a number of conventional and molecular techniques, which have become available. The wealth of information that is gained in this process can be used to enhance our understanding of variation in the gene pool and gaps in collections, geographic or otherwise, can be identified and targeted.

In my experience, the clonal conservation of arracacha is cumbersome and prone to losses. To meet the crop's ecological requirements in the Andes, field collections often have to be located far away from genebank headquarters, where they are difficult and costly to monitor. Although protocols for tissue culture storage of arracacha have now become available (Landázuri 1996), their application cannot always be recommended, as tissue culture laboratories are very vulnerable to the withdrawal of external funding necessary to sustain them. Where institutions have shown a capability to preserve field collections over many years, tissue culture undoubtedly becomes a valuable adjunct to increasing germplasm safety.

In addition to clonal collections, arracacha germplasm should increasingly be stored as sexually reproduced seed. The crop has retained the ability to produce seed and research should be undertaken to better understand the factors that induce flowering. From evidence presented in Section 4.3.1, drought stress and vernalization would appear to be factors involved and research is needed to elucidate the effectiveness of such treatments.

8.4 Crop constraints and breeding

Plant breeding is all too often seen by its practitioners as the panacea for overcoming crop constraints. This approach tends to overlook productivity gains from improved cultivation, particularly from applying standard horticultural techniques to arracacha (transplanting, sanitation of planting stocks, improved post-harvest handling). The potential of horticultural intensification probably exceeds the benefits to be had from breeding arracacha with the limited resources available for a minor crop. Also, breeding requires a clear understanding of crop constraints, whether they are related to factors that limit production or consumption. In the absence of meaningful germplasm evaluations and consumer statistics, such an understanding is not available for most arracacha-producing areas.

It is with these reservations that I turn to plant breeding as a means of increasing arracacha's competitiveness with other crops. The two single most important issues emerging in discussions with growers, extensionists and users are long crop duration and limited post-harvest life. Even when arracacha propagules are pre-cultured (to facilitate rooting and crop establishment), the crop needs 7-8 months from transplanting to harvest (see Section 4.5.1). This limits the crop's diffusion in two ways. First, entrepreneur farmers aware of the significance of the opportunity cost of land and factor productivity give preference to other vegetables with shorter durations. Second, arracacha does not fit into the tight cropping cycles of densely populated areas, nor can it be expected to expand into more temperate climates unless more precocious cultivars are available (see Section 4.6). Unfortunately, the evidence points to limited variability of crop duration in the cultivated gene pool and it is likely that only a combination of genetic improvement or selection with improved crop management will produce the desired results.

There are no data on the extent of genetic variation of root perishability in arracacha collections, but the ubiquity of the problem would suggest that possibilities

of selecting or breeding cultivars with dramatically improved shelf-life are low. Again, the potential of improved post-harvest handling (see Section 4.5.5) should not be overlooked.

Arracacha root characteristics are the subject of regional or even local preferences (for details see Section 2). It seems that preferences for yellow and intensely flavoured roots in Brazil and for white and weakly flavoured roots in other countries or regions are ingrained in local culinary customs and these need to be taken into account in breeding programmes. On the other hand, no singular cultivar is likely to satisfy the needs of different market segments. For example, some processing companies are mainly concerned about intense and evenly distributed root pigmentation while others place emphasis on high dry matter contents and strong aroma. Yet for direct consumption, weakly flavoured roots may appeal to consumers who find the strong umbelliferous aroma undesirable.

As outlined in Section 4.5.4, arracacha is affected by a number of parasitic organisms but there is no single disease or pest known to limit production across growing areas. Even if the area devoted to arracacha was to expand significantly, it would remain comparatively small and long rotations, known to control diseases and pests, would remain an effective option for phytosanitary control. Therefore, pests and diseases rank low in overall priorities and they should not unnecessarily compound the complexity of breeding programmes.

The breeder also will have to struggle with the practical problems involved in cross-pollinating arracacha. The plant has tiny flowers (see Section 4.2.2), and magnifying aids are necessary to emasculate them. Also the scarcity of pollen makes pollinations a tedious task, and hardly more than 20-50 manual pollinations can be done per hour. Moreover, a fruit develops only a maximum of 2 seeds.

The narrow variation found in the arracacha genepool would have to be widened by the use of wild *Arracacia* species. These, however, are presently too little known and no germplasm collections are available.

To my knowledge there is only one arracacha breeding programme. It was started in 1987 at EMBRAPA-CNPH in Brasilia and motivated by the need to breed cultivars with adaptations to different environments. All Brazilian arracacha is derived from one clone, but researchers noted that this cultivar releases much useful diversity when reproduced from sexual seed (Dr F.F. Santos, 1992, pers. comm.). Since the plant does not, or rarely so, set seed under the hot and dry conditions of Brasilia, self-set seed has been collected every year between November and January from farmers' fields in the cooler states of Paraná, Santa Catarina and Minas Gerais. The established seedlings are transplanted into the field and the first screening takes place at plant maturity after a 10-month crop duration. The only genotypes retained are those that show superior vigour and have strong yellow root pigmentation similar or more intense to the commercial clone and cylindrical roots which are preferred for packing. Of many thousand genotypes thus evaluated (2000-20 000 per year) only some 50-100 are further evaluated for agronomic performance, nematode resistance, post-harvest behaviour and reduced crop duration. Only about

10% of the genotypes will survive this (second) screening cycle and eventually 5-10 new genotypes are added to the collection as advanced materials ready for multilocation trials. However, other materials that are of no immediate interest to Brazil, such as white genotypes, also are retained, or others with exceptional yields, pigmentations, etc. As a result, CNPH has accumulated a collection of 2000 clones including 35 promising accessions, the latter for cultivation in Brazil.

Giordano *et al.* (1995) report significantly increased yields of several new clones which are distributed to a wide range of environments across Brazil. Also, clones with somewhat reduced crop duration but otherwise similar characteristics to the traditional clone have been identified and are being tested in multilocation trials (Dr F.F. Santos, 1995, pers. comm.).

8.5 Research needs

As with so many other minor crops, there is a plethora of possible research questions surrounding arracacha. Previous chapters have highlighted a number of issues that could be approached in only a speculative fashion because of the dearth of data. Among the most under-investigated topics is certainly the biosystematic relationships of arracacha to its closely related wild relatives. If the ancestry of arracacha could be solved, then an interesting model for the domestication of a unique umbelliferous plant would be at hand.

In the context of this monograph, the following research needs have been identified to back-up the conservation effort: studies of the factors inducing flowering, better understanding of the breeding system, germplasm conservation by sexual seed and the sanitation of planting stocks.

From a production viewpoint, two issues appear to be of utmost importance. First, how can the crop duration be reduced and what role would a crop model play in achieving this goal? Second, the storage life of the root needs to be improved, by either genetic improvement or better storage technologies.

Finally, processing research and development of new products will be instrumental in promoting this crop for urban consumption. Pilot trials should explore the potential to introduce arracacha outside Latin America.

8.6 Crop prospects

In closing this monograph, one might ask what the future will bring for arracacha. With about 30 000 ha dedicated to its cultivation and an annual production value well in excess of US\$100 million, arracacha is actually not a neglected crop. Given its versatility in cuisine, productivity, peculiar aroma and fine starch, will it ever establish itself as a global, albeit secondary crop? Or has it reached its peak distribution and will it stay within the confines of Latin American highlands?

Arracacha has not shared the stunning global success of a number of New World crops. Sweetpotatoes spread into Polynesia before the advent of the great European sea voyages. Maize was widely known in many parts of the Old World by the end of the 16th century. Potatoes, cassava and New World cucurbits became worldwide

staples long before the invention of research institutes and the surge in mass communication and travel. The failure of arracacha to conquer its niche in Africa and Asia cannot thus be explained in terms of deficient research, promotion or any other single cause.

While this recognition should be the basis for a realistic appreciation of arracacha's potential, it should not discourage us from addressing specific crop constraints. Eventually, research and, perhaps more importantly, the application of existing technology will lead to incremental improvements of the crop's competitiveness and this, aided by the increasing demand for processed arracacha products, will provide opportunities for crop expansion, both in traditional areas and beyond.

In Section 8.4, the possibilities for breeding or selecting improved arracacha cultivars were outlined. A much bolder (but infinitely costlier) approach would be the attempt to 're-design' or 're-domesticate' arracacha. We must remember that arracacha is essentially still a neolithic crop brought into cultivation thousands of years ago. Today's varieties reflect the crop's adaptation to nutrient-poor soils and rain-fed agriculture. Selection for vigorous vegetative propagules and the historic utilization of the central rootstock for food led to a plant architecture which ensures the survival of the crop in harsh conditions, but also one that compromises much of the dry matter in non-commercial storage organs, delays early plant development and results in long crop duration. Would it be possible to breed arracacha into a crop with only one central rootstock or tuber analogous to that formed by the closely related celeriac (*Apium guaveolens* var. *rapaceum*)? Could eventually, by the use of wild *Arracacia* germplasm, biennial and seed-propagated arracacha cultivars be bred with production characteristics similar to those of fast-growing Old World umbellifers? Research budgets needed to answer these questions are probably not available today, but undoubtedly, such research would provide credentials to our modern claim of 'plant improvement'.

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