

Promoting the conservation and use of underutilized and neglected crops. 20.

Peach palm

Bactris gasipaes Kunth



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Foreword

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

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

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1 Introduction

Peach palm (*Bactris gasipaes* Kunth) was a staple food crop for many pre-Columbian Amerindian communities in the lowland humid neotropics (Patiño 1963). The Amerindians domesticated peach palm and distributed it throughout much of the Amazon Basin, northwestern Andean region and Central America, producing in the process a genetically rich landrace complex (Mora-Urpí 1993; Clement 1995a). They valued peach palm for several reasons: it was easy to cultivate in traditional agroforestry systems, it yielded well on infertile soils, the fruits could be prepared into a variety of nutritious foods, and other plant parts could be consumed or used for construction and other household needs. Most European colonists, however, overlooked the value of peach palm, preferring to cultivate corn and other known staple food crops. Many people still cultivate peach palm on a small scale, but its real potential in the humid neotropics has been largely neglected until recently.

Peach palm is being rediscovered now, with promising nutritional and commercial benefits for resource-poor families in Latin America. Interest was rekindled primarily by Patiño's historical review (1958), Camacho and Soria's paper on peach palm's heart-of-palm (1970) and a National Academy of Science booklet on underexploited tropical plants (NRC 1975). Since then, national and international efforts have focused on germplasm explorations, conservation and management of genetic resources, genetic improvement, agronomic management and industrialization.

Peach palm yields two food crops with commercial potential: the fruit and heart-of-palm. The fruit provides several nutritious, staple foods: pulp for direct consumption, flour for infant formula and baked goods, cooking oil, and ration for farm animals and fish culture (Blanco-Metzler *et al.* 1992a). The flour is already on the market in parts of Central and South America, and there are plans for commercial production of animal ration. The processing of gourmet heart-of-palm for the international market is growing into a major agro-industry in producing countries (Villachica 1996).

The genepool of cultivated peach palm and its wild relatives is rich in diversity. There is considerable variation in commercially important traits that could serve future genetic improvement programmes for fruit products and heart-of-palm (Clement and Mora-Urpí 1987; Mora-Urpí *et al.* 1993). Unfortunately, genetic erosion is occurring within landraces and wild relatives, creating an urgent need for new explorations to collect germplasm of high utility value, and for development of sustainable strategies to conserve germplasm through use.

The objective of this monograph is to make information more readily available to those interested in the food-crop potential and genetic resources of cultivated peach palm. It is hoped that this will stimulate further interest in the commercial development of peach palm in the lowland humid neotropics.

2 Taxonomy, nomenclature and geographical distribution

2.1 Taxonomy

The cultivated peach palm is correctly referred to as *Bactris gasipaes* Kunth (Uhl and Dransfield 1987), but other epithets are still found in the literature. Peach palm has been placed in two different genera at various times: *Bactris* Jacquin (1777) and *Guilielma* Martius (1826). Drude (1887) was the first to place *Guilielma* as a subgenus within *Bactris*. Burret (1934), however, accepted *Guilielma* as a genus and reduced several species to synonymy with *B. gasipaes*, following Bailey (1930). MacBride (1960) agreed with Drude's decision based on external morphology, but Tomlinson (1961) supported Burret's decision based upon differences in fiber anatomy in the leaves. Uhl and Dransfield (1987), the current standard, place *B. gasipaes* within *Bactris* without defining a subgeneric category. Sanders (1991), on the basis of a preliminary cladistic analysis, considers *Bactris* to be a monophyletic genus if *Guilielma* is recognized as a section within an expanded subgenus that also includes an Antillean section.

Just as the existence of *Guilielma* itself has been questioned, the number of species included within it has waxed and waned during the last 175 years. Mora-Urpí and Clement (1981) and Clement (1988) reviewed this history and identified a core group of taxa that have remained within *Guilielma* up to the present, although Henderson (1995) recently questioned the validity of many of them. Mora-Urpí (1992) and Mora-Urpí *et al.* (1993) listed several taxa that may be new species within *Guilielma*, but they have not yet been described in the literature. Because *Guilielma* is currently in question, Clement (1995a) proposed the adoption of Harlan and de Wet's (1971) genepool terminology to organize these taxa into primary and secondary genepools. The primary genepool (*B. gasipaes*) has a domesticated subspecies (*utilis*) that contains the landraces, and a wild subspecies (*speciosa*) that contains apparently wild populations of *B. gasipaes*, some of which were originally described as species. The secondary genepool contains other *Guilielma* species that probably can hybridize with *B. gasipaes*. The tertiary genepool contains the remaining species of *Bactris*.

Table 1 outlines this proposal and some of the controversy surrounding many of the taxa. Mora-Urpí's (1993) proposal that the *Guilielma* complex is a coenospecies is conceptually very similar to the genepool proposal, but the former terminology is more widely used. At the New York Botanical Garden, A. Henderson is currently conducting a systematic revision of *Bactris* that may resolve the controversy, especially when results of isozyme and DNA studies are included. Henderson's (1995) first proposal, however, reduces the entire primary genepool to *B. gasipaes* and the entire secondary genepool to *B. macana*, without comment or analysis of variation. Because of the uncertainty about the origin of cultivated peach palm and the potential importance of wild populations and related species in genetic improvement programmes, the taxonomic revision should be based on a thorough analysis of variation within the *Guilielma* complex and the partition of this variation among and within the species that are finally accepted.

Table 1. Closely related species of the *Guilielma* complex, represented by their original names

Species	Location	Observations
<i>Bactris gasipaes</i> Kunth 1816	Ibague, Colombia	All three names correspond to cultivated peach palm
<i>Guilielma speciosa</i> Martius 18241	Maranhão, Brazil	
<i>Guilielma utilis</i> Oersted 18582	Turrialba, Costa Rica	
<i>Guilielma chontaduro</i> Triana 18543	Cauca Valley, Colombia	Wild relatives of peach palm. They need a taxonomic revision to reconfirm them as different species or synonyms
<i>Bactris speciosa</i> var. <i>chichagui</i> Karsten 18574	Magdalena Valley, Colombia	
<i>Guilielma insignis</i> Martius 18445	Beni, Bolivia	
<i>Martinezia ciliata</i> Ruiz & Pavon 17986	Huánuco, Peru	
<i>Guilielma microcarpa</i> Huber 19048	Ucayali, Peru	
<i>Guilielma macana</i> Martius 18449	Maracaibo, Venezuela	
<i>Bactris caribaea</i> Karsten 185710	Perija, Venezuela	
Chontilla (undescribed) ⁷	Esmeraldas, Ecuador	Newly found wild relatives of peach palm
Darien (undescribed) ¹¹	Darien, Panama	
Ca-Pu (undescribed) ¹²	Alto Putumayo-Caquetá Rivers, Colombia	
Azuero (undescribed) ¹³	Azuero, Panama	

¹ Bailey (1930) reduced *G. speciosa* to synonymy with *B. gasipaes* (as *G. gasipaes*, because he accepted *Guilielma*). Drude (1881) named a spineless mutant var. *mitis*. Barbosa-Rodriguez (1903) named three varieties (*flava*, *coccinea* and *ochracea*) that are normal variants in most cultivated populations. None of these varieties is accepted today.

² Bailey (1930) suggested that *G. utilis* may be a synonym of *B. gasipaes* but did not reduce it to synonymy. Burret (1934) accepted *G. utilis*. Glassman (1972) reduced it to synonymy with *B. gasipaes*.

³ Burret (1934) did not mention *G. chontaduro*. Glassman (1972) reduced it to synonymy with *B. gasipaes*. Dugand (1976) reduced it to a variety of *B. gasipaes*. This taxon is called 'chinamato' in the upper Cauca River valley, Colombia.

⁴ Also denominated var. *chiquichiqui* Karsten. Given the geographic proximity between *Guilielma chontaduro* and *B. speciosa* var. *chichagui*, they may be synonymous.

⁵ Balslev and Moraes (1989) mention that Burret (1934) thought that *G. insignis* should be reduced to synonymy with *B. gasipaes* but Burret did not do so. Saldias-Paz (1991) provided extensive numerical data on *G. insignis* populations near Santa Cruz de la Sierra, Bolivia. Henderson (1995) reduced it to synonymy with *B. gasipaes* without comment or an analysis of morphological variation.

⁶ Martius (1826) transferred *M. ciliata* to *Bactris*, and Wendland (1878) transferred it to *Guilielma*. Burret (1934), MacBride (1960) and Glassman (1972) accepted it. Bernal (1989) reduced it to synonymy with *B. gasipaes* without an analysis of morphological variation or new collections in the type locations. The photograph of *M. ciliata* in Dahlgren (1936) suggests that it is similar to *G. microcarpa*, and much smaller than *G. insignis*, but Henderson (1995) accepts Bernal's conclusion without comment. If *M. ciliata* is similar to *G. insignis*, this contradicts Henderson's description of *B. gasipaes*.

⁷ Mora-Urpí collected Chontilla in 1988, and planted it in the University of Costa Rica germplasm collection. It looks like a small *G. insignis* but is found 2000 km from Bolivia and on the other side of the Andes. It has not been described by a *Bactris* specialist.

⁸ MacBride (1960) thought this a *nomen nudum*, but Glassman (1972) accepted it, renaming it *B. dahlgreniana*. Clement *et al.* (1989) provided extensive numerical data on *B. dahlgreniana* populations in Rondonia and Acre, Brazil, and recently found a new population further west in Amazonas.

⁹ This is the only small-fruited species accepted by Henderson (1995), since he places all other small-fruited *Guilielmas* in synonymy with it, but his argument that this is the ancestral form of *B. gasipaes* essentially reduces it to synonymy with *B. gasipaes*.

¹⁰ Dugand (1976) suggested that *B. caribaea* was synonymous with *G. macana*, but never published a formal proposal.

¹¹ Mora-Urpí collected Darien in 1986, and planted it in the University of Costa Rica germplasm collection. It looks somewhat like a *B. dahlgreniana* or *B. macana*, but has not been described by a *Bactris* specialist.

¹² A US-AID financed prospection team collected Ca-Pu in 1984 (Clement and Coradin 1988). It looks like a *Guilielma*, but is quite unlike *B. gasipaes*. Unfortunately, none of the seed germinated, so it is not represented in any germplasm collection.

¹³ Collected in 1996 in Cerro Hoya National Park, Panama by J. Mora-Urpí and planted in the University of Costa Rica germplasm collection. It has not been described.

The distribution of peach palm today involves a complex pattern of landraces (Mora-Urpí 1984; Clement 1988; Mora-Urpí and Clement 1988; Mora-Urpí 1992). It has been divided into Occidental and Oriental subcomplexes based on vegetative differences (Mora-Urpí 1984), and further divided into classes based on fruit size (Mora-Urpí and Clement 1988; Mora-Urpí 1992; Mora-Urpí *et al.* 1993): the 'microcarpa' landraces have small fruits (<20 g), the 'mesocarpa' landraces have fruits of intermediate size (20-70 g), and the 'macrocarpa' landraces have very large fruits (70-250 g).

2.2 Botanical and vernacular names

Bactris gasipaes Kunth, family Palmae (Arecaceae). Common synonyms: *Guilielma speciosa* Martius, *Guilielma gasipaes* (Kunth) Bailey, *Guilielma utilis* Oersted. Haploid chromosome number $n=14$ (Mora-Urpí and Solís 1980), but Read (1966) reported $n=15$.

There are more than 200 vernacular names for *Bactris gasipaes* Kunth (Patiño 1960). The most common are: peach palm and pewa palm (Trinidad), *pejibaye* (Costa Rica and Nicaragua), *piba* (Panama), *pijiguao* and *macana* (Venezuela), *chontaduro* (Colombia and Ecuador), *pijuayo* (Peru), *tembe* and *palma de Castilla* (Bolivia), *pupunha* (Brazil), *parepon* (French Guayana). The botanical epithet (*gasipaes*) is derived from the vernacular name used in the Magdalena River valley of Colombia (*cachipay*).

2.3 Geographical distribution

Cultivated peach palm had a wide geographical distribution in pre-Columbian times, extending from central Bolivia to northeastern Honduras (approx. 17° S to 16° N) and from the mouth of the Amazon River and Guayanas to the Pacific coast of Ecuador and Colombia into Central America (Fig. 1); today it extends north to Mexico and to some Caribbean Islands, and has been taken to other continents. The wild species of *Guilielma* (Fig. 2) extend from Bolivia-Rondonia north to the upper Caquetá River area in the western Amazon Basin, and west of the Andes Mountains from the central coast of Ecuador to Nicaragua (Conzernius 1932; Arroyo and Mora-Urpí 1996).

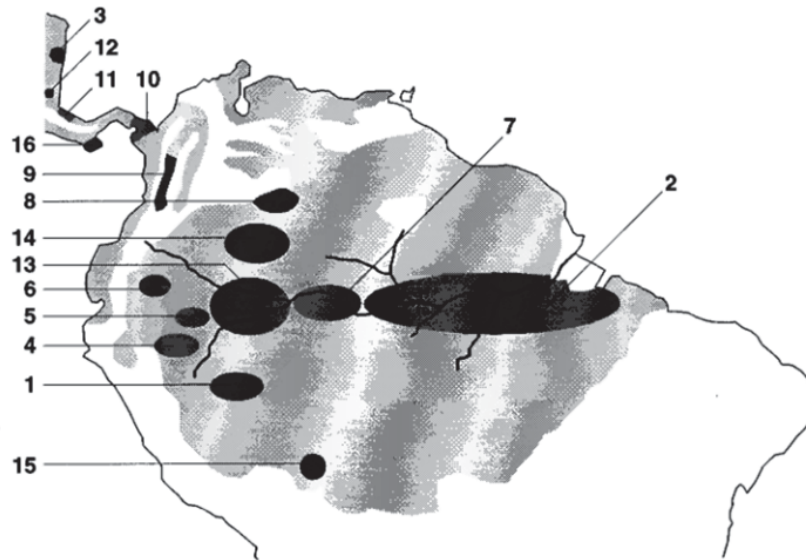


Fig. 1. Geographical distribution of *Bactris gasipaes* and its landraces: 'microcarpa' (1) Juruá, (2) Pará, (3) Rama, (16) Azuero; 'mesocarpa' (4) Pampa Hermosa, (5) Tigre, (6) Pastaza, (7) Solomões, (8) Inirida, (9) Cauca, (10) Tuirá, (11) Utilis, (12) Guatuso; 'macrocarpa' (13) Putumayo, (14) Vaupés, (15)

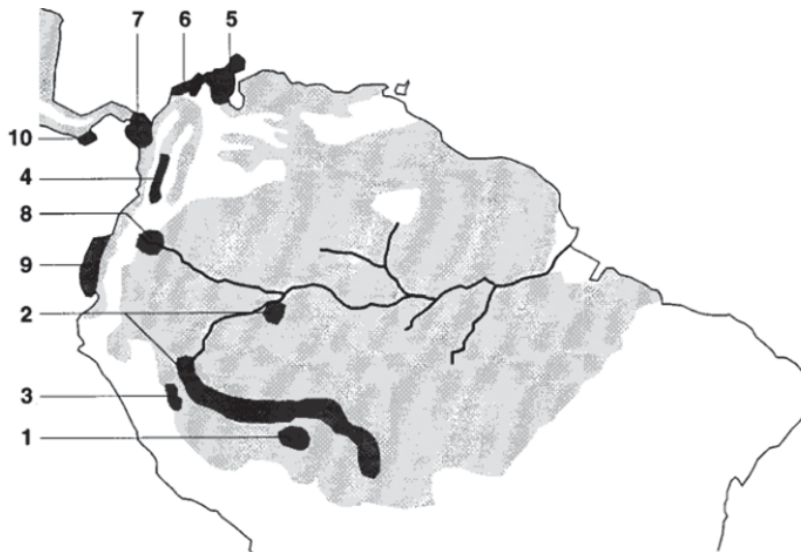


Fig. 2. Geographical distribution of the *Guilielma* complex as defined in Table 1, excluding *Bactris gasipaes* (see Fig. 1). Lightly shaded area is *Bactris* subsp. *utilis*; (1) *B. insignis*; (2) *Guilielma microcarpa*; (3) *Martinezia ciliata*; (4) *B. speciosa* var. *chichagui*; (5) *B. caribea*; (6) *G. macana*; (7)

3 Description of the cultivated species

3.1 Morphological description

The following description is based on 25-year-old cultivated peach palms in the germplasm bank at the Experimental Station of Los Diamantes, Guápiles, Costa Rica. Evaluations were made on 398 trees representing several Central and South American accessions (Mattos-Silva and Mora-Urpí 1996).

Peach palm is typically multistemmed (caespitose), although single-stemmed plants occur (Fig. 3). The 1-13 stems are straight, cylindrical, unbranched, 6-24 m tall, 12-26 cm in diameter, with nodes 2-9 cm long and internodes 7-27 cm long at breast height. Most peach palm have stems with spines on the internodes; when present, they number 1-97 per 16 cm², are usually dark in colour with variable consistency, and the majority are 3-14 cm long. Offshoots (suckers) are managed for heart-of-palm (Fig. 4): they arise from basal axillary buds, and usually vary in number from 1 to 12. Apical dominance in the main stem controls the number of offshoots that develop into stems. As the plant develops, adventitious roots produce a thick, partially superficial mat that may extend 4-5 m around the plant (Vandermeer 1977; Ferreira *et al.* 1995). Most roots occupy the upper 20 cm of the soil horizon, although some primary roots may extend to a depth of 2 m or more, depending upon soils and presumably genotype (Ferreira *et al.* 1980, 1995).

The canopy has 10-30 pinnate leaves which are spineless or have short spines along the sheath, petiole and mid-rib. Spines may also occur on the abaxial and adaxial mid-ribs and veins, and along margins of leaflets. The petiole-sheath is 49-179 cm long, the rachis is 179-396 cm long, and has 180-386 leaflets. The bifurcated

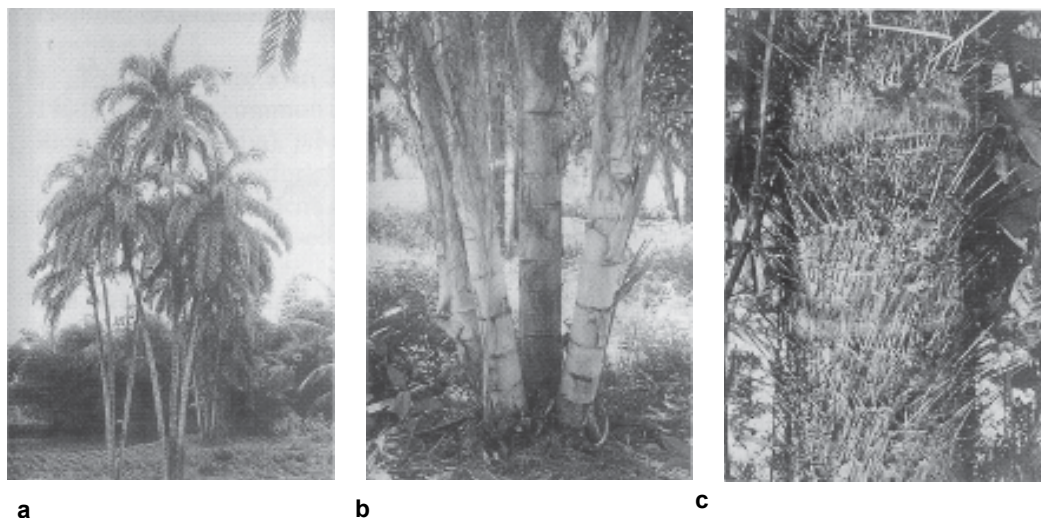


Fig. 3. Multistemmed peach palm (a), with closer view of basal offshoots (b), and spines on stem (c).

leaflets are 58-115 cm long, 3-6 cm wide, and are often fused basally and apically. Juvenile leaves have pubescent leaflets which are fused along a reduced rachis.

Multibranched inflorescences develop in the axil of the leaves. They are initially covered by two bracts. The exterior bract (prophyle) is hard and triangular, about 13 cm wide and weighs 50-875 g. The internal bract (peduncular) may be spineless or have spines that cover its entire surface or only the tip. The spathe, when fully developed but still closed, is 51-126 cm long, 6-18 cm wide, 2-15 mm thick and weighs 1-6 kg. The spathe's internal surface is cream or light yellow. The peduncle is 10-17 cm long and rarely has spines. The rachis is 31-75 cm long, has 0-16 aborted rachillae and 25-145 fertile rachillae that are 16-47 cm long. Rachillae may be straight or curved. Rachis and rachillae are covered with trichomes. Bracteoles vary in length, diameter and shape. The flowering phase is extended and indeterminate (pleoanthetic).

Peach palm is monoecious, with unisexual male and female flowers developing on the rachillae. Female flowers are irregularly arranged among male flowers. Male flowers are cream-light yellow, 2-6 mm long and 2-6 mm wide, with six stamens arranged in pairs on the sides of the corolla. Female flowers are usually yellow, or rarely green, 3-13 mm long and 4-12 mm wide. The gynoecium is syncarpous, trilocular. Occasionally functional hermaphrodite flowers are present, especially in young plants (Lima 1955). Poorly differentiated, sterile flowers also may be observed.

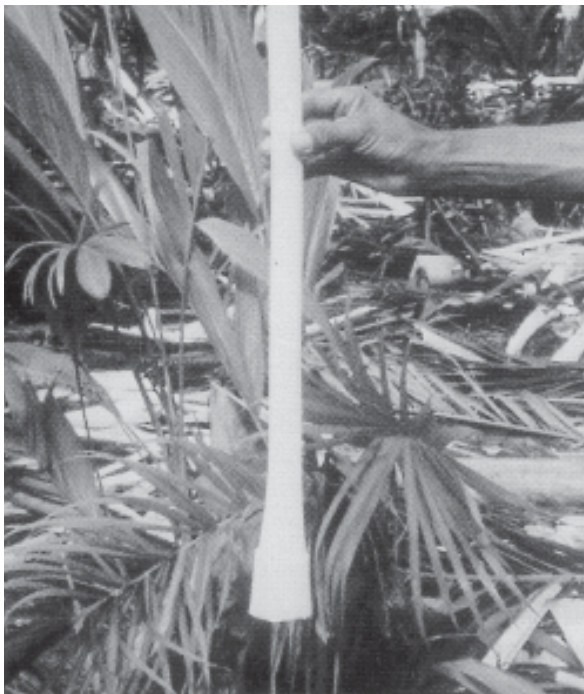


Fig. 4. Heart-of-palm extracted from basal offshoot.

The fruit is a drupe, usually shiny orange, red or yellow (Fig. 5), and may have superficial striations. The tip of the fruit may be mammiform, rounded, angular or truncated. Dimensions are quite variable: length 2-7 cm, width 2-8 cm and weight 4-186 g. Colour of the mesocarp varies from creamy white to orange. The number of mature fruits per inflorescence (commonly referred to as raceme or bunch) varies from 0 to 764, with total fruit weight 0-20 kg. Parthenocarpic fruits are common (average 21 per raceme) and generally slightly smaller than fertile fruit.

The dark endocarp, containing the seed, is usually located centrally in the fruit, but may occur at the distal end. The endocarp varies considerably in shape and dimensions: ovoid, elliptic, round, oblong or cuneiform; length 1-4 cm, width 1-2 cm, weight 1-9 g. The endocarp has three pores, two usually above the equator and the third (the germ pore) farther away; it generally has flattened fibers on its surface, and these may be free from or adhere to the mesocarp. Seeds are recalcitrant and rapidly lose viability when dried (Ferreira and Santos 1992). Germination is hypogeal. In peach palm, the endocarp with its enclosed seed is commonly known as the 'seed'. Although not technically correct, this common usage of the word seed will be followed in the text. The embryo produces a shoot and radicle, and the radicle is soon replaced by adventitious roots arising from the obconical seedling axis (Tomlinson 1990).

3.2 Ecology

Cultivated peach palm is adapted to a wide range of ecological conditions, reflecting its wide geographical distribution in the humid tropics of Latin America. It is most productive on relatively deep, fertile, well-drained soils at low to middle altitudes (<800 m asl), with abundant but well-distributed rainfall (2000-5000 mm/year) and average temperatures above 24°C. It produces relatively well on low-fertility soils, highly eroded laterites with 50% aluminium-saturated acid soils following the slash-and-burn of primary or secondary forest, but production decreases in the long term without additional nutrient inputs. It does not tolerate waterlogged soils. It can withstand relatively short dry seasons (3-4 months) if soils are not excessively sandy, but dry seasons significantly reduce growth and yield. Symbiotic associations with vesicular-arbuscular mycorrhizae improve growth (Janos 1977; Ruíz 1993), especially on aluminium-saturated soils, and are often essential for normal development (Clement and Habte 1995).

Wild peach palm (subsp. *speciosa*) occurs in disturbed natural ecosystems, principally along river beds and in primary forest gaps, while cultivated peach palm (subsp. *utilis*) occurs in ecosystems created by humans, such as secondary forest fallows that develop after slash-and-burn agriculture and in other areas of previous human settlement (Huber 1904; Clement *et al.* 1989; Saldías-Paz 1991). Wild individuals are generally scattered and relatively isolated, or occur at low density in small patches. Extensive natural stands of wild peach palm have not been reported.

Peach palm grows very rapidly under optimal conditions (Postma and Verheij 1994). Seedlings develop very slowly under forest shade conditions and mature

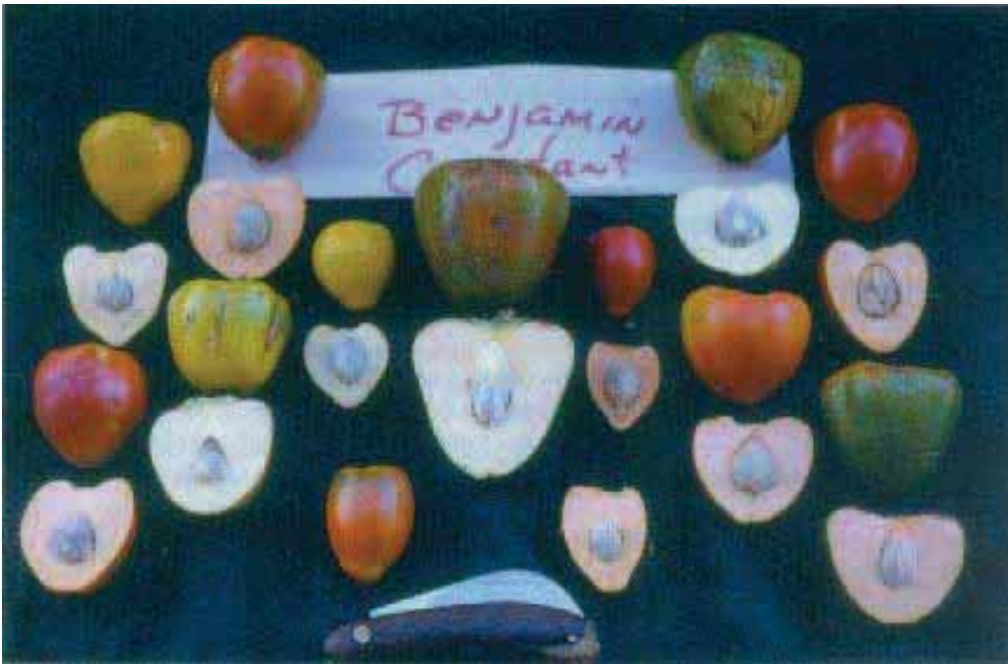


Fig. 5. Peach palm racemes with fruits (a, b) and a closer view (c) of variation in fruits and seeds observed in the Benjamin Constant population, Amazonas, Brazil.

plants require full sunlight for optimal production of flowers, fruits and offshoots. A photoperiod effect on flowering has not been observed.

Cultivated peach palm for fruit production is managed traditionally for subsistence production. Farmers typically sow it at low plant density (3-20 plants/ha) in their multistrata home gardens and swidden agroforestry systems (Clement 1989; Potters 1997) but in modern agriculture it is planted at 400-500 plants/ha for fruit and 3000 to 20 000 plants for heart-of-palm. Peach palm is perennial for both fruit and heart-of-palm production. Cutting the main stem and offshoots for heart-of-palm does not kill the plant, but instead allows preformed buds to develop into new offshoots.

3.3 Development of the stem and inflorescence

To manage peach palm for fruit and heart-of-palm production, one must have a general understanding of the development of stems and inflorescences. A brief summary of the developmental process follows.

In peach palm, axillary buds differentiate from the apical meristem almost at the same time as the leaves (Mora-Urpí 1984). When the plant is young, the first axillary buds develop and differentiate into vegetative basal offshoots if there is sufficient light; the number of offshoots varies from 1 to 12. Basal offshoots also develop around the older basal offshoots of each stem as the cluster gets older, generating an expanding cluster. When basal offshoots are cut for the heart-of-palm harvest, they do not have well-developed root systems. It has not been demonstrated that the roots continue to develop and become part of the functional root mass after the offshoot is cut.

As the stem grows, its new axillary buds differentiate into inflorescences, each subtended by a developing leaf. Three phases in inflorescence development can be distinguished: the slow-growing, fast-growing and anthesis phases (Mora-Urpí 1984; Clement 1987). Development and differentiation of these reproductive buds are controlled by a balance of plant growth regulators, light, plant nutrition, moisture and genotype, but these have not been investigated in detail. The slow-growing phase lasts about 2 years. A continuous gradation in size of reproductive buds is observed during this phase. The fast-growing phase lasts about 2 months. The transition from slow to fast growth will only occur if the reproductive buds are well developed and the plant is in good nutritional condition. During this phase, the peduncular bract rapidly breaks through the external bract, and the subtending leaf normally abscises. The fast-growing phase ends at the anthesis phase, which lasts 2 days (see Section 3.4).

Since a reproductive bud and its subtending leaf develop over a period of about 2 years, one can estimate the maximum number of inflorescences 2 years hence by counting the number of leaves that develop this year (Mora-Urpí 1984). For example, plants of the Utilis landrace in Guápiles, Costa Rica produce an average of 20 leaves/year (Sánchez 1981), so one might expect a maximum of 20 inflorescences per plant 2 years later. Normally, however, only about 50% of the

reproductive buds develop into mature inflorescences. The remainder of these buds abort during periods of nutritional stress, especially late in the fruiting season and soon after harvest when the plant's nutritional reserves are low.

Peach palm generally produces its first fruit crop in 3-5 years, and may produce one or two crops annually. In the Peruvian Amazon Basin, there is normally one crop/year and production is cyclic: 1 year of very high production followed by 1-2 years of lower production (J.M. Pérez, 1997, pers. comm.). In Costa Rica, usually there are two crops during a 12-month period: a larger crop and a smaller crop, about 6 months apart (Mora-Urpí 1984). The smaller crop mainly comes from plants that produced little or nothing in the previous crop. Flowering and harvesting seasons differ among and within regions, depending on local rainfall patterns, soils and landrace, but these factors have not been investigated experimentally. In the Amazon Basin, the main flowering season is from October to December and fruits are harvested from January to April. In Central America, flowering occurs from May to July and the main harvest is from August to October in most places.

Fruits develop to maturity in 3-4 months (115 days average in the Utilis landrace in Guápiles, Costa Rica), but not all fruit bunches (racemes) are ready for harvest at the same time. They typically mature over a 2-4 month period. There is variation in flowering/fruiting phenology, due to genotypic and nutritional conditions of the plants. Inflorescences develop in sequence on the stem, so one cannot harvest all fruit bunches on the stem at the same time. For example, during years of heavy fruit production in the Peruvian Amazon Basin, three harvests per stem are common to collect all mature fruit bunches from the stem. The first harvest normally yields the largest and best-quality fruit, while the third harvest typically yields smaller fruit with more insect damage and fungal infection (J.M. Pérez, 1997, pers. comm.). With proper irrigation and nutrition and an appropriate mixture of selected genotypes, it may be possible to produce peach palm fruit throughout much of the year.

3.4 Reproductive biology

Peach palm generally begins flowering after 3-5 years, and may produce annual fruit crops for 50-75 years (Overbeek 1990). Farmers in Tukurrique, Costa Rica state that some fruit-producing clusters are more than 100 years old. There is considerable variation in age to first flowering/fruiting and annual fruit yield (B. Pashanasi and J.C. Weber, unpublished data), but this has not been evaluated in replicated experiments. Insects are the main pollen vectors, but pollen dispersal also occurs via wind and gravity (Mora-Urpí 1982). Fruits and seeds are naturally dispersed within short distances, principally by birds and rodents and occasionally by water.

The pollination cycle lasts 3 days (Mora-Urpí and Solís 1980). The inner temperature of the unopened inflorescence rises gradually and, late in the afternoon of the first day, causes opening of the peduncular bract and exposes the receptive female flowers (Schroeder 1978). Female anthesis begins at this time, and unfertilized female flowers remain receptive for over 24 hours. The stigmas of

fertilized flowers dry out (J. Mora-Urpí, pers. observ.). Late in the afternoon of the second day, female flower anthesis normally ends and male flower anthesis begins (protogynous development). Male flowers release their pollen in 15-30 minutes, showering the inflorescence and visiting insects, and then the male flowers abscise. The insects then leave and search for a recently opened inflorescence, attracted by a scent produced by the male flowers. While they search for food and oviposition sites in the next mature inflorescence, pollen grains fall from their bodies or are brushed off their bodies on to receptive stigmas. Pollen released during the afternoon of the second day may also fall on to unfertilized receptive stigmas within the same inflorescence, or may be blown by the wind to neighbouring inflorescences with receptive female flowers on the third day.

The reproductive biology of peach palm suggests a tight co-evolutionary history with very small curculionid beetles. The curculionid *Andranthobius* (syn. *DereIomus*) *palmarum* is the main pollinator in Central America and several species of the genus *Phyllotrox* are the main pollinators in the Amazon Basin (Mora-Urpí 1982). Thousands of these small curculionids are attracted to inflorescence by chemical secretions from glands on petals of male flowers (Mora-Urpí and Solís 1980). During the 24 hours before male flower anthesis, they feed on petal tissue and specialized trichome cells that break away and cover the inflorescence (Mora-Urpí and Solís 1980), and oviposit in the male petals (Mexzon *et al.* 1997). The larvae develop in the male flowers that have fallen, then migrate to the soil to pupate. Adults emerge 11 days after oviposition, so the curculionid population grows rapidly as the flowering season progresses. Curculionid beetles have a very tight biological association with peach palm, but other insects also act as minor and occasional pollen vectors, for example, *Epurea* (Nitidulidae) in Peru (Listabarth 1996) and *Cyclocephala* (Scarabaeidae) in Costa Rica (Beach 1984).

Wind pollination may play an important role in managed peach palm plantations, but it may not be very efficient in the wild. Most wind-dispersed pollen falls near the source tree – 50% within 12 m (Solís-Fallas 1979). The distance between scattered and relatively isolated individuals in the wild may be too great for effective wind-pollination. In peach palm plantations, however, there may be an effective pollen cloud on windy days.

Peach palm is predominantly allogamous, having separate pistillate and staminate flowers and protogynous development. Self-fertilization may occur, however, and allow some isolated plants in the wild the opportunity to produce some progeny. Selfing is regulated by a genetic incompatibility mechanism (Mora-Urpí and Solís 1980), but the details of this mechanism have not been determined. There is considerable variation in self-fertility. Clement and Arkcoll (1984) observed 0-88% self-fertility among plants, based on seed set following controlled self-pollination (Putumayo landrace grown in Manaus, Brazil). Self-pollination may occur (1) within the same inflorescence since there is some overlap in female and male anthesis during the late afternoon of the second day, (2) between inflorescences of the same stem, or (3) between inflorescences on different stems

of the same plant. The relative importance of self-pollination in natural and cultivated populations has not been investigated. Self-pollination may be (1) quite high in the first case if there was no effective pollination before male anthesis, (2) very rare in the second case since inflorescences open in sequence, and (3) probably common in the third case.

Considering the reproductive biology and other factors, peach palm may be structured genetically into numerous subpopulations in the wild (Clement 1988; Clement *et al.* 1989). The small curculionid pollinators may have a flight range of only 100-200 m between trees (Mora-Urpí and Solís 1980), or as much as 400-500 m (Mexzon *et al.* 1997), and the pollen they carry has a short viability period (Miranda and Clement 1990). Since peach palm individuals are often scattered, pollen-/geneflow may be quite limited and local. Distance of seed dispersal produced by wild animals is thought to be limited. Given these conditions, effective size of breeding populations could be small and genetically isolated subpopulations could easily evolve. This has important implications for collecting, conservation, management of genetic resources and domestication.

4 Uses and properties

4.1 Traditional food products

Peach palm provided basic staple food products for many pre-Columbian Amerindian communities in Central and South America (Patiño 1958; Clement 1988; Patiño 1989). Its importance was attributable to the nutritional value of the fruit, and the variety of foods that it provided. Early Spanish settlers in Costa Rica wrote that Native Amerindians valued peach palm so highly "that only their wives and children were held in higher regard" (Godínez-Osorio 1575, cited by Fernández 1831-1907).

Native Amerindians prepared peach palm fruits in various ways (Patiño 1958). The simplest was to boil the fruit and then eat the mesocarp. A very common preparation was a beverage prepared by cooking the fruit, extracting the mesocarp, chewing it into a mash, and allowing it to ferment for 24-48 hours (Pellizzaro 1978). They added water to the fermented mash, and drank it for breakfast and at intervals throughout the day. If left to ferment for 8 days, the mash became an alcoholic beverage that was consumed during celebrations.

They also developed methods to preserve the perishable fruit during the off-season. One method was to make 'silage': the pulp was cooked and mashed, and then compressed in a hole in the ground lined with leaves from various Musaceae species. The silage was ready for consumption in a month and could be preserved for a year. When needed, it was diluted with water to make a beverage. When traveling, people carried the silage wrapped in Musaceae leaves. They also dried and smoked the fruits to preserve them (Popenoe and Jiménez 1921). These traditional preparations are still made in some Amerindian communities.

Native Amerindians also consumed the heart-of-palm of the main stem and offshoots and the stem sap (Patiño 1958, 1989) but these were not as important as the fruit. The edible parts included: the tender internodes which extend from the apical meristem down to 10-25 cm below the meristem; the tender tubular part composed of immature leaves wrapped within the tender petiole sheaths (true heart-of-palm); the tender immature leaves above the enveloping petiole sheath, and the sap, which was prepared into beverages.

4.2 Current food products and their properties

Traditional preparations of the fruit have evolved over time, and some have significant commercial potential. To prepare the beverage today, people cook the fruit, grind the mesocarp, add sugar and water, and ferment the mixture for 1-2 days (Blanco-Metzler *et al.* 1992b). A slightly modified, commercial beverage is prepared in Colombia from the mesocarp mixed with milk, sugar and several condiments (Calvo 1981).

The boiled mesocarp, with various seasonings, is a popular hors d'œuvre in many regions. It can be dried, sometimes smoked, stored for a long time and rehydrated for later use (Chávez-Parades and Alvarez-García 1993). Canned fruits

are being marketed in Costa Rica: these include whole or half fruits, either peeled or unpeeled, with or without the seed.

Fruits must be boiled and preferably peeled before consuming or processing. Calcium oxalate crystals were found just below the pericarp of uncooked fruits from the Solimões landrace (Arkcoll and Aguiar 1984) and in the heart-of-palm and edible stem of the Putumayo and Pampa Hermosa landraces (Clement 1995a). Tomlinson (1990) reports that calcium oxalate is found in most parts of all palm species, so it may be found in all peach palm landraces. In addition, a trypsin inhibitor is present in the uncooked fruit (Murillo *et al.* 1983), making protein digestion difficult. Boiling dissolves the calcium oxalate crystals and eliminates the adverse effect of the trypsin inhibitor.

Table 2. Chemical composition and mineral content of fruit mesocarp reported from different sources

2a. Chemical composition (FW=fresh weight; DW=dry weight)

Source	Moisture (% FW)	Protein (% DW)	Oil (% DW)	Carbo- hydrate (% DW)	Fibre (% DW)	Ash (% DW)
Brazil						
Arkcoll and Aguiar 1984†	55.7 (25.2-82.2)	6.9 (3.1- 14.7)	23.0 (2.2-61.7)	59.5 (14.5-84.8)	9.3 (5.2-13.8)	1.3 (0.5-1.8)
Pechnik <i>et al.</i> 1962	53.0	7.9	29.4	40.8	18.5	3.4
Colombia						
Piedrahita and Velez 1982	49.8	9.8	11.5	73.7	2.8	2.4
Zapata 1972	49.7	11.3	10.0	74.6	2.9	1.9
Costa Rica						
Johannessen 1967	55.8	5.0	12.6	78.0	2.8	1.6
CIPRONA 1986	56.7	6.1	8.3	79.9	3.6	2.1
Average	53.5	7.8	15.8	67.8	6.7	2.1

2b. Mineral content (mg/100 g fresh weight)

Source	Calcium	Iron	Magnesium	Phosphorus	Potassium	Sodium	Zinc
Costa Rica							
Blanco-Metzler <i>et al.</i> 1992a	10.9	6.1	11.7	–‡	162.8	2.7	2.1

† Range in values given in parentheses.

‡ Not recorded.

Chemical composition of the fruit mesocarp has been reported from several sources (Table 2a). Although most authors give no details about the landrace(s) analyzed, results suggest that there is considerable variation among and within landraces, with promise for genetic improvement programmes. Among the sources analyzed, those from Costa Rica and Colombia have more carbohydrate (primarily starch) and less oil in the mesocarp than those from Brazil (Pará and Solimões landraces). The variation within sources is very impressive: for example, there is nearly a 5-fold difference in mesocarp protein content and a 28-fold difference in mesocarp oil content among peach palms sampled in markets at Manaus, Brazil (Table 2a, source Pará and Solimões landraces). Esquivel and Mora (1995) have recorded mesocarp oil content as high as 72.7% in wild Chontilla from Ecuador.

The fruit mesocarp is an energy-rich source of carbohydrates and oil, but it is not a complete food. The mesocarp contains all the essential amino acids (Table 3) and is an excellent source of quality protein (NRC 1975). Nevertheless, yellow corn

Table 3. Amino acid content of fruit mesocarp reported from different sources† (% of total nitrogen)

Amino acid	Colombia (1)	Colombia (2)	Costa Rica (3)	Average
Essential				
Arginine	7.3	9.2	1.7	6.0
Glycine	3.2	4.5	5.3	4.3
Histidine	2.7	2.0	1.8	2.2
Isoleucine	2.0	1.7	3.1	2.3
Leucine	2.6	2.6	5.5	3.6
Lysine	4.2	4.6	4.1	4.3
Methionine	1.5	1.3	1.6	1.5
Threonine	2.9	2.5	3.5	3.0
Tryptophan	0.9	–†	–†	0.9
Tyrosine	1.7	1.4	2.8	2.0
Valine	2.8	2.7	3.7	3.1
Non-essential				
Alanine	4.1	3.6	–†	3.9
Aspartic acid	5.0	4.6	–†	4.8
Glutamic acid	4.7	6.3	–†	5.5
Phenylalanine	1.8	1.3	2.8	2.0
Proline	2.7	2.9	–†	2.8
Serine	3.8	3.6	–†	3.7
Protein (% dry weight)	9.0	5.7	5.1	6.6

† Sources: (1) Piedrahita and Velez 1982, (2) Zapata 1972, (3) Zumbado and Murillo 1984.

‡ Not recorded.

a higher content of several essential amino acids (Zumbado and Murillo 1984). Blanco-Metzler *et al.* (1992a) reported a high content of carotene and vitamin C in fruit mesocarp from some peach palms in Costa Rica (Utilis landrace). The abundance of carotene is important in countries like Costa Rica where vitamin A deficiency is common (Blanco-Metzler *et al.* 1992a). Although peach palm may be rich in vitamin C, much of this will be eliminated by cooking since it is thermo-labile and water-soluble. The mesocarp is also a fair source of iron (Table 2b), thiamine, riboflavin and niacin (Blanco-Metzler *et al.* 1992a).

Commercially produced flour, prepared from fruit mesocarp, was recently introduced into the Costa Rican market for use in infant formula, baked goods, soups and other products. Wheat flour must be added to recipes that require a rising agent because peach palm flour lacks gluten (Calvo 1981). The flour can be stored in hermetically sealed containers in the dark for up to 6 months. Infant formulas and other flour products are being commercialized on a small scale in several countries. Plans are underway to increase peach palm flour production for the international market.

Fruits also provide cooking oils, and meal for farm animals and fish culture (Hammond *et al.* 1982; Arkcoll and Aguiar 1984; Zumbado and Murillo 1984; Fernández-Piedra *et al.* 1995). The mesocarp oil has a relatively high proportion of unsaturated fatty acids, notably oleic acid (Table 4), and as with any vegetable oil, contains no cholesterol. Its composition varies among sources. Most sources of mesocarp oil have a small solid stearine component at room temperature, while others are completely liquid or solid (Clement and Arkcoll 1991). The highest content of mesocarp oil is found in some small-fruited landraces, especially Tembe, Pará and Chontilla (Clement and Arkcoll 1991; Esquivel and Mora 1995). High oil content is often associated with high fibre content in the mesocarp in these landraces; after

Table 4. Fatty acid content of fruit mesocarp reported from different sources†
(% of total oil)

Fatty acid	Brazil (1)	Colombia (2)	Costa Rica (3)	Average
Unsaturated	53.3	59.4	69.9	60.9
Linoleic	4.8	1.4	12.5	6.2
Linolenic	1.0	–‡	1.8	1.4
Oleic	41.0	47.5	50.3	46.3
Palmitoleic	6.5	10.5	5.3	7.4
Saturated	46.3	40.6	29.6	38.8
Palmitic	44.8	40.2	29.6	38.2
Stearic	1.5	0.4	–‡	1.0

† Sources: (1) Silva and Amelotti 1983, (2) Zapata 1972, (3) Hammond *et al.* 1982.

‡ Not recorded.

extracting the oil, the remaining meal could be commercialized as an animal food supplement (Arckoll and Aguiar 1984). The protein, oil and fibre contents of the seed are also appropriate for use as an animal food supplement (Zumbado and Murillo 1984). Like other palms, the seed is rich in saturated fatty acids, and could be used to manufacture cosmetics and soap.

Heart-of-palm is developing into an important commercial crop, especially for the gourmet market (Villachica 1996). Fresh, dried and canned hearts-of-palm are being marketed for preparation of salads, soups, roasted chips and fillings. It is a good source of dietary fibre, and a moderate source of magnesium and iron (Table 5).

Table 5. Chemical composition and mineral content of heart-of-palm reported from different sources

5a. Chemical composition (% of fresh weight)

Source	Moisture	Protein	Oil	Carbohydrate	Fibre	Ash
Brazil						
Ferreira and Pashoalino 1988	88.4	2.3	2.2	4.0	1.1	1.2
Peru						
D'Arrigo 1993	91.4	2.9	0.6	3.0	1.0	0.9
Costa Rica						
Asunción 1991	90.5	2.3	0.1	2.7	0.9	0.9
Average	90.1	2.5	1.0	3.2	1.0	1.0

5b. Mineral content (mg/100 g dry weight)

Source	Ca	Fe	Mg	P	K	Na	Zn
Brazil							
Ferreira and Pashoalino 1988	114.0	4.3	80.0	94.0	337.6	1.3	0.8

4.3 Minor products

Native Amerindians used several other parts of peach palm (Patiño 1958; Clement 1988). The stem provided durable material for bows, arrows, fishing poles, harpoons, carvings, and flooring and paneling in their houses. The Ticuna people of the upper Solimões River in Brazil also extract a green dye from the leaves for colouring other fibres (C.R. Clement, 1996, pers. observ.). The long spines were

fashioned into sewing needles. The cooked male flowers served as a condiment (Aguilar and Clement 1984), and the roots provided a vermicide (Patiño 1958).

The durable stem is still valued for parquet, furniture and carvings. Stems could be a valuable by-product from fruit plantations: they could be cut when the tree is too tall to effectively harvest or when declining fruit production no longer warrants a harvest. There is considerable variation among trees in stem characteristics related to wood-product quality: height and diameter of the stem and thickness of the central cylinder and cortex. In heart-of-palm plantations, unused leaf and stem parts could be used to manufacture paper, organic fertilizer and animal food supplement, although continued harvesting of these by-products could reduce the long-term sustainability of low-input plantation systems (see Section 9.5). Some peach palm phenotypes also have commercial value as ornamentals, for example a spineless stem with pendant or erect leaflets.

5 Origin and domestication

There is debate about the centre(s) of origin and domestication of cultivated peach palm. Some authors hypothesize a single origin in the western Amazon Basin (Huber 1904; Seibert 1950; Vavilov 1951; MacBride 1960; Prance 1984; Clement 1988, 1992, 1995a). Others suggest a multiple origin including territories in the western Amazon Basin, western and northwestern side of the Andes, and lower Central America (Mora-Urpí 1984, 1993; Arroyo and Mora-Urpí 1996). There is no direct evidence to establish the centre(s) of origin and domestication, so the hypotheses discussed below are speculative.

Authors supporting a single origin have different opinions about the specific centre of origin and domestication. Huber (1904) proposed a hybrid origin between *G. insignis* from the Bolivian Amazon and *G. microcarpa* from the Brazilian Amazon. Huber thought that fruits of *G. microcarpa* would have been too small to stimulate interest in domestication, and assumed that genes for larger fruits came from *G. insignis*. Vavilov (1951) listed peach palm among the plants from his Andean Center of Origin, but did not elaborate. Seibert (1950) assumed that peach palm originated in northeastern Peru, based on the occurrence of wild peach palm found in the Huallaga River Basin. Prance (1994) proposed origin and domestication in the western Amazon Basin, followed by introduction of the domesticated peach palm west and north of the Andes Mountains: west through the lower passes of the Andes, and north with the sea voyages of Caribbean Indians. Clement (1988, 1992, 1995a) suggested that peach palm's origin and initial domestication occurred in the southwestern Amazon, from one of two possible progenitors (*B. dahlgreniana* or *B. insignis*). He proposed that existing variation in peach palm reflects a long history of Amerindian selection, germplasm migration, adaptation to different environmental conditions, and introgression with species in its secondary gene pool.

Mora-Urpí (1984, 1993) and Arroyo and Mora-Urpí (1996) proposed that cultivated peach palm had multiple origins, resulting from the synthesis of independently domesticated wild ancestors in several areas in the western Amazon Basin, western and northwestern regions of the Andes Mountains, and lower Central America. They suggested that several small-fruited wild species could be progenitors of cultivated peach palm, since spontaneous mutations in small-fruited individuals occasionally give rise to larger, starchier fruits. These 'starchy' mutants may have been the initial selections brought into cultivation. The distribution of wild populations of peach palm extends in a disjunct fashion over an extensive area in the western Amazon Basin, northern Andean region and into Central America (Martius 1847; Conzemiuss 1932; Antezana 1972; Dugand 1976; Clement *et al.* 1989; Saldías-Paz 1991; Mora-Urpí 1982, 1993; Arroyo and Mora-Urpi 1996). The wild populations found in this immense area are geographically separated from each other by physical barriers such as rivers, mountains, dry or swampy areas. They have experienced climatic changes that probably affected their geographical distribution and subsequent evolution. For example, the last glaciation (28 000-12

000 years before present) may have produced drought in the Amazon Basin and other areas for thousands of years, leaving only some humid areas as refugia (Prance 1985). Different Amerindian societies developed in this area (Brunhs 1994) and may have domesticated different wild populations.

Pickersgill (1977) argued that many neotropical crop species had multiple origins and were domesticated independently in different areas, and peach palm may have been one of these species. Blumler (1992) reviewed the evidence for multiple origins of crop species, and considered that they were rare. At this time, there is no conclusive evidence for either a simple or multiple origins of peach palm.

Sauer (1958) and Mora-Urpí (1982, 1993) suggested that peach palm was initially domesticated for starch from the pulp, which is the present use. Clement *et al.* (1989) offered another possibility: oil from the pulp motivated domestication, with *B. dahlgreniana* as a wild progenitor of peach palm. They proposed that the nearly continuous gradation in fruit size is due to starch accumulation during the domestication progress. Patiño (1989) suggested that the stem wood was the initial impetus for domestication, and only later was there selection for the fruit. The stem wood was used to fabricate weapons and other artifacts, and for construction. Whatever motivated the initial domestication, starch certainly became the dominant factor in all landraces from small to intermediate and large fruits, referred to as 'microcarpa', 'mesocarpa' and 'macrocarpa' landraces (Mora-Urpí and Clement 1988).

It is not known when or where Native Amerindians began to domesticate peach palm. Stone (1951) proposed that a pre-Columbian Chibcha civilization from South America introduced peach palm as a staple food into Central America. Judging from seed remains found in Costa Rica, the Chibchas from this country may have been cultivating peach palm 2300 to 1700 years ago (Corrales-Ulloa and Mora-Urpí 1990); there is no published reference of earlier cultivation. By the time Spain colonized the Americas, the fruit was a staple food of many Amerindian communities from Bolivia and Brazil to lower Central America (Fernández 1831-1907; Patiño 1960, 1963).

6 Genetic resources

6.1 Diversity among and within landraces

As mentioned in Section 2.1, today cultivated peach palm is a complex of diverse landraces (Fig. 1). Mora-Urpí (1984) divided the known landraces into two subcomplexes: the Occidental group includes landraces found north and west of the Andes Mountains; the Oriental group includes landraces from the Amazon and Orinoco Basins. In general, landraces in the Occidental group have stouter and harder stems, more and stronger spines, larger leaves and better anchorage in the soil when young, compared with the Oriental group (Mora-Urpí 1984; Mora-Urpí and Clement 1988). In fact, peach palm is known as *chontaduro* (hard palm) along the Pacific coasts of Colombia and Ecuador because of these characteristics.

The Oriental and Occidental subcomplexes were further divided, somewhat arbitrarily, by fruit size into numerous 'microcarpa', 'mesocarpa' and 'macrocarpa' landraces (Mora-Urpí and Clement 1988; Mora-Urpí 1992; Mora-Urpí *et al.* 1993). It is thought that the gradation from 'microcarpa' to 'macrocarpa' landraces reflects the intensity and possibly the duration of selection by Amerindians for fruit-quality characteristics, primarily fruit size (Clement 1988). The primitive 'microcarpa' landraces have small fruits, relatively little pulp tissue compared with seed volume, and the pulp is generally very fibrous and oily. The more derived 'mesocarpa' and 'macrocarpa' landraces have progressively larger fruits, with more pulp, and the pulp contains more starch and less oil. Some populations show fruits from 'microcarpa' to 'macrocarpa', such as in the south Pacific region of Costa Rica where fruits weigh from 20 to 200 g. The landrace complexes and subcomplexes are neither definitive nor complete, pending further germplasm exploration, taxonomic review and appropriate experimental trials.

Phenotypic differences in fruit pulp weight, stem spininess, stem diameter, leaf area, susceptibility to insect pests and many other commercially important characters have been observed among landraces in the field (Clement and Mora-Urpí 1988; Mora-Urpí and Clement 1988) and in germplasm banks (Morera 1981; Clement 1986; Mattos-Silva 1992; Astorga 1993; Pashanasi 1993; Varela-Torres 1993). To date, most landraces have not been compared in multilocation replicated trials, so the distribution and significance of genetic variation among and within landraces have yet to be determined. Nevertheless, several landraces clearly possess desirable characteristics for fruit and heart-of-palm production (e.g. Pampa Hermosa, Putumayo and Vaupés).

There is likely to be considerable genetic variation within landraces, considering the allogamous breeding system. Analyses of phenotypic variation within natural populations are consistent with this hypothesis (Clement and Mora-Urpí 1988). As mentioned in Section 2.2, much of the genetic variation within landraces may occur among numerous small subpopulations (Clement 1988). Within these small subpopulations, there may be relatively low heterozygosity due to inbreeding and genetic drift (Clement *et al.* 1997).

Diverse hybrid populations have developed around many major cities and towns in the Amazon Basin owing to the introduction of foreign germplasm, followed by hybridization and introgression between landraces (Mora-Urpí and Clement 1988). These hybrid populations offer plant breeders the opportunity to see the results of crosses among landraces. They are valuable areas for germplasm collecting because they contain considerable genetic diversity within relatively small geographic areas. One of the oldest hybrid populations, and perhaps one of the oldest centres of domestication, occurs around Yurimaguas, Peru, where the Putumayo, Pampa Hermosa and other unidentified landraces have hybridized. The International Center for Research in Agroforestry (ICRAF), collaborating with national research institutes, private enterprise and local farmers, started collecting germplasm in this region in 1997 for on-farm progeny trials and seed orchards (J.C. Weber, principal investigator).

There has been no systematic study of genetic diversity in peach palm. Rojas-Vargas (1993) and Miranda (1993) were the first to publish results of isozyme analyses of peach palm. Rojas-Vargas (1993) identified the juvenile leaf as the best tissue for enzyme extraction, evaluated the activity and resolution of 10 enzymes from five populations, and separated the isozymes in polyacrilimide gel. The sample size was too small for genetic analysis ($n = \text{five plants/population}$). Nevertheless, Rojas-Vargas' (1993) cluster analysis, based on nine enzymes, supports previous morphometric analyses separating Central American populations from Amazonian populations (Clement 1986), supports Mora-Urpí's (1984, 1993) observation of the morphological similarity between the Tembé landrace (Chapare, Bolivia) and the Pará landrace of eastern Amazonia, and the relative uniqueness of the Yurimaguas population. Miranda (1993) extracted four enzymes from pollen of five plants from Yurimaguas, Peru, and separated the isozymes in polyacrilimide gel. She reported very low levels of variation, suggesting low heterozygosity.

Clement (1995b) identified the apical meristem as the best tissue for enzyme extraction, and reported activity for 28 of the 32 enzymes examined in nine progenies from the Benjamin Constant population of Brazil (Putumayo landrace). Ten of these enzymes, with 17 putative loci, were easily interpreted for genetic analysis. Mean heterozygosity was extremely low (0.074) for an allogamous species, but the population was established with a limited genetic base. The low heterozygosity may also explain the lack of significant correlations between isozyme heterozygosity and various morphological and growth traits, even though these traits varied significantly among progeny.

Clement *et al.* (1997) examined isozyme variation in three spineless populations. They extracted nine enzymes, with 16 putative loci, from the apical meristem of plants from San Carlos, Costa Rica (Guatuso 'mesocarpa' landrace), Benjamin Constant, Brazil (Putumayo landrace) and Yurimaguas, Peru. The highest heterozygosity was observed in the Yurimaguas population: 33 alleles, 2.06 ± 0.23 alleles/locus, 68.7% polymorphic loci (loci with most common allele < 0.99

frequency), 0.141 ± 0.035 observed mean heterozygosity, $0.191 + 0.047$ expected heterozygosity under Hardy-Weinberg equilibrium. The observed heterozygosity is lower than values reported for other palms, and may be partially explained by the history of the germplasm that was analyzed in Hawaii (limited genetic base). Although sample size was adequate for genetic analysis, larger samples and more systematic analyses are necessary to elucidate the relationships among landraces. In addition, the inheritance of isozyme phenotypes should be determined.

Morphological, chemical, isozyme and DNA differences may be useful for identifying plants that, when crossed, would produce more variable progenies, possibly resulting in heterotic effects on growth and yield. However, the lack of significant correlation between isozyme heterozygosity and other traits, if generally true, suggests that expectations may be modest (Clement 1995a).

6.2 Existing germplasm banks

Several *ex situ* field germplasm banks were established in the early 1950s, but not all of them were maintained. Collecting and genebank establishment started at Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica in the 1960s. In the late 1970s, considerable efforts were made to enlarge the collection. Since the 1970s, interest in peach palm has increased, bringing financing for international germplasm collections, and stimulating a more sustained interest in peach palm among participating countries. Germplasm has been collected in Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Nicaragua, Panama, Peru and Venezuela. Some collections followed a targeted sampling strategy, attempting to select phenotypically superior individuals in the field, while most collections included both targeted phenotypes and randomly selected individuals. Although significant, these collections represent only a small area in each country where cultivated peach palm is thought to occur, with extensive areas yet to be explored and collected.

There are now germplasm banks at experimental stations in Brazil, Colombia, Costa Rica, Ecuador, Nicaragua, Panama, Peru and Venezuela (Table 6). Most of these are located within the natural range of cultivated peach palm (except those in São Paulo and Bahia, Brazil and Tovar, Venezuela). They are not replicated experimentally, and accessions are generally represented by only nine plants (3 to >30 in some cases), with interplant spacing of 5 m. Most of them have not been characterized and evaluated and, although most of the germplasm banks are being maintained, many accessions are being lost owing to decreasing plant vigour and offshoot production.

Nearly all of these germplasm banks have both local and international accessions, and some accessions are present in several banks. In 1983-84, the US Agency for International Development funded extensive germplasm collecting in Brazil, Colombia, Ecuador and Peru (Clement and Coradin 1988), organized by two Brazilian research institutes (Instituto Nacional de Pesquisas a Amazônia, Centro Nacional de Recursos Genéticos e Biotecnologia). The collections included both targeted phenotypes and randomly selected individuals in numerous populations

Table 6. Peach palm germplasm banks: location, number of accessions and origin, year established and current condition

Location†	No. of accessions	Origin‡	Establ. year	Condition
Brazil				
Campinas, São Paulo	43	BRA, CRI, PER	1974	Good
Manaus, Amazonas	450	BRA, COL, CRI, ECU, PAN, PER	1979	Poor
Una, Bahia	27	BOL, BRA, COL, CRI	1993	Good
Colombia				
Bajo Calima, Buenaventura	–§	BRA, COL, CRI, ECU, PER	1979	Poor
Florencia, Caquetá	58	COL	1989	Fair
Santuario, Caquetá	38	COL	1989	Fair
Costa Rica				
Guápiles, Limón	1207	BOL, BRA, COL, CRI, ECU, HND, PAN, PER, VEN	1970	Good
Turrialba, Cartago	50	CRI, PER	1963	Good
Turrialba, Cartago	650	BOL, BRA, COL, CRI, ECU, PAN, PER	1963 (UCR)¶ 1967 (CATIE)	Good
Ecuador				
Napo-Payamino, Napo	322	COL, ECU, PER	1979	Good
Nicaragua				
El Recreo, Rama	40	CRI, NIC, PER	1982	Good
Panama				
Las Pavas	54	CRI, PAN, PER	1986	Fair
Peru				
Iquitos, Loreto	113	BRA, COL, ECU, PER	1983	Good
Yurimaguas, Loreto	142	BRA, COL, ECU, PER	1983	Fair
Venezuela				
Saman Moche, Carabobo	42	CRI, VEN	1992	Good
San Nicolas, Portuguesa	42	CRI, VEN	1992	Good
Cataniapo, Puerto Ayacucho	31	VEN	1996	Good

† Institutions and scientists currently managing the germplasm banks are listed in Appendix I.

‡ Abbreviations for countries of origin: BOL=Bolivia, BRA=Brazil, COL=Colombia, CRI=Costa Rica, ECU=Ecuador, HND=Honduras, NIC=Nicaragua, PAN=Panama, PER=Peru, VEN=Venezuela.

§ Passport data and many of the 400 original accessions have been lost.

¶ UCR=University of Costa Rica; CATIE=Centro Agronomico Tropical de Investigacion y Ensenanza.

and provided the basis for the classification of landraces. Accessions were distributed among germplasm banks in Brazil (Manaus), Colombia (Bajo Calima, Araracuara and San José del Guaviare), Costa Rica (Guápiles and Turrialba), Ecuador (Napo) and Peru (Iquitos and Yurimaguas). Costa Rica has also shared some of its germplasm with Brazil, Colombia, Ecuador, Nicaragua, Panama and Venezuela. All of these countries have carried out their own collecting programmes, especially Brazil, Colombia and Costa Rica. Costa Rica has the largest collection in existence.

6.3 Useful and unusual phenotypes

Several unusual phenotypes have been found in the wild and in germplasm banks, and some of these mutants may be useful in fruit and heart-of-palm plantations. In most cases, experimental crosses have shown them to be recessive traits (Mora-Urpí, unpublished data). Some of these potentially useful phenotypes are described below.

Spineless phenotypes are relatively common in some landraces (e.g. Guatuso, Pampa Hermosa and Putumayo) and are well represented in most germplasm banks. Spininess on the stem, petiole and spathe is a quantitative trait (Chávez-Flores *et al.* 1990; Clement 1995b). Spinelessness is important in both fruit and heart-of-palm production systems because it reduces injuries to field workers during maintenance and harvesting. However, the presence of spines may be important under certain conditions. Abundant spines may discourage large predatory insects and small mammals (and theft by humans). Stem spines also help evacuate rainwater, keeping the stem relatively dry much of the time, and thereby reducing germination and growth of epiphytic and parasitic plants on the stem. Spininess can be selected against in the nursery.

The semidwarf stem phenotype, similar to the semidwarf coconut palm, would greatly facilitate harvesting in fruit plantations. Expression of the trait is thought to be controlled by a single gene in peach palm (J. Mora-Urpí and R. Mexzon, unpublished data). Semidwarf spineless phenotypes have been obtained but produce few stems, low fruit yields and small fruit (although of good quality).

An erect-leaf phenotype, called 'erecta-2', has a short leaf blade with a pronounced vertical orientation relative to the stem (about 45°). The tubular sheath develops normally, but the blade is usually twisted slightly, similar to the twist of coconut palm leaves. The erect leaves of this phenotype allow greater light penetration to the ground, which promotes development of offshoots. Plantation density may be increased using this phenotype, but other factors must be considered (root competition, ease of maintenance and harvest operations, etc.). Spineless, erect-leaf phenotypes with high-quality fruit have been produced through controlled crosses for evaluation in field trials (Mora-Urpí, unpublished data). Another phenotype, called 'erecta-1', has leaf blades with an even more vertical orientation (about 20-25°), producing an excessively compact canopy. Inheritance is unknown because no crosses have been obtained. The 'erecta-1' may be useful if crosses between 'erecta-1' and individuals with normal leaves yield progeny that are similar to 'erecta-2'.

In the 'viviparous' phenotypes, offshoots develop on the stem from vegetative buds that originate in the leaf scars. The 'vivipary-1' phenotype is quite variable in expression, ranging from individuals with undifferentiated tissue on the stem to those with numerous offshoots possessing well-developed roots. Otherwise, the plant develops normally, producing fruit and basal offshoots. 'Viviparous' phenotypes that produce numerous offshoots on the stem are being selected, and may be valuable for establishing heart-of-palm and fruit plantations (J. Mora-Urpí, unpublished data). The 'vivipary-2' phenotype produces numerous offshoots with root systems on the stem when the plant is very young. In this case, the stems do not reach sexual maturity and do not produce basal offshoots of commercial size for heart-of-palm, presumably because the numerous offshoots on the stem are strong nutrient sinks.

6.4 Genetic erosion

Many peach palm populations have completely disappeared, and many more, both wild and cultivated, are in peril. There are several reasons for the genetic erosion in peach palm. The European settlers were alien to Amerindian cultures and crops, and promoted short-cycle food crops such as banana, cassava and rice to support their urban population centres. Peach palm fruit and heart-of-palm are highly perishable, so marketing the crops was difficult or impossible without appropriate processing facilities. Many populations, notably the diverse hybrid populations around Iquitos and other large cities, have disappeared or been reduced under the pressure of urban and peri-urban expansion during the last 20-30 years. In addition, the extensive conversion of forests to pasture has eliminated many populations because peach palm does not tolerate fire or cattle, which eat the offshoots and compact the soil.

Genetic contamination from introduced germplasm is also threatening the integrity of most landraces. In Ecuador, for example, the large-fruited spineless Putumayo landrace was common throughout the Napo-Payamino-Lago Agrio region, but spiny germplasm of unknown origin is being introduced and replacing the local landrace. The genetic integrity of the remaining Putumayo landrace in that region is threatened with dilution through hybridization and introgression. This is also occurring in Brazil, where Putumayo and Pampa Hermosa germplasm is being introduced in many areas for fruit and heart-of-palm production.

6.5 Germplasm collecting and conservation

Several biological characteristics and practical aspects should be considered when determining an appropriate germplasm collecting strategy.

- Cultivated peach palm is an ancient and widely distributed species in South and Central America.
 - The cultivated part of the primary genepool is a genetically diverse landrace complex. Diverse ancestral forms still occur in the wild.
-

- Census population size is generally small, sometimes only a few individuals, and effective population size would be even smaller.
- Most variation probably occurs among populations rather than within populations.
- Target collecting of superior phenotypes in the field may limit future breeding and research options, while random collecting may miss superior phenotypes.
- The harvest season lasts 2-4 months, depending mostly on environment.
- Germplasm collecting is expensive and time-consuming. Travel is difficult in most regions. A team of three people can collect fruit and data (minimum descriptor list) from an average of 10 accessions per day.
- Field genebank collections are expensive to maintain, characterize and evaluate.
- Genetic erosion in cultivated peach palm has not been quantified, but is occurring throughout most of its natural range.

With the above considerations in mind, we recommend that future germplasm collecting of cultivated peach palm should attempt to (1) sample a few individuals from many populations rather than many individuals from a few populations, and (2) sample some randomly selected individuals and some phenotypically superior individuals in each population (target/random sampling strategy). Ideally, selections should be made collaboratively with local people, in order to benefit from their knowledge of the local germplasm. The objective of this strategy is to capture germplasm of high utility value and collect as much genetic diversity as possible for genetic improvement, conservation through use, and basic research such as crop evolution. In addition, efforts should be made to identify and manage ancestral forms to maintain their genetic integrity.

Conservation efforts have so far relied entirely on the establishment of large *ex situ* field genebanks. These serve as sources of germplasm for research and use, but they are not a secure approach for long-term conservation. Maintenance, evaluation and renewal of accessions in these large field genebanks are very expensive and require a long-term commitment. To promote that commitment, the practical value of these field genebanks for national and regional economic development must be clearly demonstrated, for example as part of a larger, successful genetic improvement programme. Unfortunately, there is often a lack of continuity in policies and funding in Latin American countries that threatens any long-term project, however well justified. Entire *ex situ* collections of peach palm already have been lost by various institutions. Other *ex situ* collections may be lost in future, considering the condition of some existing germplasm banks (Table 6).

In situ conservation approaches may be necessary to maintain the genetic integrity of valuable landraces and ancestral forms of cultivated peach palm. Again, however, this requires long-term policy and funding commitments. Some landraces and ancestral forms may occur in existing national parks and reserves, as is the case in the Amboró National Park, near Santa Cruz, Bolivia (Saldías-Paz

1991), the National Park of Darien and the National Park of Cerro Hoya, both in Panama (Arroyo and Mora-Urpi 1996). More than likely, new *in situ*, *ex situ* or *circa situ*¹ management areas would be needed to conserve valuable landraces and ancestral forms. These management areas might take various forms: for example, commercial cooperatives of farmers for the conservation through use of valuable landraces of cultivated peach palm; and managed ecosystem reserves for conservation of ancestral forms, and research on their potential value for genetic improvement of cultivated peach palm. Farmers are already managing genetic resources of peach palm, but some of their practices may lead to a reduction in genetic variation at the farm, community and/or regional level (Brodie *et al.* 1997). It is necessary to increase awareness among farmers about the potential implications of their management practices, emphasizing the commercial gains associated with more appropriate management practices. In Peru, for example, the International Centre for Research in Agroforestry (ICRAF) is promoting this awareness by developing a network of farm- and community-level seed orchards, established with germplasm that farmers selected in their fields. These seed orchards not only provide income for the farmers, but also serve as *ex situ* or *circa situ* management and conservation areas.

For conservation through use to be successful, the utility/market value of the crop must provide a sufficient and sustainable incentive for local farmers to develop and conserve the crop's genetic resources. This may be the case for the more valuable landraces of cultivated peach palm, especially if farmers are organized into commercial cooperatives which provide members with improved germplasm, more productive agronomic techniques and access to new markets. It is unlikely, however, that farmers or national governments would show much interest in conserving peach palm's primitive forms, unless the utility/market value of the germplasm were clearly demonstrated. The primitive forms may have useful genes for future genetic improvement of cultivated peach palm, but the research to determine this would require considerable time and money.

Seed germplasm banks are not yet feasible owing to the recalcitrant nature of the seed. More promising, however, is conservation via tissue culture. Seed dormancy and tissue culture research require greater attention (see Sections 8.2 and 8.3).

¹ In *circa situ* conservation, germplasm is collected from a site and conserved in sites nearby; thus there is a possibility for gene flow between the sites (unlike *ex situ* conservation, where germplasm is collected from a site and conserved in a completely different site, so that gene flow

7 Genetic improvement strategies

Genetic improvement programmes for cultivated peach palm are still in the early stages of development. Fortunately, pre-Columbian Native Amerindians improved peach palm considerably, producing a diverse landrace complex that provides valuable germplasm for contemporary improvement programmes. National and international organizations have funded germplasm collections of several landraces and established germplasm banks in different countries (see Section 6.2). These banks have served as base populations for mass selection, breeding and applied genetics research. Costa Rica, followed by Brazil, have the most advanced improvement programmes. Both countries have extensive germplasm banks and enterprises actively involved in the commercialization of peach palm's products.

Table 7. Tentative crop ideotype for fruit production

-
- Stems
 - * dwarf with low annual height increment: <1 m/year during first 5 years in field
 - * spineless internodes
 - Leaves
 - * short, erect petiole and blade
 - * annual production >10 leaves/year
 - * net assimilation rate high
 - Basal offshoots
 - * multiple offshoots developing into 5-12 stems after 12 months
 - Racemes, fruits and seeds
 - * precocious maturity: <3 years
 - * raceme/total plant biomass high (high 'bunch index')
 - * raceme annual production >15/year, each >8 kg (total >120 kg/year)
 - * fruit weight >85% of total raceme weight
 - * fruits >100 per raceme (more fruits per raceme if fruits are small)
 - * fruit weight >50 g
 - * fruit exocarp waxy, no fibres or striations, red colour
 - * seeds small, ~2 g, and separate easily from mesocarp
 - Mesocarp composition
 - * water content low: <50%
 - * protein content high, dry weight >14%
 - * carbohydrate (starch) content high >60%
 - * fibre content low, dry weight <10%
 - * carotene content high: 20-70 mg/100 g fresh weight
 - * locally acceptable flavour
 - Resistant to leaf mite
 - Resistant to fruit borer
 - Broad agronomic adaptability.
-

Several authors have discussed current and proposed strategies for genetic improvement of cultivated peach palm (Clement and Mora-Urpí 1987; Clement 1988, 1995b; Clement *et al.* 1988; Clement and Arkcoll 1991). Although the specifics differ among countries, current approaches largely depend on mass selection for crop ideotypes within base populations (landrace populations and derived germplasm banks), production of progeny families through controlled crosses among selected individuals in germplasm banks (within and among landraces), and evaluation of selected germplasm in a range of environmental conditions. Characteristics of proposed crop ideotypes for fruit and heart-of-palm are listed in Tables 7 and 8, respectively. Mesocarp characteristics of the fruit ideotype differ depending on the primary commercial product: whole fruit for direct human consumption, flour, oil or animal ration. This list is tentative and requires considerable refinement based on research results. It includes too many characteristics to be realistic in practice, since genetic advance would be too slow if all characters were selected.

Since peach palm has a relatively long generation time and is primarily outcrossing, traditional breeding approaches would require considerable investment in time and money. Clonal approaches may be faster and achieve greater impact than traditional breeding, but clonal propagation of peach palm has been difficult in practice (see Section 8.3). Whatever the approach, the improvement programme must ensure a broad genetic base in the breeding and production

Table 8. Characteristics of proposed crop ideotype for heart-of-palm production

-
- Stems
 - * long internodes
 - * spineless internode (and sheaths)
 - * soft without much lignification
 - Leaves
 - * long, tender sheath (erect blade)
 - * net assimilation rate high
 - Basal offshoots
 - * early appearance: <6 months after field planting
 - * rapid growth: <6 months to harvest
 - Hearts-of-palm
 - * early first harvest: <10 months with 9 cm stem diameter
 - * annual production >4 plants/year beginning at 24 months
 - * 'quality' type >150 g, 'caulinar' type >300 g
 - * white colour
 - * flavourful
 - * natural peach palm odour for fresh and dehydrated consumption, odourless for canning
 - Resistant to leaf mite
 - Broad agronomic adaptability.
-

populations (Leakey and Newton 1994). This is especially important in programmes that produce improved germplasm for small-scale farmers, since they may reduce the genetic base in their fields through subsequent selection and propagation of the best individuals (Brodie *et al.* 1997). The improvement programme should also be participatory, involving farmers in all phases of the programme. This participatory approach may be most important in countries without a strong national programme in genetic improvement.

Research in several areas is necessary for success of genetic improvement programmes for cultivated peach palm. Considering that peach palm is still a relatively minor crop, the research areas of highest priority are (1) future market supply and demand for peach palm products, and (2) costs and benefits of genetic improvement programmes for these products, including establishment of conservation projects for valuable landraces and primitive forms of peach palm. Clement (1988) discussed some other research needs:

- complete characterization and evaluation of existing germplasm banks
- further germplasm collecting of landraces in areas not included in previous collecting missions
- chemical characterization of fruit from promising germplasm
- determination of growth, yield and physiological parameters
- phytosanitary aspects.

In addition, research is needed to:

- improve methods for propagation of selected clones (vegetative propagation of offshoots and tissue culture)
- determine the most efficient methods and strategies for seed production (centralized seed orchards, decentralized production areas, etc.)
- determine the distribution of genetic variation in commercially and adaptively important traits among and within landraces, and quantify genetic parameters such as heritability, norm of reaction of genotypes and genetic correlations for these traits
- determine the efficiency of phenotypic selection in the field, and multitrait selection indices for early selection in the nursery and experimental plots
- determine inbreeding and heterotic effects on commercially and adaptively important traits
- determine the effectiveness of molecular markers in indirect selection of traits, especially those with low heritability.

Research in some of these areas is planned or underway.

8 Propagation

8.1 Pollen collecting, handling and controlled pollination

Practical methods for pollen collecting, handling and controlled pollination are essential for breeding programmes and some seed production systems. Relatively simple methods, developed in Costa Rica, are briefly described below (Mora-Urpí and Mexzon 1996). The most difficult part is pollen collecting and pollination in tall trees.

Before collecting the pollen, one must predict when the inflorescence will open. The immature inflorescence has a nearly vertical orientation. In the Utilis landrace, the inflorescence assumes a more horizontal inclination 1-2 days before opening. In other landraces, this change in inclination occurs anywhere from 1 to 7 days or more before opening; therefore, it is a less valuable predictor.

There are three simple pollen-collecting methods, although the first is most practical.

1. Remove the inflorescence just before it opens. Cut it open lengthwise, remove the rachillae and spread them on kraft paper. Dry them in an oven at about 40°C or in a handmade plant dryer using a light bulb as the heat source. Pollen will be released 24 hours after the inflorescence opens (see Section 3.4).
2. Remove the unopened inflorescence just before it opens. Quickly put the peduncle in a jar of water, and support the inflorescence on an open frame above a piece of kraft paper or aluminium foil. Male anthesis develops normally and pollen is released 24 hours after the bract opens.
3. Place a kraft paper bag around the inflorescence the day before it opens. To prevent the extremely small curculionid beetles from entering, place a cotton washer with insecticide in the mouth of the bag and seal the bag tightly. Remove the bag with pollen 2 days later. With this method, much of the pollen adheres to the paper and could be wasted; the bag can be oven-dried to recover some of this pollen. A greater potential problem may be the effect of male flower fermentation inside the bags before collecting and removing the pollen. Fermentation may begin during the night after flower abscission.

The collected pollen includes debris such as male flowers, anthers and trichome cells. The flowers and anthers can be screened out, leaving only the pollen and trichome cells. Only 50% or less of the material collected after screening is pollen; the larger, spherical, darker bodies are the trichome cells. This mixture can be diluted even more with talc for use in controlled pollination, but this is only recommended for very scarce and valuable pollen.

After collecting, pollen should be dried 24-48 hours with CaCl₂ or silica gel, then refrigerated or frozen. Under these conditions, pollen should maintain about 40% viability for 6 months (Miranda 1986; Miranda and Clement 1990). Viability is easily tested by germination on simple media (Mora-Urpí 1984; Miranda 1986; Miranda and Clement 1990): on 2.5% sucrose or 5% glucose agar in a petri dish, or on a small square of cellophane floating on the solution. Pollen can also be germinated on filter

paper moistened with a 2.5% sucrose or 5% glucose solution, but this method is more difficult in practice. The fibres of white filter paper are similar in appearance to the pollen tubes, making it difficult to count germinated grains (C.R. Clement, 1997, pers. observ.). Fresh pollen germinates in about 75 minutes on these media at room temperature (about 25°C).

Controlled pollination will be most effective if done when female flower anthesis begins, i.e. late in the afternoon on the first day of the flowering cycle (see Section 3.4). At this time, however, contamination by airborne and insect-dispersed pollen from other inflorescences is very likely. For these reasons, controlled pollination is recommended early the following morning when curculionids are inactive and there is little airborne pollen. Using a simple hand-held blower, the pollen is introduced through an opening in the protective bag enclosing the inflorescence (bag put in place 1-2 days earlier), and the bag is then carefully resealed. Bags can be removed the day following pollination.

Prior to controlled pollination, emasculation of male flowers is often considered to prevent self-pollen contamination, but this has serious disadvantages in peach palm. In theory, emasculation is not necessary, since male anthesis occurs late on the second day of the flowering cycle (see Section 3.4) and by that time fertilization should have occurred if the controlled pollination was done properly; it is also possible to test the degree of self-sterility a year before, although nothing is yet known about the effects of the environment on the genetic self-sterility system. In practice, however, there is no guarantee of 100% crossing success, so some self-pollen contamination is possible. Emasculation is difficult, however, especially in tall trees. It is also time consuming (30-45 minutes for one inflorescence), tends to block the pistil with trichomes which reduce pollination efficiency, and may stress the inflorescence so much that even successfully pollinated flowers may abscise. Selfing can be checked after germination by analyzing the isozyme or DNA profiles of the seedling progeny, if their parents have contrasting alleles at one or more loci; this is only justified, however, for very important crosses and probably cannot serve as a general practice at this time.

8.2 Seed

Peach palm seed may be purchased from commercial dealers in Brazil, Colombia, Costa Rica and Peru (contact researchers listed in Appendix I for appropriate seed sources). Although commonly known as the seed, technically this is the endocarp with enclosed seed. Most of this seed is collected from local farmers, and is of unknown genetic quality. Improved seed for fruit production is practically unavailable. There are small plantations in Brazil and Costa Rica that produce seed from selected germplasm, primarily for heart-of-palm plantations. However, the genetic base of some of these plantations may be very restricted and create a phytosanitary risk in future (C.R. Clement, 1997, pers. comm.). For example, the main plantation in Manaus, Brazil is derived from four accessions from Yurimaguas, Peru and these accessions are probably related. Two subsequent selection cycles

in the plantation have probably significantly reduced its genetic variability and made the material vulnerable to future phytosanitary problems.

Seeds are relatively easy to prepare for sowing. Extract the seeds from recently matured fruits, and soak them 1-2 days to soften the mesocarp, which generally adheres to the seed. Then rub the seeds together under running water to remove any attached mesocarp, and treat them with fungicide for 15-30 minutes (contact researchers listed in Appendix I for appropriate treatments). Dry them in a ventilated, shady location for 8-24 hours to evaporate excess superficial moisture. When they appear slightly moist but not dry, they are ready for sowing or storage.

The seed is considered recalcitrant, but management of its moisture content and storage temperature may extend storage time (Villalobos 1991). The fresh seed has a moisture content of 45-50%. When seed moisture falls below 38-40% germination is reduced (Ferreira and Santos 1992). Excessive seed moisture favours fungal growth. Villalobos and Herrera (1991) tested the effect of seed moisture content (20, 30 and 40%) and storage temperature (5, 15 and 25°C): after 12 months storage in plastic bags, the best germination was 64% at 40% initial moisture and 25°C. In this treatment, seed moisture content fell from 40% to 31% during storage, but was raised again to 40% before germinating the seeds (imbibition in water for 3-4 days).

Seeds can be germinated in different ways: in nursery beds or bags with substrate, and in plastic bags or containers with minimal water and no substrate (Mora-Urpí 1980; Villachica 1996). Seeds should not be exposed to direct sunlight during germination, and, if necessary, watering must be carefully regulated to avoid fungal growth. Various substrates are used in the nursery beds: coarse sand, decomposed sawdust, light-textured soil, and mixtures of these materials. Seeds can be sown in nursery beds for production of bare-root seedlings (20 x 20 cm spacing). Alternatively, they can be sown at closer spacing and, after germination, transplanted to nursery bags (black plastic, 20 cm diameter x 30 cm tall) or other containers. During germination, the seeds should be covered with about 2 cm of soil or decomposed sawdust. A thin layer of leaves placed over the soil/sawdust will reduce water erosion and help shade the seeds from direct sunlight. No additional shading is necessary during germination. Germination in plastic bags requires less space than germination in nursery beds: the seeds are placed in bags and, with appropriate initial humidity, they require no watering. However, fungal growth is often a problem in the plastic bags, especially if the mesocarp was not completely removed and has fermented, and if the seeds were not treated properly with fungicides.

Seeds normally germinate in 30-90 days without any special pretreatment. One simple pretreatment may accelerate germination: place the seeds between sheets of transparent plastic and cover this with black plastic, place it in full sunlight and water frequently (Herrero-Haack 1988). This method requires refinement since results have not been consistent (Villalobos and Herrera 1991). Attempts to accelerate germination by rupturing the seed coat and other pretreatments involving temperature, substrate, plant growth regulators and other chemicals

(gibberellic acid, 6-benzyl amino purine, hydrated cyanamide, ethaphon) have not been successful or have given inconsistent results (Villalobos 1991; Villalobos and Herrera 1991; Villalobos *et al.* 1992a, 1992b; Clement and Dudley 1995).

Seedlings require about 6-9 months in the nursery before transplanting. Proper fertilization with adequate phosphorus is critical to seedling growth and resistance to anthracnose (Clement and Habte 1994). Vesicular-arbuscular mycorrhizal symbioses enhance uptake of phosphorus and other nutrients (Janos 1977; Ruíz 1993; Clement and Habte 1995), thereby reducing time to transplant and increasing survival in the field (Ruiz 1993). A foliar antitranspirant (or molasses solution) should be applied the day before transplanting, especially for bare-root seedlings. Transplanting should be done when the soil is humid and potential evapotranspiration rate is low (cloudy with little wind).

8.3 Asexual propagation

There are two potential means for asexual propagation of peach palm: offshoots and tissue culture. Neither of these has been developed into a widespread commercial practice.

Basal offshoots can be propagated but survival after transplanting in the field is generally low (Sattler 1986; Pinedo-Panduro and Meléndez-Torres 1993). The most common method in Peru is to partially sever the basal connection between an older shoot or stem and a young offshoot with preformed roots (20-40 cm tall), allow the young offshoot to further develop its roots in place for several weeks, then completely sever the connection, transplant the rooted offshoot into nursery containers, allow it to develop in the nursery for several (2-7) months, and then transplant it into the field. Alternatively, offshoots without preformed roots can be rooted in non-mist propagators for 2-3 months (with or without plant growth regulators), transplanted to nursery pots, allowed to develop for 2-3 months under shade and 1 month in full sunlight, then transplanted to the field (J.C. Weber, H. Jaenicke and C. Sotelo-Montes, unpublished data). Survival of offshoots is high while they are still semi-attached to older shoots or stems (or in non-mist propagators), but this is deceiving, since it decreases dramatically after removal and transplanting. For example, 78% of offshoots survived for 45 days while still partially connected to older shoots (Pinedo-Panduro and Tanchiva, unpublished data). In another study, 3-month-old rooted offshoots were transplanted to the field: 63% survived for 3 months, but only 9% survived for 9 months (Pinedo-Panduro and Meléndez-Torres 1993). Application of IBA (Indole-3-butyric acid) increased the offshoot's root production, which provided better survival after transplanting in the field, but the IBA application was associated with lower aboveground growth rate in the field (Pinedo-Panduro and Meléndez-Torres 1993). As mentioned in Section 6.3, some 'viviparous' phenotypes also develop vegetative shoots on the stem, and these are relatively easy to propagate.

Sattler (1986) found that offshoots in the transition stage from bifid to pinnate leaves and with well-developed root systems gave the best results, but still only

found 63% survival after 70 days. Survival in the field can be improved to 90% by careful attention to details (R. Chumbimune, unpublished data): select plants with vigorous offshoots 30-60 cm tall; dissect the root mass with offshoots 2-3 months after harvesting the heart-of-palm; isolate and mound up soil around offshoots; allow 2 months for the root-mass sections to recuperate before transplanting to the field; and carry out all steps during the rainy season. Mora-Urpí (unpublished data) follows a modification of the methods described: selecting the entire cluster of mature heart-of-palm carrying large offshoots (each over 50 cm high), and taking along most of their well-developed root systems when transplanting. This method has been successfully used to fill empty spaces in commercial palm plantations. This method is not practical when dealing with full-grown fruit-producing trees because of the large size, hard wood and long roots of the cluster.

More research on vegetative propagation of offshoots is required. Improving survival of rooted offshoots is clearly needed. In addition, the limited number of offshoots per plant (1-4 per year) does not allow rapid multiplication of selected germplasm (Blaak 1980). Simple methods to stimulate offshoot development are being investigated (H. Jaenicke, J.C. Weber and C. Sotelo-Montes, unpublished data).

Tissue culture would be the most efficient means for mass propagation of selected peach palms. After more than 15 years of research, a commercial method has finally been developed. Historically, attempts to culture various tissues did produce some plants (Pinedo-Panduro 1987), but often with unreproducible results (Arias and Huete 1983; Arias 1985; Valverde and Arias 1986; Pinedo-Panduro 1987; Valverde *et al.* 1987; Stein 1988; Fisse 1990; Pinedo-Panduro and Díaz-Jamara 1993; Almeida 1994). Pinedo-Panduro (1987) tried direct organogenesis from cultured stem apices and was able to develop some vegetative shoots from meristematic buds. Almeida (1994) improved this method. No somaclonal variation is expected with this procedure since it involves direct development from meristematic axillary buds.

The University of Costa Rica has now developed a repeatable tissue culture procedure for commercial application (L. Gómez and R. Vargas, unpublished data). The greatest commercial limitation was production time: more than 2 years were necessary to develop a rooted plant from the explant stage, and another year was necessary for acclimatization and growth in the nursery. Now these problems have been overcome and multiplication is possible. With an efficient tissue culture method the screening of selected genotypes is underway; this is necessary because not all genotypes are equally easy to propagate. Now clonal variety trials under different ecological conditions can be carried out.

Some individuals may produce apomictic seeds coming from fruits that appear parthenocarpic (smaller, later maturing within a bunch) (J. Mora-Urpí, pers. observ.), but genetic evidence of apomixis in peach palm has not been demonstrated (e.g. mother plant and progeny with identical isozyme or DNA fingerprints). In addition, fruits appear parthenocarpic (smaller, later maturing than normal fruits) but they contain seeds with a fully developed embryo.

9 Agronomy of fruit and heart-of-palm production

9.1 Fruit: planting density and pruning

On the basis of experience and some research results, the recommended density for adoption of large-scale peach palm fruit plantations is about 400 plants/ha. Plants can be spaced equally within and among rows (5 x 5 m) or spaced unequally in a double-row arrangement (two rows at 4 x 4 m, with an 8-m strip between double rows). This double-row arrangement has approximately the same density (416 plants/ha) as equal spacing at 5 x 5 m, and it has an advantage: other crops can be cultivated within the 8-m strips for a longer time than in the 5 x 5 m arrangement. The length of the intercropping phase is an important consideration for adoption of larger-scale fruit plantations by small-scale farmers, since the farmers are often reluctant to dedicate land and labour to fruit production if they must wait 3-5 years for the first marketable product.

No long-term experiments have been conducted to determine the most sustainable combination of plant density and number of stems/plant for fruit production. Zamora (1985) tested different plant densities in Guápiles, Costa Rica using the Utilis landrace. Basal offshoots were pruned to leave only one stem per plant. The highest density tested (555 plants/ha with 6 x 3 m spacing) produced the highest fruit yield, but plot size was too small and yield was evaluated for only 3 years. Another experiment was designed to test the effect of stems/plant on fruit yield of the Utilis landrace in Guápiles. Plants were pruned to leave one, two or three stems in a 10-year-old plantation at 7 x 7 m spacing, and evaluated for 3 years. Yield did not vary significantly among these treatments, i.e. plants with one, two or three stems produced about the same fruit yield under these conditions (A. Sáenz, unpublished data). Multiple stems/plant will increase self-shading and may reduce fruit yield at higher plant densities, but at the wider spacings used by some farmers (e.g. 10 x 10 m), there may be no negative effect on yield. An advantage of single-stemmed plants is that harvesting is easier and fruits are less easily damaged than during the harvest of multistemmed plants. This is an important consideration for the fresh-fruit market because physically damaged fruits deteriorate rapidly after harvest.

New basal offshoots must be allowed to develop to ensure replacement of the old stem when it is too tall to harvest in a practical and economical manner. Pruning large offshoots that have smaller offshoots can maintain a permanent source of new offshoots without developing a clump that makes harvesting more difficult. Sometimes buds remain dormant for years, covered by adventitious roots, and resume growth when exposed to sunlight, but it is not safe to rely on dormant buds to manage a fruiting clump.

9.2 Fruit: mineral nutrition

There are no experiments to determine the long-term mineral requirements of a peach palm fruit plantation. The most general deficiencies observed in fruit

plantations are due to nitrogen (general yellowing of leaves), magnesium (yellow stripes on leaflets) and boron (young leaves with leaflets fused at their tips). Some other mineral deficiencies are more difficult to recognize visually, but they should be assessed in certain areas: for example, many heavily leached, tropical soils are deficient in calcium, sulphur and zinc. Potassium is essential for fruit production, and deficient plants (leaflets with brown tips and margins) are very susceptible to diseases. Available nitrogen and potassium are perhaps the most important minerals for sustained production of peach palm fruit on the relatively young volcanic soils of Costa Rica (J. Mora-Urpí, pers. observ.). In ultisols of the Peruvian Amazon Basin, the nitrogen and potassium requirements may be satisfied in the short term (10 years) by interplanting a nitrogen-fixing leguminous cover crop and incorporating its biomass into the soil (Pérez *et al.* 1993a; J. Alegre, unpublished data), but long-term sustainability of this practice has not been evaluated. Available phosphorus is limited in many aluminium-saturated soils of the Peruvian Amazon Basin, but phosphorus deficiencies are rarely observed in peach palm because of its symbiotic association with vesicular-arbuscular mycorrhizae (Ruiz 1993; J. Alegre, unpublished data).

Fertilizer applications recommended for heart-of-palm plantations (see Section 9.5) may be appropriate for a young fruit plantation in the vegetative phase, if adjusted for plant density and local soils (J. Mora-Urpí, pers. observ.). Pérez *et al.* (1993b) investigated the fertilizer response in a young fruit plantation on ultisols in Yurimaguas, Peru. They recommended 180 kg nitrogen, 25 kg phosphorus, 50 kg potassium and 100 kg magnesium sulphate/ha per year during the first 4 years on similar soils. Research is needed to determine long-term mineral requirements of fruit plantations on the different soils found in producing countries. These results, combined with local soil analysis, could then be used to develop recommendations for local fertilizer applications based on annual monitoring of plant soil nutrients.

9.3 Fruit: harvest and post-harvest handling

Fruit from spineless peach palm is typically collected by climbing the stem, and lowering the fruit bunches (racemes) to the ground with a rope or dropping them into a net. Most peach palms have spiny stems, however, and these are very difficult to climb. To harvest fruits from spiny peach palm, farmers often use bamboo poles with a hook at the end to make a long 'telescoping' pole. From the ground, they dislodge the fruit bunch and catch it with a net or foam cushion. More sophisticated telescopic poles and mechanized extendible arms are also used to harvest from the ground. However, the mechanized equipment is not practical in hilly terrain, and is too expensive for most farmers and farmers' associations. Harvesting from the ground is faster and safer than climbing the stem to collect fruit, but it causes more damage to the fruit.

Fresh fruit is very perishable. It can be maintained in good condition without refrigeration for only 4 days if treated with fungicide and wax. With refrigeration

(60°C, 70% relative humidity) storage can be extended to 8 days (Piedrahita 1993). Fruits should not be refrigerated if the seeds are destined for sowing, because embryo viability decreases rapidly at lower storage temperatures (J.M. Pérez, unpublished data). Shelf-life of fresh fruit can be extended by collecting well-developed fruits that are just starting to change from green to their final colour (M.L. Pineda, 1996, pers. comm.). Frozen, dried or canned fruit can be conserved for months, but with the consequent loss of final flavour and colour (M.L. Pineda, 1996, pers. comm.).

Fresh fruits are commonly sold by the bunch, or they are processed and packaged. The processing is minimal: remove fruits from the bunch, wash and wax, sort and classify, and package in net bags of specified weight. Cooked fruit is also handled like fresh fruit. If fruits are destined for flour, they should be processed on the day of harvest or the following day: cook the entire bunch to facilitate removal of the fruit, denature potential toxins, and improve starch quality; cut the whole fruits into small pieces; remove the seed, and dry the pulp and peel (red peels give a golden colour to the flour); then grind and package. Processing fruits of low phytosanitary quality is more difficult and expensive, requiring careful sorting and peeling.

9.4 Heart-of-palm: planting density and pruning

Peach palm is planted at high density for heart-of-palm production (4 000-20 000 plants/ha) (Fig. 6), so plant spacing, geometric arrangement and number of stems/plant become very important considerations. At the higher plant densities,



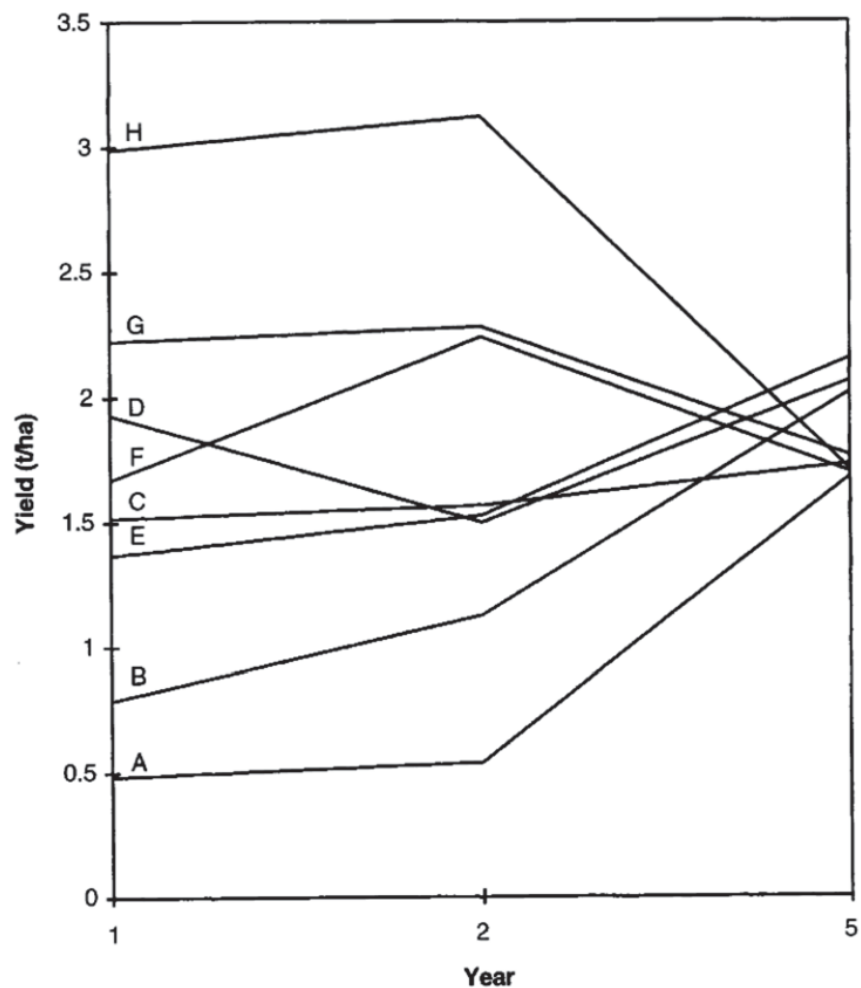
Fig. 6. High-density plantation in Costa Rica.

production may decline in time, primarily owing to shading, which limits new offshoot development, and competition for water and nutrients. At lower plant densities, production is suboptimal during the early years because above- and belowground resources are not fully utilized. One might consider planting at higher density for maximum production during the first years, and then thinning plants and/or reducing the number of stems per plant progressively in the following years. The production potential and economic costs/benefits of this progressive thinning approach have not been fully quantified. Under some conditions farmers may not adopt a progressive thinning approach. Most farmers interviewed in the Peruvian Amazon Basin prefer to sow perennial plants at final density; they are reluctant to sow them at high densities and then thin to a lower density (Brodie *et al.* 1997). This is well accepted in Costa Rica, however, where this thinning approach is becoming a common practice (J. Mora-Urpí, pers. observ.). Agricultural extension programmes may change farmers' attitudes in some regions.

Some research on plant densities and spatial arrangements for heart-of-palm production has been conducted. When interpreting results of these experiments, three factors should be kept in mind: production during the first years may not be a reliable indicator of later production; nutrient inputs are necessary to maintain high production over time (see Section 9.5); landraces, and perhaps plants within landraces, may respond differently to management treatments and environmental conditions (e.g. plant density, number of stems per plant, local soil, climate and fertilization).

Sowing at higher plant densities can produce higher heart-of-palm yields during the first years, but production may fall in subsequent years if plants are not properly managed. For example, Chalá (1993) and Játiva (pers. comm.) evaluated yield at eight plant densities for 5 years in northeastern Ecuador, using local peach palm seed. Chalá (1993) observed the highest second-year yield at the highest density tested, 16 666 plants/ha (Fig. 7, H). The fifth-year yield (M. Játiva, unpublished data) was greater than the second-year yield in plots with 8888 or fewer plants/ha (greatest increase at the lowest density) but was lower in plots with 10 000 or more plants/ha (sharpest decline at highest density). Plants in the highest-density plots produced thin hearts-of-palm, indicating the need for thinning. Densities of 8888 or more plants/ha were established by sowing 2 or 4 plants/site. If each of these 2 or 4 plants/site produced a single stem per year, the total number of stems would be equal to a plantation sown with half as many plants but managed for 2 or 4 stems per plant per year. In this study, the highest yield in the fifth year was at 1.5 x 1.5 m spacing with 2 plants/site, but this was only slightly greater than the yield at 1.5 x 1.5 m spacing with 1 plant/site. The number of stems per plant and fertilization schedule were not reported. The cumulative increase in yield (approx. 1.75 t in 5 years) may cover the additional cost of producing, planting, managing and harvesting the 4444 extra plants/ha used. In Costa Rica, with the Utilis landrace and fertile soils, the most common density has changed from 5000 plants/ha (2 x 1 m spacing; 1 plant/site) to 10 000 plants/ha (2.0 x 0.5 m spacing; 1 plant/site), although multiple plants per site are sometimes used. Lower plant densities are recommended for soils of lower fertility (Mora-Urpí 1984).

There are two different approaches to managing offshoots for heart-of-palm: not



	Plants/ha	Spacing (m x m)	No. plants/site
A	2500	2x2	1
B	4444	1.5x1.5	1
C	6666	1.5x1.0	1
D	8000	1.25x1.0	1
E	8888	1.5x1.5	2
F	10000	2x1	2
G	14183	1.5x1.5	4
H	16666	2x1	4

Fig. 7. Heart-of-palm yield at eight plant densities in years 1, 2 and 5. Adapted from Chalá 1993;

pruning and pruning (Villachica 1996). Offshoots usually appear about 6 months after planting in the field, but this varies among and within landraces (J. Mora-Urpí, unpublished data). In both approaches, all offshoots are left to develop until the first harvest at 12-18 months, when the main stem attains commercial dimensions and is cut (see Section 9.6). In the first approach, there is no management of the offshoot cluster. In the second approach, which is more prevalent, offshoots that are high in the cluster are pruned at least twice a year. If they are left to develop then production of the entire cluster decreases because the offshoots are above ground level and the root system is weakened. The superficial cluster body tends to rise out of the soil and the root system deteriorates owing to lack of new tissue that allows its renewal (J. Mora-Urpí, pers. observ.). The second approach also controls the number of offshoots for successive harvests. This involves a selective thinning of offshoots greater than 30 cm tall, leaving four vigorous offshoots of different sizes. Vigorous offshoots less than 30 cm tall are allowed to develop. At the next harvest, the dominant offshoot in the group of four is harvested, and replaced by a smaller offshoot. The idea is to maintain one dominant offshoot and three others of different sizes for four successive harvests. Ideally the four offshoots should be separated as much as possible (e.g. every 90° around the stem), and have their basal part in contact with the soil.

9.5 Heart-of-palm: mineral nutrition

Successive harvests of heart-of-palm will deplete soil nutrients, but this is reduced by recycling most of the harvested biomass and applying fertilizers. Herrera (1989) calculated that 21.25 t ha⁻¹ year⁻¹ of dry biomass were harvested in a heart-of-palm plantation (Guápiles, Costa Rica) that produced 9600 harvestable offshoots ha⁻¹ year⁻¹, but only 8.24% of this biomass was removed from the plantation for processing (Table 9). The removed biomass includes the commercial heart-of-palm and by-

Table 9. Biomass removed, recycled or wasted in a heart-of-palm plantation with 3200 plants/ha and 9600 harvested offshoots ha⁻¹ year⁻¹

Plant part	Fresh weight (t ha ⁻¹ year ⁻¹)	Dry weight (t ha ⁻¹ year ⁻¹)	Use of biomass
Leaves	39.80	15.10	Recycled in plantation
Leaf sheaths	21.70	4.40	Recycled in plantation
Heart-of-palm†	12.50	1.75	Removed for processing
Heart-of-palm	1.70	0.20	Consumed
By-products	2.90	0.30	Part consumed, part recycled or wasted
Leaf sheaths	7.90	1.25	Recycled in plantation or wasted
Total	74.00	21.25	

Adapted from Herrera 1989.

† Includes commercial heart-of-palm, by-products and non-commercial leaf sheaths.

products, and the non-commercial leaf sheaths surrounding the heart-of-palm. More than 91% of the harvested biomass was used as mulch in the plantation for soil conservation and nutrient recycling (Fig. 8). If the non-commercial leaf sheaths were returned to the plantation for mulch, only 2.35% of the harvested biomass ha⁻¹ year⁻¹ would be removed from the plantation.

In the same plantation mentioned above, Herrera (1989) also determined nutrient content of the aboveground plant parts (stems, leaves and offshoots) and of the plant parts removed for processing (commercial heart-of-palm and by-products, and non-commercial leaf sheaths). The quantity of phosphorus, potassium and magnesium removed with these plant parts is relatively high (Table 10), and these nutrients should be carefully managed with appropriate fertilizer applications. The quantity of micronutrients removed is relatively low and should constitute limiting factors only in soils that are already deficient in these micronutrients (Villachica 1996), a situation frequently found in the humid tropics. Recycling the non-commercial leaf sheaths as mulch in the plantation would slightly reduce the amount of nutrients removed from the soil with each harvest.

The range in foliar nutrients associated with vigorous offshoot development is listed in Table 10. These values are based on analysis of the fourth leaf from vigorous plants managed for heart-of-palm production (P. Guzmán, unpublished data), and can be used as a guide to the nutritional status of plants in the plantation.



Fig. 8. Biomass is a by-product of the heart-of-palm harvest, and is used as mulch for soil

Table 10. Nutrient content of total aboveground biomass and biomass removed in heart-of-palm harvest from a plantation with 3200 plants/ha and 9600 harvested offshoots ha⁻¹ year⁻¹, and foliar nutrient range associated with vigorous heart-of-palm growth

vigorous growth Nutrient	Biomass nutrient content (kg ha ⁻¹ year ⁻¹)		% of total removed‡	Foliar nutrient range biomass for (dry weight)
	Total†	Removed‡		
Nitrogen	531.00	28.005.27	3.5 - 4.5 %	
Phosphorus	37.90	4.80	12.66	0.17 - 0.20 %
Potassium	248.30	31.00	12.48	1.0 - 1.2 %
Calcium	64.80	4.70	7.25	0.4 - 0.6 %
Magnesium	43.00	3.90	9.07	0.24 - 0.36 %
Sulphur	47.23	3.36	7.11	0.24 - 0.28 %
Boron	0.56	0.03	5.36	32 - 48 ppm
Copper	0.18	0.02	11.11	5 - 15 ppm
Iron	1.83	0.03	1.64	145 - 180 ppm
Manganese	2.27	0.09	3.96	95 - 140 ppm
Zinc	0.25	0.05	20.00	20 - 27 ppm

Sources: biomass nutrients adapted from Herrera 1989 and foliar nutrients from P. Guzmán, unpublished data.

† Includes all stems, leaves and offshoots.

‡ Includes commercial heart-of-palm, by-products and non-commercial leaf sheaths.

In the early heart-of-palm plantations, only nitrogen was applied because the vegetative growth response to nitrogen was very rapid (Herrera 1989; Pérez *et al.* 1993b). However, repeated applications of nitrogen increased soil acidity and led to a reduction in available calcium, magnesium, potassium and perhaps other nutrients (Herrera 1989). In addition, the plants were more susceptible to water stress and the normally ivory-coloured hearts turned yellow (tannin oxidation), which reduced its commercial value.

Fertilizer applications recommended by different investigators are listed in Table 11. Only Herrera's recommendation is based on experimental results. It is effective on the rich volcanic soils of Hawaii and on infertile oxisols near Manaus, Brazil (C.R. Clement, 1997, pers. observ.). The actual quantities will vary, depending on local soil characteristics, climate, mineralization rates of nutrients in the mulch, and the plants' mineral-use efficiency (Villachica 1996). Fertilizer may not be necessary in the first year of cultivation following the slash-and-burn of secondary or primary forest, but the highest levels are recommended for soils that have been cultivated for several years after slash-and-burn and have no residual effect of the ash. Lime application is recommended for soils with more than 50% aluminium saturation, which is common in the Amazon Basin (apply 100-200 g/plant in planting hole and again 30 days after transplanting). Magnesium and boron deficiencies are common.

Table 11. Range in nutrient inputs for heart-of-palm production (kg ha⁻¹ year⁻¹) recommended by different investigators

Source	N	P ₂ O ₅	K ₂ O	MgO	CaO	S
Costa Rica						
Molina 1997	200-250	50-100	60-150	30-60	400-1000	40-80
Herrera 1989	200-250	20	160-200	50-100	400-500	-†
Peru						
Villachica 1996	120-160	20-40	120-160	20	-†	-†

† Not mentioned.

9.6 Heart-of-palm: harvest and post-harvest handling

Offshoots are harvested when they reach commercial dimensions, which depend on factory and market demands for heart-of-palm. For the international market there are two basic qualities: true or 'quality heart-of-palm' is a cylinder composed of a tender petiole-sheath enveloping the developing leaves above the apical meristem, and the 'caulinar heart' or tender stem tissue below the apical meristem. The quality heart commands a higher price when it has a



Fig 9. Transport of heart-of palm to the factory.

narrow diameter and is called 'extra fine'. The caulinar heart commands a much lower price, and is presented in different sizes and shapes, but provides the industry with larger earnings because it comes with the free material they receive from the farmers.

In Brazil, there is a demand for three heart-of-palm dimensions (C.R. Clement, 1997, pers. observ.): thin (1.5-2.5 cm) hearts to be canned for the internal and export markets; medium (2-4 cm) hearts for the fresh market in Brazil; thick (3-6 cm) hearts for the Brazilian *churrascaria* market (restaurants that specialize in barbecued meat with thick hearts-of-palm as garnish).

For hearts-of-palm with 2-3 cm diameter, offshoots are harvested when they attain diameters of >9 cm, measured at 20-30 cm above the ground. Offshoot diameter and other morphological characteristics are correlated with heart-of-palm yield, but in practice only diameter is measured to determine if the offshoot is ready for harvest because there is a good correlation between yield and diameter under normal nutritional conditions.

When offshoots are ready for harvest, they are cut and the outer fibrous leaf sheaths are removed. Two non-commercial leaf sheaths, surrounding the heart-of-palm, are normally left to protect it from rapid moisture loss and mechanical damage during transport. Ideally the heart-of-palm should be transported to the processing plant on the day of harvest to minimize moisture loss (Fig. 9). If transport delays are anticipated, more leaf sheaths should be left surrounding the heart-of-palm, a paraffin/beeswax mixture should be applied to the cut ends, and they should be stored in a shady place (Villachica 1996). These post-harvest treatments will normally conserve fresh heart-of-palm for 4 days without significant moisture loss or fungal infection.

Basic production parameters in one region may serve as a reference for comparing production in other regions, and offer targets for agronomic and genetic improvement research programmes. Production parameters for heart-of-palm from the Utilis landrace in Costa Rica are given below (Mora-Urpí, unpublished data from 1995, 5000 plants/ha).

- Time from plantation establishment to first harvest of all plants (9 cm offshoot diameter) is 18 months.
 - Number of harvested offshoots is 8000/ha in the first year of production (12-24 months), and 10 000/ha each year thereafter.
 - Field-harvested shoots contain 70% leaf sheaths and 30% 'quality' and 'caulinar' heart-of-palm.
 - Average yield of 'quality' heart-of-palm after processing is 1.35 t/ha, beginning in the second year of production (10 000 harvested offshoots/ha, each yielding 0.135 kg of 'quality' and 0.05 kg of 'caulinar' heart-of-palm).
 - Number of heart sections per 'quality' heart-of-palm is 4.5 after processing (each is 9 cm long).
 - Number of stems (9 cm diameter) required for 1 'equivalent box' is 40. In Costa Rica, industrial plants use a unit called the 'equivalent box', which equals 24 half-liter cans containing a total of 5.2 kg of processed heart-of-palm.
-

9.7 Pests and pathogens

Several pests and pathogens may create problems during seed storage, in the nursery, and in fruit and heart-of-palm plantations. Some of these develop because the plants are stressed, and can be avoided by maintaining the plants in healthy condition. Effective chemical controls exist for some pests and pathogens, but these imply additional costs, which may not be appropriate for many small-scale farmers. Biological control within an integrated pest management programme should be promoted. Peach palm plantations are visited by many insects, some of which provide biological control of insect pests. With this in mind, selective weed control should be practised, since some weed species may serve as hosts for beneficial insect species (Mexzon 1997).

It seems that there is a higher incidence of pests and pathogens on cultivated peach palm in Costa Rica than in the Amazon basin, which is perhaps related to the more extensive cultivation of peach palm in Costa Rica (Villachica 1996). For example, some small-scale farmers in the Peruvian Amazon Basin state that peach palm fruit yield is higher and has less insect damage if plants are grown at very low density (about 10 plants/ha) in mixtures with other secondary forest species (J.C. Weber, pers. observ.). These traditional agroforestry systems may provide useful models for research on integrated pest management if intensive agriculture is not practised.

The most common pathogens of fruits, seeds, leaves and stems are listed in Table 12. Fungal infections on fruits in the field are generally associated with high relative humidity, and may be controlled agronomically (e.g. improve drainage and air circulation, eliminate shading). The 'black rot' fungus develops on fruits damaged during harvest. Some fungi may destroy peach palm seeds after fruit harvest, in storage or during germination (Coates-Beckford and Chung 1987). According to Vargas (1993), fungi do not normally penetrate the seed before fruit harvest. Fungal infections in seed storage and during germination are generally due to excessive humidity (see Section 8.2) and/or inappropriate treatment with fungicide. Leaf and stem infections probably indicate that the plant is stressed, and efforts should be made to identify and correct the stress factors (e.g. soil/plant nutrient analysis). The two 'spear rot' infections kill the affected stem, but normally do not spread to other stems in the cluster, so a multistemmed plant normally survives. Various fungicides and bactericides are used to control pathogens on peach palm (contact researchers listed in Appendix I for appropriate treatments).

Several small mammals and birds can be serious pests. For example, the gopher (*Orthogeomys cherriei*) is the most economically important pest in peach palm plantations in Costa Rica (Delgado 1990). Gophers live underground in a network of tunnels, and eat bulbs, tubers and roots. Young peach palm roots and stem tissue, when available, seem to be a preferred part of their diet. They can be controlled by poisons and traps. Rats and mice eat peach palm seeds and young plants, and may become serious pests in nurseries and plantations if the surrounding area offers them an appropriate habitat (very weedy or with piles of dry plant material). Keeping the surroundings clean is the best preventive measure. If rats and mice are already present, they can be controlled with commercial rodenticides. Rats and mice apparently find fungicides unpalatable, so seeds can be treated with fungicide to protect

Table 12. Fungal and bacterial pathogens (and symptoms of infection) of peach palm fruits, seeds, leaves and stems

Fruits

Monilia spp. 'White rot' fungus, with early fruit abscission. Soft, watery yellow spots appear on exocarp, and develop into larger white spots (fungal fructifications).

Phytophthora palmivora. Similar to 'white rot' fungus, but white mycelium covers entire fruit. So far, seen only on Brazilian accessions in germplasm bank in Guápiles, Costa Rica.

Diplodia spp. 'Basal rot' fungus, possibly with early fruit abscission. Necrosis appears where fruit attaches to rachilla. Then soft brown rot, surrounded by yellow ring, spreads into seed cavity.

Ceratocystis spp. (*Graphium*). 'Black rachilla' fungus. Necrosis of rachillae, with early fruit abscission. Most common in years with light pollination.

Thielaviopsis paradoxa and *Chalaropsis* spp. 'Black rot' fungus, with strong fermentation odour. Related to post-harvest fruit damage.

Seeds

Thielaviopsis paradoxa and *Chalaropsis* spp. Follows 'black rot' of fruit, entering and destroying seed.

Schizophyllum commune, *Botrydipodia theobromae*, *Fusarium* spp., *Penicillium* spp., and *Xylaria* spp. Superficial fungal infection during storage, entering and destroying seed during germination.

Leaves

Pestalotiopsis spp. 'Yellow spot' fungus. Moist yellow, oval spots turn dark brown, then necrotic.

Mycosphaerella spp. 'Brown spot' fungus. Light brown, circular spots appear, surrounded by dark brown inner ring and yellow outer ring.

Colletotrichum spp. 'Black spot' fungus. Black spots appear, surrounded by chlorotic ring. Sometimes facilitates secondary infection of bacteria *Erwinia chrysantemi*.

Desclera incurvata. 'Ring spot' fungus. Dark brown rings appear, with clear centre and chlorotic outer ring.

Fusarium moniliformae. 'Cork vein' fungus. Mid-rib of spear leaf develops corky, hard texture. May facilitate secondary infection of bacteria *Erwinia chrysantemi*.

Stems

Phytophthora palmivora. 'Spear rot' fungus. Spear leaf rots at base, leaf appears chlorotic then brown. Normally white heart-of-palm turns brown, rots and has putrid odour.

Erwinia chrysantemi. 'Spear rot' bacteria. Symptoms like 'spear rot' fungus, but normally new leaves under spear leaf dry out first, with moist putrefaction and sudden stem death.

Sources: Villaplana 1984, Vargas 1993, Villachica 1996.

them prior to sowing. Parrots consume immature fruits, but not mature fruits. Large flocks may arrive close to harvest time and damage much of the fruit crop. It is very difficult to keep them out of the fruit plantation (using guardians with weapons, and programmed noisemakers), and poisoned bait is prohibited in some producing countries.

Several insect species may directly or indirectly lead to the early abscission of fruits. Two small curculionid beetle species are associated with serious early fruit abscission along the Pacific coasts of northern Ecuador and Colombia (Lehmann 1993). Females of both species oviposit in fruits of any age, the larvae feed on the fruit tissue, and fruits fall before normal harvest time. The most important of these two has not been identified (known only as the 'small black curculionid'), and the other is *Parisoschoenus* spp. Covering the racemes with plastic bags or applying insecticides will control these insects, but these are difficult and expensive operations (especially in tall palms). *Leptoglossus lonchoides* (Heteroptera) is associated with serious early fruit abscission in Brazil, but the insect is thought to be a catalyst rather than a cause of the problem (Couturier *et al.* 1991). The cause is still unknown but micronutrient deficiencies, nutrient imbalances and drought stress are possible factors being investigated.

The coconut beetle (*Rhynchophorus palmarum*) attacks coconut and African oil palm, transmitting the 'red ring' disease (*Rhadinaphelenchus cocophilus*) to these palms. It is a large, black curculionid (2-5 cm long), whose larvae feed on the apical meristem of these palms. Peach palm was infected with the 'red ring' disease after artificial inoculation (Victoria 1979), but the disease has not been reported on peach palm under normal conditions. The coconut beetles may shift from their primary hosts to peach palm if the fruit and heart-of-palm plantations are under stress (e.g. during a long dry season). This should be carefully monitored, especially in areas with a defined dry season.

Strategeus aloeus, a large scarab beetle, is also a common pest in coconut plantations and may develop as a pest on peach palm. Females oviposit in the belowground clustering body, which the larvae consume. Normally they do not kill peach palm (unlike coconut), and can be controlled with insecticides or commercial pheromone traps. This beetle is not yet an economically important pest on peach palm.

Another curculionid, the sugar cane beetle (*Metamasius hemipterus*), mainly attacks sugar cane, but is also found in banana and pineapple plantations and sometimes affects peach palm. On peach palm, the larvae feed around the tissue where the fruit bunch attaches to the stem, causing the bunch to fall (Mexzon 1997). They can be controlled with commercial pheromone traps.

Two other beetles, *Calyptocephala marginipennis* and *Demotispa pallida*, may be seasonal pests on peach palm in Costa Rica (Mexzon 1997). Both are leaf scrapers, whose populations may grow large enough to become economically important.

The foliage mite (*Retracus johnstoni*) is an economically important pest of adult peach palm, but has not yet become a pest in heart-of-palm plantations. Some peach palm landraces (e.g. Putumayo) seem to be more susceptible than others to the foliage mite (J. Mora-Urpí, pers. observ.). The mite causes yellow patches on leaflets, extending sometimes over the entire leaflet surface. They attack young leaves but the symptoms only become apparent in older leaves. Chemical control would be expensive and has not been tried, but good nutrition seems to reduce its attack.

10 Production areas and commercial potential

10.1 Fruit

Peach palm fruit is still produced principally as a subsistence crop for local consumption and sale. Consequently, although fruit production occurs in many regions, the total land area under production is rather limited. It is an item of broader national commerce only in Colombia, Costa Rica and Panama, and international commerce is just beginning to develop. Currently, the major exporting country is Costa Rica, which sells a small amount of processed fruit to other countries in Central America, to the United States and Canada. South American producing countries are not yet exporting processed fruits, but some are exporting seeds to expand heart-of-palm plantations. International commerce in the fruit is limited because: (1) the fruit has a peculiar texture and taste to the uninitiated (starchy rather than juicy), (2) fresh fruits are highly perishable, (3) processed products of high quality are lacking, (4) alternative processing approaches to develop new high-quality products have not received much consideration, and (5) the few processed products that currently exist have not been adequately marketed, resulting in little demand. If an imaginative marketing campaign were to create demand for quality fruit products, fruit production could be increased relatively quickly to satisfy the demand.

Reliable production data per country are not available because the fruit is still relatively unimportant for national and international commerce. The major areas of peach palm fruit production and consumption are listed below.

- Bolivia – produced mainly in Chapare region and Santa Cruz Province north to Brazil.
 - Peru – produced mainly in Loreto province of the Amazon Basin, especially near the lower Ucayali, lower Huallaga, lower Marañón and upper Amazon rivers; well-known production areas are Yurimaguas, Iquitos and Pevas.
 - Brazil – available in nearly all markets along the Amazon River and its tributaries; most common in Belém, Santarém, Manaus, Tefé, Tabatinga, Cruzeiro do Sul, Rio Branco and Plácido de Castro.
 - Ecuador – produced on both sides of Andes Mountains; consumed mainly in the Amazon Basin, and in Esmeraldas Province on the Pacific Coast.
 - Colombia – produced mainly near the Putumayo, Caquetá, Vaupés, Inírida and Guaviare rivers of the Amazon Basin; also produced along the Pacific Coast and the middle Magdalena River west of Andes Mountains, and in the Urabá region on the Caribbean side. Cali is a large market for fruit produced along the Pacific Coast and Putumayo River.
 - Panama – produced mainly in the Chiriquí, Bocas del Toro, central Panama and Darien regions. Panama City is the largest market. Some production from Chiriquí is sold in Costa Rica.
 - Costa Rica – produced mainly in Tucurrique, and also along the Caribbean and southern Pacific Coasts; marketed throughout the country.
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- Nicaragua – produced mainly on the Caribbean side.
 - Honduras – produced and consumed only in the northeastern region.
- Larger-scale plantation systems may become more attractive if market opportunities develop. The commercial potential of a peach palm plantation is illustrated with data from Costa Rica during 1995 (Mora-Urpí, unpublished data). The approximate cost of a fruit plantation from seed to initial production (year 3) is US\$2000/ha, and subsequent annual maintenance is US\$800/ha. The selling price is US\$0.30/kg at the farmer's gate. Even with yields as low as 10 t/ha, gross annual income would be US\$3000/ha for the farmer. Improved agronomic practices should reduce production costs and increase yield, leading to higher income, but market price and farmer's-gate price may decrease.

10.2 Heart-of-palm

Heart-of-palm from cultivated peach palm is a relatively new product on the international market (Camacho and Soria 1970). Brazil introduced heart-of-palm, extracted mainly from *Euterpe edulis*, into the international market in the 1950s (Ferreira and Paschoalino 1988). Extraction of *E. edulis* from Brazilian forests is now prohibited, owing to overexploitation and threat of species extinction. After driving *E. edulis* to economic extinction, Brazil's heart-of-palm industry moved to the Amazon River estuary to exploit the extensive natural populations of *E. oleraceae*, which soon became Brazil's principal source of heart-of-palm, representing 80% of the 19 000 t of heart-of-palm exported worldwide in 1995 (Gonzalez 1996). Brazil actually produced about 140 000 t of heart-of-palm in 1995, primarily for the national market.

Only about 20% of the heart-of-palm exported by producing countries in 1995 came from cultivated peach palm (Gonzalez 1996), but this is changing rapidly (Villachica 1996). Cultivated peach palm is replacing wild palms as a source of heart-of-palm because it yields more (Bovi *et al.* 1987), is of higher quality, wild populations are becoming increasingly more difficult to find and exploit, and international consumers are beginning to demand cultivated heart-of-palm because its production is environmentally more sustainable than extraction of wild palms (Mora-Urpí *et al.* 1991). Currently, Costa Rica is the only producing country which exclusively exports heart-of-palm from cultivated peach palm.

The largest producers of peach palm hearts are Costa Rica, Brazil and Ecuador. Production also occurs in Peru, Bolivia, Colombia, Guayana, Surinam, Venezuela, Panama, Guatemala and the Dominican Republic. It is being promoted as an alternative to illegal coca production (*Erythroxylum coca*) in the El Chapare region of Bolivia and parts of the Peruvian Amazon Basin. Information about heart-of-palm production from peach palm in the major producing countries is given below:

- Costa Rica – produced mainly in the northern and Caribbean regions around Upala, Río Frío, Guápiles, Guácimo and Bataán; Corredores on the Pacific side; and irrigated plantations are now being established in the dry tropics of Guanacaste. Over 10 000 ha were planted as of 1996.
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- Brazil – produced mainly in the states of Acre, Espirito Santo, Bahia, São Paulo and Pará. At least 6000 ha were planted as of 1996 (Bovi 1997).
- Ecuador – produced mainly near Santo Domingo de los Caballeros west of the Andes Mountains; some also produced near Guayaquil, near the Pacific Coast, and in the Napo region of the Amazon Basin. In total there are approximately 4000 ha as of 1996.
- Peru – is planning to plant 10 000 ha by the year 2002 in the Peruvian Amazon Basin (Iquitos, Pucallpa, Yurimaguas) (J. Weber, pers. observ.).
- Bolivia – is planting an additional 4000 ha during 1997-98.

Although the international market for heart-of-palm is still small and expanding slowly, it is becoming increasingly important for the economies of some producing countries (Mora-Urpí *et al.* 1991; Torres 1992). For example, the European Community paid US\$1.51-2.22/kg in 1994 and US\$2.15-3.26/kg in 1995 for imported canned heart-of-palm (mostly from *Euterpe* species, higher price for 'quality' than for 'caulinar' type; source: Marketing Department, Consejo Nacional de Producción, Costa Rica). Costa Rica increased its contribution to this market from 24% in 1994 to 41% in 1995, and the heart-of-palm was entirely from cultivated peach palm. The major importing countries in 1995 were France (30%), Argentina (27%), United States (11%), Spain (7%), Canada, Chile, Israel and Italy (3-5% each).

The demand for fresh heart-of-palm is increasing rapidly in Brazil. Fresh heart-of-palm had a large market before *E. edulis* was driven to economic extinction, and now the demand is being fed by the expansion of peach palm plantations in southern Brazil. Fresh heart-of-palm was introduced successfully into the Hawaiian market (Clement *et al.* 1993, 1996), and is attracting a lot of attention in Asia. Fresh heart-of-palm and the 'caulinar' heart are now being introduced into markets in the central United States. Considering the interest in fresh heart-of-palm expressed by gourmet chefs, and the prices that they are willing to pay (US\$6/lb in Hawaii in 1995), the market for fresh heart-of-palm has enormous potential, and perhaps more potential than the market for processed heart-of-palm.

The incomes from peach palm plantations for heart-of-palm and fruit are roughly equivalent in Costa Rica (Mora-Urpí, unpublished data). Beginning in the second year, a heart-of-palm plantation yields an average of 10 000 stems ha⁻¹ year⁻¹ and generates about US\$2800 ha⁻¹ year⁻¹ gross income for a farmer. With proper management of offshoots, production may be maintained but it is not known for how long. The oldest heart-of-palm plantation was established in 1974 in Sarapiquí, Costa Rica and is still in production. Villachica (1996) provides a detailed economic analysis of production costs for peach palm hearts in Peru.

11 Limitations and prospects of the crops

The major limitations of these food crops are related to management and marketing. Most plants have spines on the stems and leaves, which makes the harvest of fruit and heart-of-palm both difficult and dangerous. In addition, fruit harvesting becomes increasingly more difficult as the palm grows in height. Selection and breeding for spineless, semidwarf peach palms are underway in Costa Rica to overcome these limitations. Most stems produce relatively few offshoots per year, and the offshoots are often difficult to propagate and/or establish in the field. Improved methods for propagation and establishment of offshoots, and methods to stimulate offshoot production, are being investigated in Peru (H. Jaenicke, J.C. Weber and C. Sotelo-Montes, unpublished data).

The major limitations to expanded commercialization of peach palm's products, especially fruit products, are related to product development and entrepreneurial interest. There are not enough entrepreneurs interested in commercializing peach palm because: (1) high-quality products are not being developed, (2) entrepreneurs do not have the marketing information necessary to promote these products, (3) improved germplasm appropriate for these products is lacking, and (4) production costs/benefits using the improved germplasm are not available.

There is considerable potential for expanded commercialization of peach palm fruit and heart-of-palm, with consequent economic development in farming communities of Central and South America. Commercialization of fruit products could also improve food security for small-scale farmers and their domestic animals, which is a major concern in some regions (Brodie *et al.* 1997). In the long term, the fruit may become as important worldwide as the heart-of-palm because of its food value, suitability for a range of products and potential for sustainable production on the poor soils of the humid tropics. Heart-of-palm has greater immediate commercial potential, however, considering the growing markets for this gourmet food (Villachica 1996).

Many farmers recognize the potential value of peach palm fruit. For example, ICRAF and collaborating institutes (Instituto Nacional de Investigaciones Agrarias, Instituto de Investigación de la Amazonía Peruana, Universidad Nacional Agraria La Molina) investigated farmers' preferences for tree species in the western Amazon Basin of Peru. Farmers interviewed around Iquitos, Yurimaguas and Pucallpa value more than 150 tree species for agroforestry systems, but peach palm is one of their most preferred species, especially around Iquitos and Yurimaguas (C. Sotelo-Montes and J.C. Weber, unpublished data). Peach palm fruit is currently the third most valuable food crop produced by farmers around Iquitos and Yurimaguas, and the seventh most valuable food crop produced around Pucallpa (R. Labarta-Chevarri and J.C. Weber, unpublished data). Small-scale farmers in Iquitos and Yurimaguas currently dedicate about 72% of their annual production of peach palm fruit for sale in local markets, with average annual profits of about US\$900 in Iquitos and US\$300 in Yurimaguas. The remaining fruit is consumed on-farm (human food and animal ration) or traded with neighbouring farmers for

other products. Although these profits may appear small, most farmers currently cultivate only 20-50 peach palms in their agroforestry systems, but could produce much more with improved agroforestry systems and germplasm. Farmers around Pucallpa would like to produce more peach palm fruit for sale, but most of them do not have access to the preferred spineless germplasm (Brodie *et al.* 1997). Those who do have spineless peach palm are expanding their own production, and distributing the seed to neighbours who also want to increase production. ICRAF concluded from this research that peach palm should be the top-priority agroforestry species for its genetic improvement programme in the Peruvian Amazon Basin. This means that ICRAF will dedicate much of its research and development efforts in the Amazon Basin to agroforestry systems centred around peach palm, and actively seek additional international donor funding to promote development of these production systems.

The national and international gourmet markets for hearts from cultivated peach palm are growing (Villachica 1996), and some countries are expanding production in anticipation of continued market development (notably Costa Rica and Brazil). While significant for future economic development, this may benefit only the large-scale farmers in many regions, unless farm credit policies are liberalized. In relatively poor regions with undeveloped infrastructures, such as the Peruvian Amazon Basin, farmers may prefer to produce the fruit rather than heart-of-palm because of food security concerns (C. Sotelo-Montes and J.C. Weber, unpublished data; R. Labarta-Chavarri and J.C. Weber, unpublished data; Brodie *et al.* 1997). While this situation may be true in a large portion of the Amazon Basin, it is not the case in Central America. In Costa Rica, small-scale farmers produce most of the fruit and heart-of-palm and their new success is inducing them to get organized into associations for better marketing and to install their own industrial plants.

12 Future research needs

There is a need for considerable basic and applied research to manage and effectively use peach palm's genetic resources. Since peach palm is not yet a major crop, attention should focus initially on industrialization, marketing and the socioeconomics of production systems. Modern agro-industry requires high product quality and uniformity; marketing, in turn, depends on having a quality product to sell; this is especially true for fruit products. Research needs are listed below, arranged in order of general priorities, although different national or institutional programmes may have different specific priorities.

Industrialization, marketing and socioeconomics of production systems

- Develop market intelligence to estimate supply and potential demand for peach palm products, and develop strategies to stimulate market demand for these products.
- Improve the quality of existing processed products, and develop alternative processing approaches for new high-quality products.
- Improve post-harvest handling methods to extend the shelf-life of fresh fruit and heart-of-palm. Appropriate methods should be developed for the range of producers (e.g. small-scale farmers, cooperatives, large commercial enterprises).
- Evaluate fruit and heart-of-palm production in plantation systems and in traditional agroforestry systems, and model the socioeconomic and market factors that affect farmers' decisions to adopt more extensive production systems.
- Determine: (1) how farmers manage peach palm germplasm, (2) the movement of germplasm within and among communities and regions, and (3) current and projected supply and demand for improved germplasm at the farm, community and regional levels.

Vegetative propagation and seed physiology

- Improve methods for: (1) vegetative propagation of offshoots, (2) meristem tissue culture, and (3) successful establishment of asexually produced plants in the field.
- Evaluate growth and yield of asexually produced plants, compared with sexually produced plants.
- Improve methods to control seed dormancy for long-term seed storage, and for more rapid and uniform germination.

Pest management, agronomy and crop physiology

- Develop integrated pest management programmes for fruit and heart-of-palm production in plantations and in traditional agroforestry systems.
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- Determine: (1) the most sustainable combination of plant density and number of stems/plant, and (2) the mineral requirements for long-term fruit production in plantations and in traditional agroforestry systems.
- Determine: (1) the most sustainable combination of plant density, planting arrangement and offshoot management, and (2) the mineral requirements for long-term heart-of-palm production in plantations.
- Determine the physiological, genetic and environmental factors involved in differentiation, development and phenology of vegetative and reproductive buds.
- Determine the factors involved in the abscission of immature fruits in regions where this is a problem.
- Quantify growth, yield and physiological parameters for fruit and heart-of-palm production.

Genetic improvement

- Determine the costs and benefits of genetic improvement programmes for peach palm's major products, including establishment of conservation projects for valuable landraces.
 - Characterize and fully evaluate accessions in existing germplasm banks, and analyze fruit quality characteristics of promising accessions.
 - Collect selected germplasm from the more valuable landraces of cultivated peach palm for provenance trials, progeny tests, germplasm banks and breeding populations (e.g. Vaupés, Colombia for fruit, and Pampa Hermosa around Yurimaguas, Peru for heart-of-palm). Collecting should target phenotypically superior individuals as identified by farmers.
 - Evaluate genetic variation in adaptively and economically important traits among and within landraces of cultivated peach palm in replicated multilocation provenance trials, and estimate their genetic parameters in replicated multilocation progeny tests. Traits are listed in Tables 7 and 8.
 - Determine the effectiveness of phenotypic selection in the field, and multitrait selection indices for early selection in the nursery, germplasm banks and experimental plots.
 - Determine the genetics of the incompatibility mechanism and the rate of selfing among and within landraces.
 - Determine inbreeding and heterotic effects on adaptively and economically important traits.
 - Determine if apomictic seeds are produced, and the frequency of apomixis if present.
 - Assess the potential value of peach palm's ancestral forms for incorporation into genetic improvement programmes. Studies of indigenous knowledge about these ancestral forms could provide insight into their potential value.
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Management of genetic resources and seed production

- Determine the most appropriate approaches for *in situ* management/conservation of the major landraces of cultivated peach palm. These approaches should be based upon farm/community-level management and use of genetic resources for local and regional economic development.
- Determine the genetic structure and effective size of breeding populations in traditional agroforestry production systems, using electrophoresis and molecular methods, to help formulate management strategies for genetic resources on farm.
- Determine the most efficient methods for seed production of selected germplasm.

Taxonomy and phylogeny

- Conduct a thorough systematic revision of the genus *Bactris*, including analysis of variation among and within species in the *Guilielma* complex, and determination of species status for the small-fruited ancestral forms.
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Appendix I. Institutions and scientists managing germplasm banks and conducting research on peach palm

Institution†	Scientist and research interest
Bolivia	
Herbario Nacional de Bolivia Casilla 10077, Correo Central La Paz Tel/Fax: (591-2) 797511 Email: monica@palma.bo	Lic. Mónica Moraes: taxonomy
Museo de Historia Natural 'Noel Kempff Mercado' Casilla 702 Santa Cruz de la Sierra Tel/Fax: (591-3) 342160 Email: museo@mitai.nrs.bolnet.bo	Lic. Mario Saldías: taxonomy
Brazil	
Instituto Nacional de Pesquisas de Amazônia - INPA CP 478 69011-970 Manaus, Amazonas Tel/Fax: (55-92) 6421845 Emails: cclement@internext.com.br sanf@inpa.gov.br yuyama@inpa.gov.br lyuyama@inpa.gov.br ires@inpa.gov.br	Dr Charles R. Clement: germplasm bank (Manaus), genetics, plant breeding, agronomy Dr Sidney A.N. Ferreira: seed technology Dr Kaoru Yuyama: plant breeding, agronomy Dr Lucia K.O. Yuyama: human nutrition, carotene Dr Ires P.A. Miranda: pollen
Instituto Agronômico de Campinas Ave. Barão de Itapure 1481 agronomy 13020 - 002 Campinas, São Paulo Tel/Fax: (55-192) 314943 Email: mlabovi@cec.iac.br	Dr Marilene L.A. Bovi: germplasm bank (Campinas), plant breeding, agronomy Eng. Gentil Godoy Jr.: germplasm bank (Campinas), agronomy

† See Table 6 for more information about germplasm banks: number and origin of accessions, year established, and present condition.

Centro de Pesquisas de Cacau - CEPEC
APT. CEPLAC
45660-000
Ilheus, Bahia
Tel/Fax: (55-73) 2143204

Eng. Maria das Gracias C.P.C. Silva:
germplasm bank (Una), plant
breeding, agronomy
Eng. Ismael Sousa Rosa: germplasm
bank (Una), agronomy

Universidad Estadual da Santa Cruz
Gerencia de Laboratorios
Rodovía Ilheus - Itabuna, km 16
45.650-000
Ilheus, Bahía
Tel: (55-73) 214-5122, Fax: (55-73) 212-2195

MSc. Luis A. Mattos-Silva:
plant breeding, taxonomy

Colombia

Universidad Nacional de Colombia
Instituto de Ciencias Naturales
Bogotá
Tel: (57-1) 3684262, Fax: (57-1) 3681345

Dr Rodrigo Bernal: taxonomy

Secretaria de Agricultura de Valle
CAD Calle 2, N. 3
A-01
Buenaventura, Cali
Tel: (57-224) 24426, Fax: (57-2) 8810199

Ing. John Rico: germplasm bank (Bajo
Calima), agronomy

Universidad del Valle
Departamento de Tecnología de Alimentos
Cali
Tel/Fax: (57-2) 6643920

Lic. Carlos Piedrahita: food technology

Private consultant
Apdo. 2154
Cali
Tel/Fax: (57-2) 5511323

Dr Víctor M. Patiño: economic botany

Private consultant
Apdo. 7534
Cali
Tel/Fax: (57-2) 3329231

Ing. Armando Velasco: agronomy

Corporación para Investigación
en Ciencias Agrícolas - CORPOICA
Centro de Investigación Macagal
A.A. 337
Florencia, Caquetá
Tel: (57-88) 352631

Ing. Juan Carlos Escobar: germplasm
bank (Florencia), agronomy

Instituto Técnico Agropecuario
Sabio Calas, Secretaria de Educación
Florencia, Caquetá
Tel: (57-88) 353887

Ing. Hernán Loaiza: germplasm
bank (Santuario), agronomy

Corporación para Investigación
en Ciencias Agrícolas - CORPOICA
El Mira, Tumaco

MSc. Rafael Reyes: plant breeding,
agronomy

Costa Rica

Universidad de Costa Rica
Escuela de Biología
San José
Tel: (506) 2075375
Fax: (506) 2249367
Email: pejibaye@cariari.ucr.ac.cr

Dr Jorge Mora-Urpí: germplasm bank
(Guápiles), genetics, plant breeding,
agronomy

Universidad de Costa Rica
Escuela de Agronomía
San José
Tel/Fax: (506) 2259694
Email: citaucr@cariari.ucr.ac.cr
jherrara@cariari.ucr.ac.cr
hlezama@cariari.ucr.ac.cr

Dr Luis Gómez: tissue culture,
electrophoresis
Dr Claudio Herrera: seed technology
MSc. Claudio Gamboa: integrated pest
management
MSc. Ramón Mexzón Vargas:
germplasm bank (Guápiles),
integrated pest management
MSc. Mario Murillo: animal nutrition
MSc. Augusto Rojas: animal nutrition
Ing. Carlos Arroyo: germplasm bank
(Guápiles), agronomy
Ing. Edgar Vargas: plant pathology
Lic. Ruth de la Asunción: food
technology
Lic. Wilfredo Gómez: food technology
Lic. Maria Lourdes Pineda Castro: food
technology

Universidad de Costa Rica
Sede Regional
Turrialba
Tel/Fax: (506) 5567020

Lic. Elena Castillo: germplasm bank
(Turrialba, 1963 bank), DNA
technologies

Centro Agronómico Tropical
de Investigación y Enseñanza - CATIE
Apdo. 25
Turrialba
Tel/Fax: (506) 5561533
Email: castorga@computo.catie.ac.cr

MSc. Carlos Astorga: tissue culture,
genetic resources

Instituto Costarricense para la
Investigación y Enseñanza de Nutrición
y Salud - INCIENSA
Apdo. 4-2250
Tres Rios
Tel/Fax: (506) 2799911
Email: adrianab@cariari.ucr.ac.cr

MSc. Adriana Blanco-Metzler: food
technology

Ministerio de Agricultura y Ganadería
Estación Experimental Los Diamantes
Guápiles
Tel: (506) 7107851

Ing. Antonio Bogantes: agronomy

Ecuador

Instituto Nacional de Investigación
Agropecuaria - INIAP
Estación Experimental Napo-Payamino
Km. 6 via Coca-Lago Agrio
Coca, Napo
Tel: (593-6) 528650, Fax: (593-6) 504240

Ing. Mario Jativa: germplasm bank
(Napo)

Nicaragua

Ministerio Desarrollo Agropecuario
y Reforma Agraria - MIDINRA
Apdo. 5735
Managua
Tel/Fax: (505) 226796

Ing. David Varela: germplasm bank (El
Recreo), genetic resources, agronomy

Panama

Instituto de Investigación Agropecuaria de Panamá - IDIAP
 Apdo. 604391
 El Dorado 6A
 Tel/Fax: (507) 642270

Ing. Omar Alfaro: germplasm bank (Las Pavas), genetic resources

Peru

International Centre for Research in Agroforestry - ICRAF
 INIA-PNIACT
 Carretera Federico Basadre Km. 4.2
 propagación,
 Pucallpa, Ucayali
 Tel/Fax: (51-64) 579078
 Emails: j.weber@cgnet.com
 j.alegre@cgnet.com
 d.bandy@cgnet.com
 h.jaenicke@cgnet.com
 c.sotelo@cgnet.com
 l.arevalo@cgnet.com
 r.labarta@cgnet.com

Dr John C. Weber: on-farm provenance trials, progeny tests and management of genetic resources, community-level seed orchards, vegetative agroforestry systems

Dr Julio Alegre: nutrient cycling in agroforestry systems

Dr Dale Bandy: agroforestry systems

Dr Hannah Jaenicke: physiology of offshoot production, apical dominance, vegetative propagation

MSc. Carmen Sotelo-Montes: on-farm management of genetic resources, community-level seed orchards, vegetative propagation, agroforestry systems

MSc. Luis Arévalo: nutrient cycling in agroforestry systems

Ing. Ricardo A. Labarta-Chávarri: markets, economic potential, agroforestry systems

Asociación para el Desarrollo Sostenible Eduardo del Aguila 393
 Pucallpa, Ucayali
 Tel/Fax: (51-64) 576949

Dr Hugo Villachica: agronomy, seed merchant

Instituto Nacional de Investigación Agraria - INIA
 Estación Experimental San Roque
 Jirón Pevas 274
 Iquitos, Loreto
 Tel/Fax: (51-94) 235637

MSc. Rafael Chumbimuni: germplasm bank (Iquitos), agronomy

Instituto de Investigación de la
Amazonía Peruana - IIAP
Estación Experimental San Ramón
Yurimaguas, Loreto
Tel/Fax: (51-94) 352261

Ing. Beto Pashanasi: germplasm bank
(Yurimaguas), agronomy

Productos y Servicios Agroecológicos
- PROSAE
Libertad 417
Yurimaguas, Loreto
Tel/Fax: (51-94) 352544

Ing. Jorge Pérez: agronomy, seed
merchant

Compañía Amazónica de Producción
Florestal
CAMPFOR S. R. Ltda
Caja Postal 471
Calle Nunay 110
Iquitos, Loreto
Fax: (51-94) 23-7438
Email: campfor@rail.org.pe

Mario H. Pinedo P.: private consultant,
seed merchant

Venezuela

Universidad Central de Venezuela
Instituto de Agronomía
Apdo. 4574
Maracay
Tel/Fax: (58-43) 463455

Dr Miriana de Miranda: germplasm
bank (Saman Moche, San Nicolas),
seed technology, genetic resources
Ing. Romulo E. Salas: germplasm bank
(Saman Moche, San Nicolas),
agronomy, genetic resources
Ing. América Trujillo de Leal:

germplasm

bank (Saman Moche, San Nicolas),
agronomy, genetic resources

Ministerio de Recursos Naturales
Renovables - MARNR-SADA Amazonas
Puerto Ayacucho
Tel/Fax: (58-43) 463455 (Maracay)

Ing. Jesús Infante: germplasm bank
(Cataniapo), agronomy
