Annona species

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Abbreviations

BAP - Benzylamino purine
EDTA - Ethylene Diamino Tetra Acetic Acid
EMBRAPA - Brazilian Corporation for Agricultural Research
FAO - Food and Agriculture Organization of the United Nations
FOB price - Free on Board price
GA - Gibberellic Acid
GXE – Genotype by Environment Interaction
HIV - Human Immunodeficiency Viral Disease
IBA - Indole Butyric Acid
IAA - Indole Acetic Acid
IPGRI - International Plant Genetic Resources Institute
MS - Murashige and Skoog growth medium
MTH - Monotetrahydrofuran
NAA - Napthalene Acetic Acid
NAS - National Academy of Sciences
NPK - Nitrogen, Phosphorus, Potassium (fertilizer)
NRC - National Research Centre
ODEPA - Oficina de Estudios y Politicas Agrarias del Chile
PROCIANDINO - Programa Cooperativo de Investigación y Transferencia de Tecnología Agropecuaria para la Region Andina
RAPD - Random Amplified Polymorphic DNA
RH - Relative Humidity
THF - tetrahydrofuran
UFAL - Federal University of Alagoas
USDA - United States Department of Agriculture

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Alberto Carlos de Queiroz Pinto, Brasília, DF, Brazil

Preface

Increasing demand for exotic fruits for human consumption has become evident in many countries, both tropical and temperate. The indigenous and often "underutilised" fruits in many developing countries can provide the vitamins, mineral salts and fibre in their diets.

The majority of the *Annona* species are considered to be underutilised, hence information on them is scarce and widely scattered. However, the areas under production have increased more rapidly than the contributions from science and technology. There is a need for better information for academics, researchers, extension workers and growers.

The information available varies from species to species. Far less is known about *A. senegalensis* and *A. reticulata* than the other three species. It is hoped that the information provided will make this account useful to all those interested in annonas and encourage their wider cultivation and use.

This is a reference text bringing together available information on five *Annona* species, with the aim of identifying gaps in knowledge and thus research needs. With an accompanying extension manual, this will provide opportunities for both resource-poor as well small-scale commercial farmers to develop this species for income generation. The monograph is written for researchers and extension agency offices. The extension manual is designed to meet the needs of farmers and small-scale producers. We hope that this work may encourage further production, processing and marketing of annonas particularly at the village level, and researchers and scientists to further explore the benefits of indigenous tropical fruit trees such as annona. For further information visit: www.civil.soton.ac.uk/icuc.

Preparation and publication of this book has been funded by the Department for International Development (DFID), UK as part of a project called "Fruits for the Future". In addition to ICUC, other partner organisations involved are the World Agroforestry Centre (ICRAF) and the International Plant Genetic Resources Institute (IPGRI).

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Editors, November 2004

Chapter 1. Introduction

A. C. de Q. Pinto

Four of the five species covered in this monograph originated in South or Meso-America and one seems to have originated in eastern Africa. The first group includes *Annona cherimola* Mill, cherimoya, *A. muricata* L., soursop, *A. reticulata* L., custard apple, and *A. squamosa* L., sugar apple. The African species is *A. senegalensis* Pers., wild soursop. Cherimoya is the only species adapted to subtropical or tropical highland conditions; the others are mostly adapted to the tropical lowlands but can be grown in the subtropics. Two, cherimoya and soursop, received international attention in publications of the US National Academy of Sciences (NAS, 1975, NRC, 1989). These five species have been selected for attention because available evidence suggests the possibility of expanding their use and importance. This does not mean that other *Annona* species have no potential. Three others, at least, have been recommended for attention. *A. purpurea* Moc. and Sassé, soncoya, is a small tree of Mexico and Central America that is occasionally cultivated for its agreeably flavoured fruit (see Gauthier and Poole, 2003, Enhancing the role of forest fruits in sustaining livelihoods of forest margin communities (R7349 - FRP)). *A. scleroderma* Saff., posh té, is from the same area and has a fruit that is reputed to taste better than soursop (Uphof, 1959). In the Brazilian Cerrados (the savannahs of central Brazil), *A. crassiflora* Mart., araticum, is a popular minor fruit, also used in traditional medicine (Almeida et al., 1998), and is now receiving research attention. Other species, supposedly with promise, were introduced to certain areas but did not become important. The case of *A. glabra* L., pond apple, taken to S. E. Asia is an example.

The strongest consumer demand, and hence production, is for cherimoya, soursop and sugar apple. The fruits of these species are delicately flavoured and are marketed mainly in local, regional or national trade, only rarely in international trade. Pulp of these fruits is sold fresh or frozen, and is usually used for desserts or made into sherbets and ice cream. Although custard apple and wild soursop are less important economically, their fresh fruits are sold in the markets of some developing countries, and their pulp and seeds are also used for medicinal purposes more commonly than those of the major species.

In many countries, the species are grown in small areas by small scale farmers, who generally have difficulty accessing internal and external markets. Major limiting factors are (1) climatic limitations and other growing conditions, (2) ineffective or poor agronomic techniques, (3) limited post-harvest knowledge for harvesting, handling and transporting, (4) lack of agribusiness initiatives to stimulate production, marketing and research, and (5) lack of knowledge about the fruits' nutritional values, and techniques for the elaboration of processed products.

The major species, such as cherimoya in countries with subtropical climates, and soursop and sugar apple in tropical regions, are becoming better known and are finding their way into commercial marketing channels. Nonetheless, better technical and scientific knowledge is needed to sustain and enhance the development of these species in appropriate regions.

This monograph systematizes information from different areas of study, such as taxonomy and botany, origin and distribution, ecology, properties and uses, agronomy, harvesting and post-harvest processing and the economics of production. This monograph is expected to be useful to students, research and development specialists, annona farmers and others interested in these fruits. The companion extension manual is expected to be useful to the same set of people, but is prepared especially for annona farmers and fruit extension agents.

Chapter 2. Taxonomy and Botany

A. C. de Q. Pinto

2.1 General

The number of genera and species in the family Annonaceae is still debated. Bailey (1949) affirmed that Annonaceae has 46 genera and between 500 and 600 species, while Fries (1959), cited by Geurts (1981), affirmed that it contains 119 genera and over 2,000 species. Popenoe (1974 a) described the family as having 40 to 50 genera and more than 500 species, most of which are shrubs and small trees. A limited number of species produce edible fruits, including many gathered from the wild, and some that have been domesticated (Ochse *et al*., 1974). Most of the species are found in the tropics, with only a few genera present in the temperate zone.

According to Geurts (1981), of the 119 species described in the genus *Annona*, 109 are native to tropical America and 10 to tropical Africa. All of the domesticated species are American, while one African species (*A. senegalensis*) is probably in the process of domestication.

2.2 Specific and common names

The names of the five annona species dealt with in this monograph are presented in Table 2.1. The number of common names is large for some of the species, and they need to be used with caution because some names may be applied to two or more species in different countries, or even in different regions of the same country. Clearly therefore, the botanical descriptions are essential for extensionists, students and growers to distinguish one species from another.

The relevant botanical details of the species are outlined in section 2.3 below. Mistaken identities among botanically similar annonas are relatively frequent. For instance, atemoya (a hybrid between cherimoya and sugar apple) was mistakenly called custard apple for many years (Morton, 1987), when this name more properly relates to *A. reticulata*. Custard apple is sometimes confused with *A. glabra*, and *A. montana* has been confused by some Brazilian growers with *A. muricata*. Key botanical literature includes Bailey (1949), Geurts (1981), Léon (1987), Ochse *et al*. (1974), Pinto and Silva (1996) and Popenoe (1974 a, b).

Table 2-1. Botanical or specific, common and vernacular names and their synonyms of the five *Annona* species studied

Botanical	**Synonyms**	**Common**	**Other common names**
A. cherimola Mill.	*A. tripetala* Aiton, *A. pubescens* Salisb.	Cherimolia, Cherimoya	Cherimoya, anona del Peru, chirimoyo del Peru, catuche, momora (Spanish), chérimolier (French), cherimoya, cherimoyer, annona, custard apple (English), honumanaphala (Kannada), lakshamanphal (India), noina ostrelia (Thai), anon (Spanish, Guatemala), cherimólia, anona do Chile, cabeça de negro (Portuguese), cerimolia (Italian), chirimoyabaum, peruanischer flaschenbaum, flachsbaum (German)
A. muricata L.	*A. muricata* L. *A. bonplandiana* Kunth.; *A. cearensis* Barb. Rodr.; *A. macrocarpa* Werckle; *A. muricata* var.*borinquensis* Morales; *Guanabanus muricatus* Gómez	Soursop	Guanábana (Spanish), corossolier (French), zuurzak (German), munolla (India), mulluseeta, pullupala (Tamil), mullu ramaphala (Kannada), mullanchakka, vilathinura (Malayalan), graviola (Portuguese), durian belanda (Malaysian), mamon (Spanish, Philippines)
A. reticulata L.	*A. excelsa* Kunth; *A. laevis* Kunth; *A. longifolia* Moc. and Sessé; *A. riparia* Kunth.	Custard apple	Bullock's heart, corazon (English), condessa e coração-de-boi (Portuguese), buah nona (Indonesian), ramphal (India), ramaseeta (Tamil), ramasitapalam (Tegelu), vilathi (Malayalan), ramaphala (Kannada)

Botanical	**Synonyms**	**Common**	**Other common names**
A. senegalensis Pers.	*A. arenaria* Thonn.; *A. chrysophylla* Boj.; *A. chrysophylla* var. *porpetac* Bail.; *A. porpetac* Bail.; *A. senegalensis* var. *porpetac* Bail. Wild	Wild soursop	Mchekwa, (kishwahili), mtomoko (kichaga), mtopetope (kirufiji), gishta gaba (Arabic), annone africain, pomme cannelle du Sénégal (French), nhonokono nwitu, ntokwe, mtokwe (Kenya), nchakwa (Tanzania), mposa, muroro, mponjela, mulembe (Malian), ntantanyerere, mtopa (Zambia), gishit'a (Ethiopia), dau-ha, dyangara (Bambara), moupa (Dierma), bu bualansambu, goritsaa tibu, iuboualansahu (Gourmancho), barkudugo, bakikudiga, barduki, barkudugo, barkoudouga (Moore), barkoutahe, dokumi, doukouhi (Peulh), digor, dugor, jorqut (Wolof)
A. squamosa L.	*A. asiatica* L.; *A. cinerea* Dunal; *Guanabanus squamosus* Gomez	Sugar apple	Sweetsop, sugar apple, custard apple (English), ata, pinha or fruta do conde (Portuguese, Brazil), attier (French), saramuya and Aztec (Mexico), sitaphal, (Tamil), seethapalam, athichakku (Malayalan), nona sri kaya (Malaysian) seethapandu (Tegelu), amritaphala, seethaphala (Kannada), aatoa, shariffa, sitaphal (Hindi), ata, luna (Bengali), sita pandu (Tebgu), noina (Thai)

2.3 Botanical description

2.3.1 Description of the genus

The name annona derives from the Latin "annual harvest" (Lizana and Reginato, 1990). The genus presents numerous unifying characteristics, especially relating to plant height, root system, bark, stem, floral biology, pollination, fruit set and fruit type (Ochse *et al.*, 1974; Geurts, 1981; León, 1987). There are important variations among annona seedlings in the same species, affecting not only the mature foliage and productivity of the plants, but also the fruit size, form, colour, quality and number of seeds in the fruit. These variations are often pronounced enough to have resulted in several botanical names for the same species.

In general, the annonas are shrubs or small trees, whose height varies from 5 to 11 m depending on several factors, such as species, climate, soil and crop management. They are erect or somewhat spreading in habit, with grey-brown bark, often rough and corrugated (León, 1987). Generally, annona stems are ferruginous to greyish, and tomentose when young but later becoming glabrous. With few exceptions, annonas are deciduous, even tropical species, especially when cultivated in areas with dry or cool seasons and without irrigation.

The root system has abundant thin lateral roots and a taproot that is not as strong as in other tropical fruit trees, such as mango (*Mangifera indica* L.). Although the taproot is not generally pronounced, the lighter the soil texture the longer the taproot will grow. The taproot of an adult soursop tree can reach approximately 1.5 to 1.8 m in depth in oxisols of the Cerrado ecosystem (Brazilian savannah) in Central Brazil (Pinto and Silva, 1996).

Annona flowers are hermaphrodite, usually somewhat fragrant, solitary or in fascicles with 2 to 4 flowers, with three green sepals and six petals arranged into two verticils. The external verticil has three yellow-greenish petals and the internal one has three yellowish petals. The flowers have several conglomerated and spirally arranged stamens below and around an upper globose (conical) shaped dome of numerous united carpels, which have one ovule each. After fertilization, the united carpels will form a syncarp or composite fruit.

Flowering starts when the plant is three to four years old, although it may occasionally occur earlier depending upon environmental conditions. Anthesis (flower opening) starts slowly, with the separation of the apex of the external petals and takes from 6 to 8 h to complete.

Pollination is mainly carried out by insects or sometimes by wind. The fact that flowers are protogynous (pistils are mature before pollen is liberated from anthers) suggests that self-pollination is not the rule for annonas. Due to the protogynous flowers, fruit set may be poor when the pollinating insect populations are small, and small, asymmetric fruits may be produced, since fruit size and form depends on the number and position of fertilized ovules. As a result, the number of fruits per plant, and fruit size and shape are highly dependent on abundant insect pollination and amenable to control via hand pollination where the pollinating insects are rare.

2.3.2 Description of the species

***1. Annona cherimola* (cherimola)**

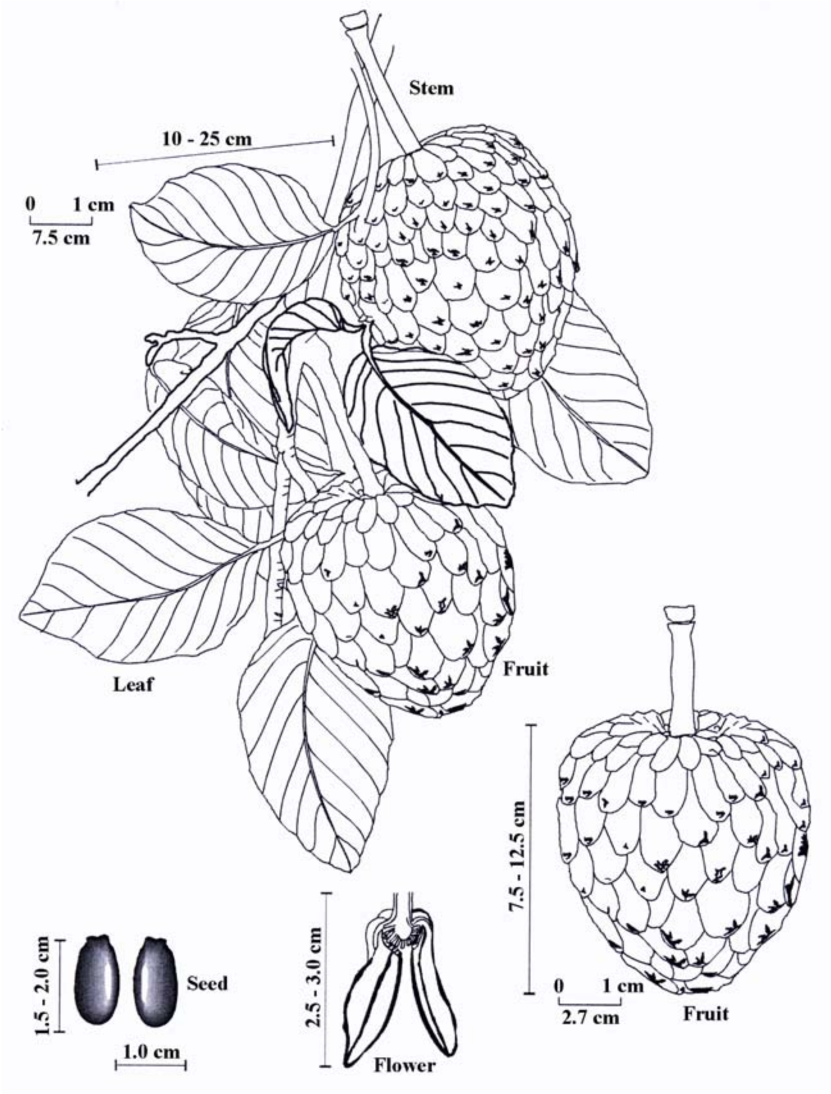
The name cherimoya derives from the Quechua name "chirimuya", which means "cold seeds" (Lizana and Reginato, 1990). It is a small, erect and/or somewhat spreading, deciduous tree, rarely reaching a height of more than 7.5 m. Its stem frequently divides at ground level into several stems (NRC, 1989). It was domesticated in the mid-elevation Andes of South America.

It has simple, alternate, 2 to 4 ranked leaves, which are ovate-lanceolate to elliptical in shape, 10 to 25 cm long, glabrous on the ventral surface and pubescent dorsally, with leaf shedding in the spring.

The single, protogynous, fragrant flower emerges from the leaf axils, and possesses a short peduncle, *ca* 2.5 cm in length (Fig. 2.1). Flowering occurs once a year, the season depending on the environment and it starts when the tree is 3 to 4 years old. Flower anthesis starts in the early morning and it takes 8 h to attain complete opening.

The fruit is normally heart-shaped, conical, oval or somewhat irregular in form due to irregular pollination. Fruits measure 7.5 to 12.5 cm in length and weigh from 200 to 700 g (Fig. 2-1). The fruit surface is smooth in some varieties; in others, it is covered with small conical protuberances over the carpels. The fruit rind is delicate and thin, and is greenish-yellow when ripe (Popenoe, 1974 a). The white, subacid flesh has a fragrant, delicate flavour, like that of pineapple and banana. The fruit has numerous seeds (21 to 41 seeds/fruit), which are 1.5 to 2.0 cm in length and approximately 1.0 cm in width (Manica, 1997).

Figure 2-1. Botanical characteristics of some plant parts of cherimoya (*Annona cherimola* Mill.)



Popenoe (1974 a) cites five botanical forms differentiated on fruit shape and skin design (due to the variable structure of the carpel protuberances and outlines over the carpel segments called areoles).

Forma impressa: Finger-printed - This form is called *anona de dedos pintados* (finger printed annona) in Costa Rica. The fruit is conoid or subglobose in shape, and has a smooth surface covered with U-shaped areoles resembling finger-prints in wax. Fruits tend to be of good quality, although the fruit contains many seeds.

Forma laevis: Smooth - This form is called *cherimoya lisa* (smooth cherimoya) in South America and *anon* in Mexico City. It is often mistaken for *A. glabra* or *A. reticulata* because of the general appearance of the fruit and on account of the name *anon*, which is also applied to *A. reticulata*. This is one of the finest botanical forms.

Forma tuberculata: Tuberculate - This is the commonest form. The fruit is heart-shaped and has wart-like tubercles near the apex of each areole. The cultivar *Golden Russet* belongs to this botanical form.

Forma mamillada: Mammillate - This form is called *"cherimoya de tetillas"* (nippled cherimoya) in some South American countries. It is said to be common in the Nilgiri Hills in southern India, and to be one of the best types grown on Madeira Island.

Forma umbonada: Umbonate - This form is called *"cherimoya de púas"* (barbed cherimoya; spiny cherimoya) and *"anona picuda"* (pointy anona) in Latin America. It has a thick skin, with more acidic flesh than other types, and the seeds are numerous. The fruit is oblong-conical, with the base somewhat umbilicate and the surface studded with protuberances, each of which corresponds to a carpel component.

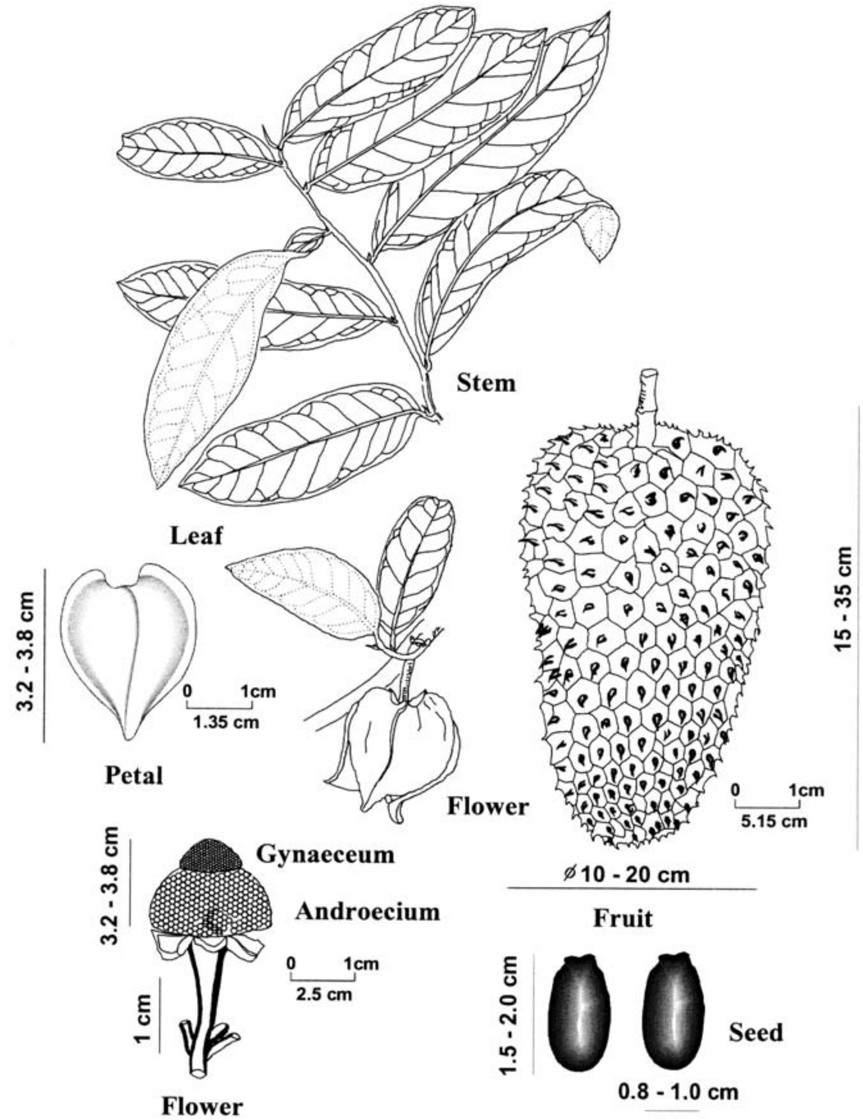
Numerous cultivars have been described, both in the area of origin, where every valley has its particular type, and in the numerous areas where cherimoya was introduced. The germplasm introduced to Spain alone appears to have included about 200 traditional cultivars. Modern commercial cultivars have been developed since these introductions. NRC (1989) mentioned such well known North American cultivars as ‘Booth’, ‘White’, ‘Pierce’, ‘Knight’, ‘Bonito’, ‘Chaffey’, ‘Ott’, ‘Waley’ and ‘Orchard’, and stated that cultivars exhibit a wide variation in climatic and soil requirements (see also Table 9.2).

***2. Annona muricata* (soursop)**

The soursop has an erect growth habit with a high canopy height-to-diameter ratio (Pinto and Silva, 1996), although it tends to be low-branching and bushy, with upturned limbs (NAS, 1975). It is a small, slender, evergreen tree, 4 to 8 m tall when fully mature. It was domesticated in lowland South America as a garden plant.

The stems are rounded, rough and not pubescent, with a dark-brown colour. The leaves have short petioles, and are oblong-ovate to cylindrical, 14 to 16 cm in length and 5 to 7 cm in width. Because of similarities of plant canopy and leaf form, soursop and mountain soursop (*A. montana* Macf.) are often confused. The flowers of soursop are much larger than those of the other four species listed in this monograph, being 3.2 to 3.8 cm in length (Fig 2-2).

Figure 2-2. Botanical characteristics of some plant parts of soursop (*Annona muricata* L.)



The flowers start to open in the early morning and complete anthesis takes approximately 6 h, depending on the climate. Flowering is more or less continuous. This species also experiences inefficient natural pollination (normally done by beetles) and frequently poor fruit set; hence hand pollination is an important orchard management practice.

Soursop produces an ovate, conical or heart-shaped fruit, that is dark green when unripe and a slightly lighter green when ripe. The rind has many short, fleshy, pointed carpel protuberances and is popularly regarded as 'spiny'. The soursop has the largest fruit in the genus, weighing from 0.9 to 10 kg, and averaging 4 kg. Its white, cottony-fibrous, juicy flesh resembles that of cherimoya in colour. The flavour is more acid and less sweet than cherimoya, and calls to mind a mixture of pineapple and mango.

The fruit has 127 to 170 seeds, scattered throughout the pulp. They are toxic. Seed size varies from 1 to 2 cm in length and from 0.33 to 0.59 g in weight, with a black colour soon after harvest, but becoming dark-brown later (Pinto and Silva, 1996).

Few cultivars of *A. muricata* exist, and comparisons among them have not been made to assess their validity. In particular, those with good-sized, low-fibre fruits need to be identified (NAS, 1975). All known selections are Latin American.

3. Annona reticulata (custard apple)

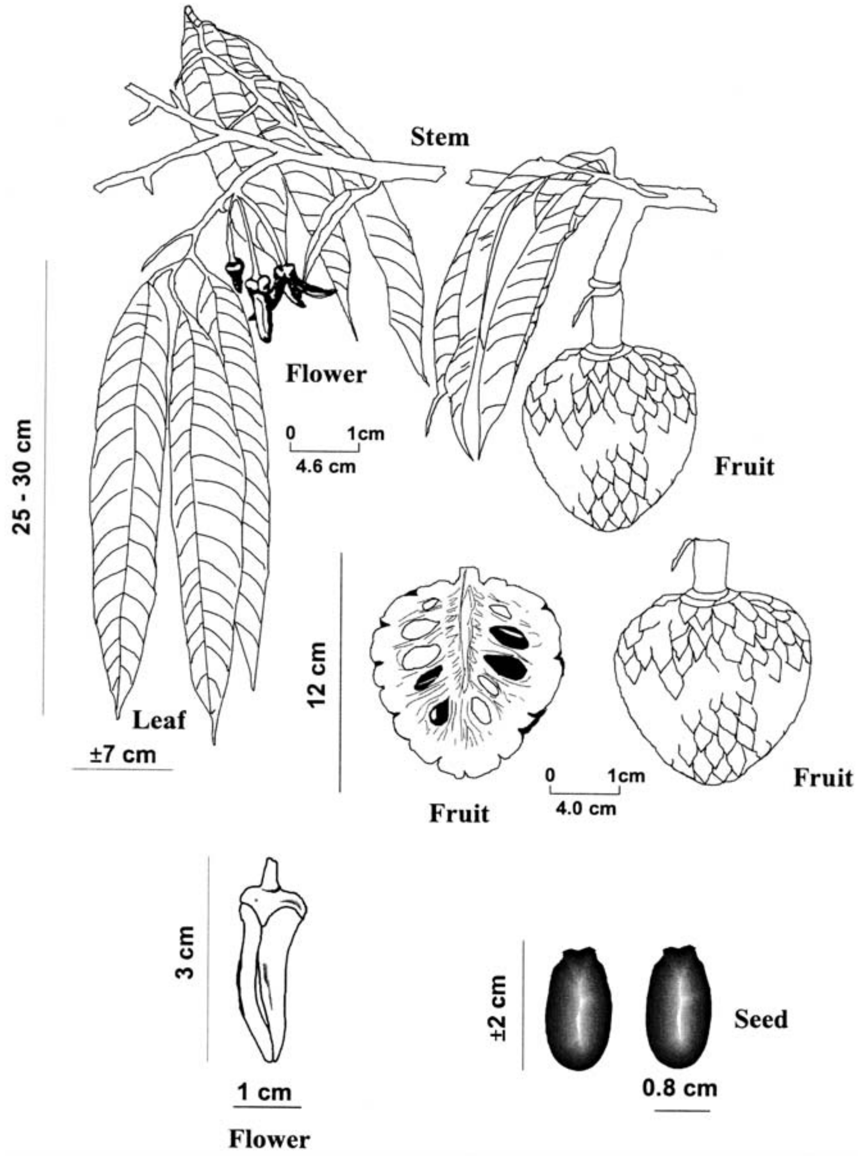
The tree reaches 6.0 to 7.5 m in height, with many lateral branches; stems are cylindrical, with lenticels and very short coffee-coloured hairs. It is considered the most vigorous of the annonas described in this publication. Custard apple is thought to have been domesticated, even though the fruit is considered to be of inferior quality. It can be distinguished from cherimoya by its long, narrow, glabrous leaves, from sugar apple by its solid, compact fruit, as well as its larger leaves, and from *A. glabra* by its small, dark brown seeds (León, 1987).

The leaves are oblong-lanceolate and dark-green, measuring 25 to 30 cm in length and 7 cm wide, with 10 to 20 vein pairs and a pubescent petiole.

Flowers are similar in form to those of sugar apple, except that they are grouped in a short inflorescence with 2 to 10 flowers, with pedicels measuring 1.5 to 3.0 cm in length. This species also presents inefficient natural pollination and poor fruit set.

Fruits weigh from 0.1 to 1.0 kg and are commonly heart-shaped, but may be conical, ovate or irregular in form, and 10 to 12 cm in length (Fig. 2-3). They are coriaceous and have a reddish-yellow surface colour, with impressed lines (around 5 to 6 angled areoles) above the carpels. The flesh is milk-white and sweet, although insipid in flavour, being considered the least tasty of the cultivated annonas. There are commonly more than 40 oblong, dark coffee-coloured seeds per fruit (León, 1987).

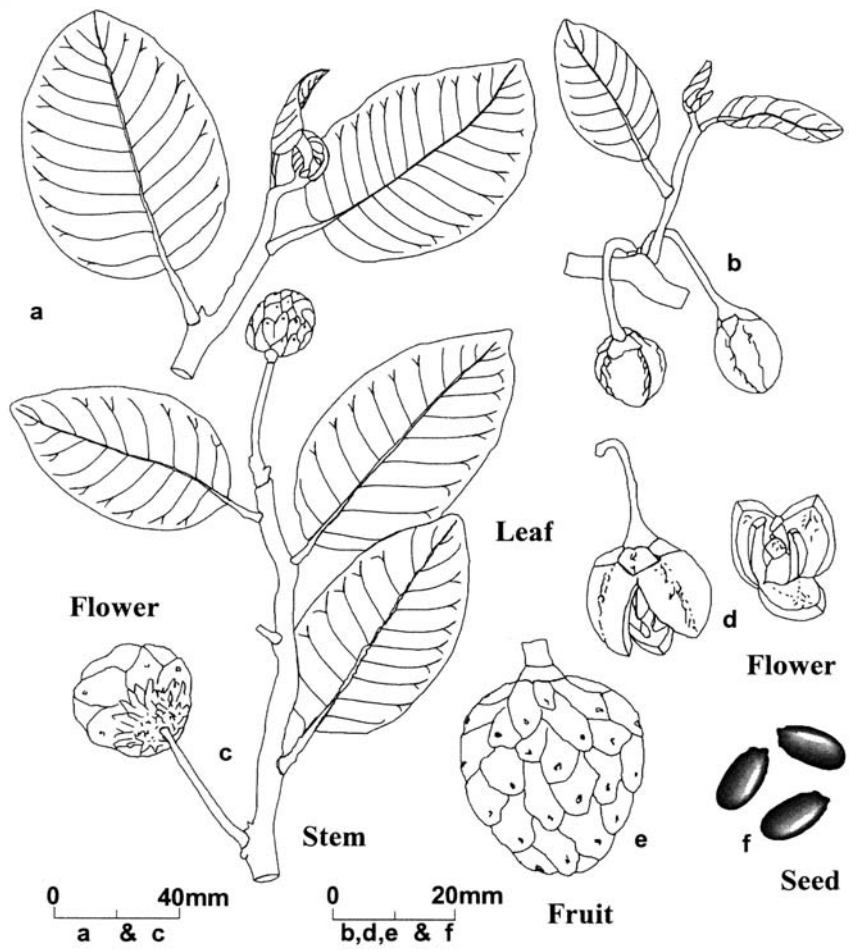
Figure 2-3. Botanical characteristics of some plant parts of custard apple (*Annona reticulata* L.)



4. *Annona senegalensis* (wild soursop)

Wild soursop is a spreading shrub or small, semi-deciduous tree, 1.5 to 11.0 m (averaging usually about 3.5 m) in height, with a stem diameter up to 28 cm at breast height (FAO, 1983, 1988). It has a greyish-black bark, often rough and corrugated, branching near the ground, with young stems mostly ferruginous, velvety to greyish or red-brown tomentose, later becoming glabrous. It is not strictly domesticated, but some trees are 'protected' due to preferred qualities.

Figure 2-4. Botanical characteristics of some plant parts of wild soursop (*Annona senegalensis* L.)



Source: FAO (1983)

The leaves are ovate, oblong-elliptical or oblong-ovate in form, 8 to 17 cm by 4 to 10 cm, with an acute, obtuse, rounded or slightly emarginate apex, and upper surface smooth, lower surface pale brown and hairy. Like other annonas, the leaves are simple, alternate, with 0.5 to 2 cm long petioles.

The flowers are inconspicuous, green, single or grouped on long smooth stalks (in fascicles with 2 to 4 flowers). They are fleshy, up to 3 cm diameter and usually fragrant. Although there is no available information on flower opening, pollination and fruit set of this species, it seems obvious from its flower biology (FAO, 1983) that it has problems similar to the other annonas mentioned here.

The fruit has an ovate, globose or subglobose form, measuring 2.5 to 5.0 cm in length and 2.5 to 4.0 cm in width (Fig. 2-4). The unripe fruit is green with white specks turning yellow or orange when ripe. The white to yellow edible flesh, which has many seeds, has a pleasant aroma, resembling pineapple, but tasting of apricot. One hundred seeds weigh *ca.* 40 g. There is a recognized botanical variety, var. *posteide* (Bail.) Diels., and no known cultivars. There is a dwarf form in Malawi where the plant is so small that the fruits grow 'on the ground' and this form is thought to taste the best by the locals (Williamson, 1974).

***5. Annona squamosa* (sugar apple)**

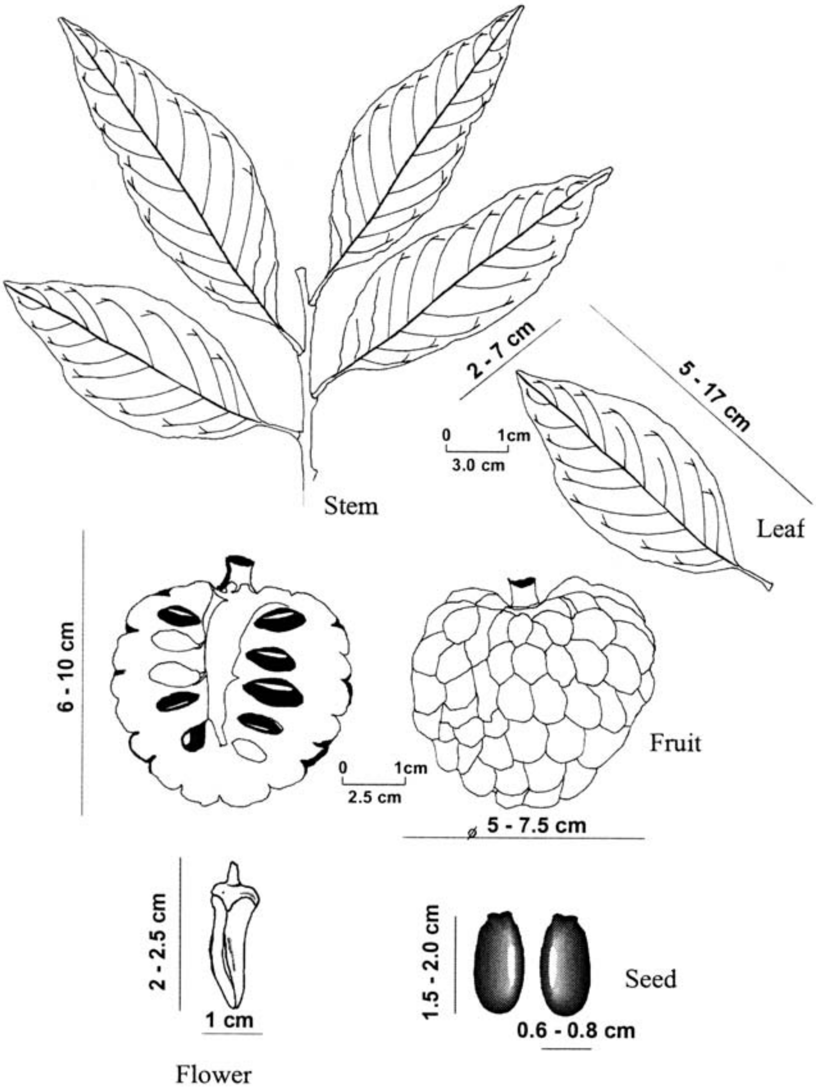
The sugar apple tree is deciduous and much smaller than the soursop, reaching a maximum of 6.0 m in height, with many lateral branches. The stems present lenticels, while the young shoots are pubescent and the oldest are smooth. It was domesticated in the circum-Caribbean or northern South American lowlands.

Like other annona species, it has deciduous leaves that are brilliant green above and bluish green below, with petioles 0.7 to 1.5 cm in length. The leaves are oblong-elliptical in form, measuring 5 to 17 cm in length and 2 to 7 cm in width, with an obtuse or acuminate apex. The blade has 15 to 17 pairs of veins (Ochse *et al*., 1974).

The flowers measure 2.0 to 2.5 cm in length and are much smaller than soursop flowers, being similar in size and form to those of cherimoya. Pollination and fruit set problems are similar to those of other annonas. Pollen germination is low and may influence final fruit set, which varies from 5.4% to 5.6% (Thakur and Singh, 1965).

The fruit is rounded, heart-shaped, ovate or conical, 5 to 7.5 cm in diameter, 6 to 10 cm in length and weighing 120 to 330 g (Fig. 2-5). Fruit size depends on cultivar, pollination, nutrition and other factors, but its form resembles a hand-grenade, with a tuberculate surface covered with a whitish bloom. The white, custard-like pulp has a pleasant sweet-sour flavour. The fruit contains 35 to 45 black seeds, each 1.5 to 2.0 cm in length and 0.6 to 0.8 cm in width. There are a few recognized cultivars of sugar apple, with the majority of these in India, and their names give some idea of their origin as introductions: ‘Mammoth’, ‘Barbados’, ‘British Guinea’, ‘Balondegar’, ‘Red Sitaphal’, and ‘Sindhan’, the last being local to Gujarat (Singh, 1992). A dwarf cultivar is ‘Lal Sitiphal’.

Figure 2-5. Botanical characteristics of some plant parts of sugar apple (*Annona squamosa* L.)



Chapter 3. Origin and Distribution

A. C. de Q. Pinto

The origin of most of the species treated in this book is South America and the Antilles, however wild soursop is thought to have originated in Africa. The current distribution of these five species covers almost all continents, with soursop and sugar apple showing the widest distribution, mainly in tropical regions (Fig. 3-1).

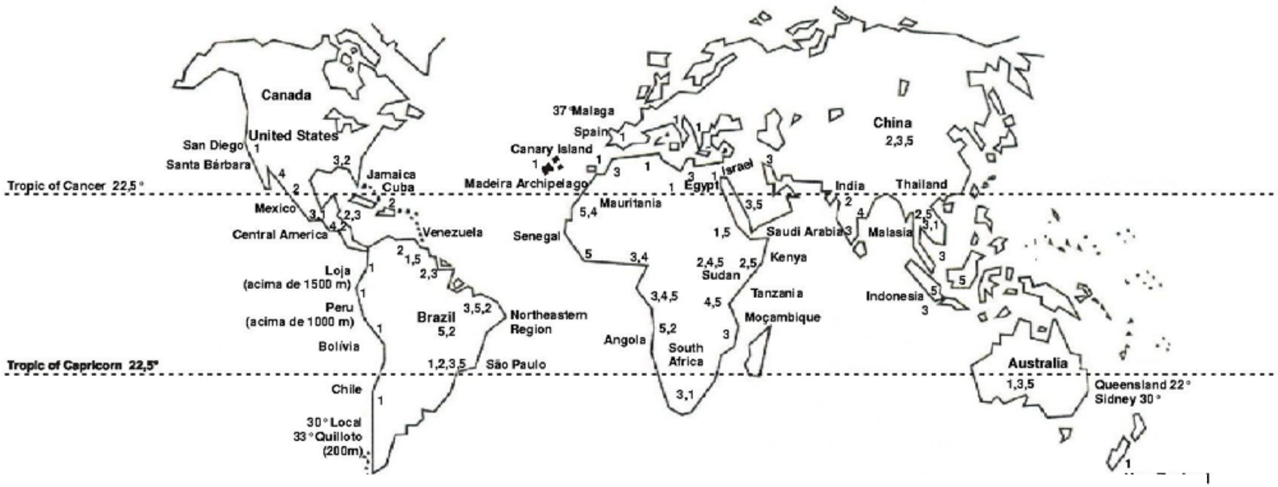
Although there is controversy about the origin of cherimoya, the majority of the literature (Fouqué, 1972; Ochse *et al.*, 1974; Popenoe, 1974 a) attributes the area of origin to the Andean Valleys of Ecuador, Peru and Chile, at altitudes of 1,600 to 2,000 m. The primary centre of diversity probably occurs there, corresponding roughly to Vavilov's South American centre. Hermoso *et al.* (1999) suggested a secondary centre of diversity in Central America, based on work by Perfectti (1995) using molecular markers.

Cherimoya is an ancient domesticated crop: seeds have been identified in archaeological sites in Peru and fruits are depicted on pre-Inca pottery (NRC, 1989). Wild populations can be found in Ecuador, Peru and Bolivia (Smith *et al.*, 1992) and the Loja area of SW Ecuador appears to be a centre of diversity of wild material.

The early Spanish explorers introduced cherimoya to Mediterranean countries, as well as to Asia, via Africa (Ochse *et al.*, 1974). The cherimoya was introduced to the USA in 1871 by Judge Ord, of Santa Barbara, California, from Mexico (Popenoe, 1974 a). Currently, Spain and Chile are the main producing countries and also distribute cherimoya germplasm around the world.

Soursop most likely originated in Central America, the Antilles or Northern South America, and is found in the Andean valleys in Peru, presumably as an ancient introduction. Spanish colonizers distributed it to other tropical regions of the world (Popenoe, 1939; Purseglove, 1968). The existence of several wild types of soursop in the Amazon region (Cavalcante, 1976) suggests that this may be a primary centre of diversity, but the types could be remnants from cultivated introductions. Wild populations of soursop are well known in the West Indies and on Barro Colorado Island, Panama (Croat, 1978; Smith *et al.*, 1992).

Figure 3-1. Global distribution and occurence of 5 annona species



1. Cherimoya (*Annona cherimola*); 2. Soursop (*Annona muricata*); 3. Custard apple (*Annona reticulata*); 4. Wild soursop (*Annona senegalensis*); 5. Sugar apple (*Annona squamosa*)

In south-eastern Brazil, cultivated soursop was introduced during the sixteenth century. Nowadays it is found in almost all Brazilian states, except in the southernmost states, where low temperatures and occasional snowfall do not allow the tree to grow and produce (Pinto and Silva, 1996). Soursop is now a popular fruit in Cuba, Mexico, Central America and throughout South America. It is also found in Sri Lanka up to elevations of 460 m, in China and many parts of Polynesia. In the USA it is grown in southern Florida.

Custard apple or bullock's heart is believed to have originated in the Antilles (Fouqué, 1972) and other parts of the circum-Caribbean region. From the Antilles, Spanish explorers may have distributed this species to Mexico, and certainly did to Asia and Africa. Primitive germplasm was transported by Native Americans and wild populations in Costa Rica probably represent this. Although widely distributed in the tropical world today, it is a fruit of little commercial value.

Custard apple is very commonly found in home gardens of coastal towns throughout tropical America. It is also cultivated in India, Sri Lanka, the Malay Archipelago, Polynesia, the Philippines, Australia and most of the countries of Africa. The vernacular name "custard apple" is usually applied to sugar apple in India.

There is no precise information on the origin and diversity of wild soursop. FAO (1983) states that this species is most widely distributed in Tanzania, Kenya and Mozambique, and in the Zanzibar and Pemba Islands, suggesting that eastern Africa may be the region of origin and diversity. In Sudan, this species is found where rainfall is greater than 500 mm, typically in tall-grass savannah areas. It is distributed across the Sahel in semi-arid to sub-humid areas. It also grows in Angola, Senegal and Mauritania (Vogt, 1995).

The sugar apple originated in lowland Central America, where it is indigenous. From there, it was distributed to Mexico and throughout tropical America. In the lowlands of Mexico it is found in a naturalized or wild state. It is grown from Central America southwards to northern South America, extending to north-eastern Brazil, where it is one of the most popular fruits. It is believed that it was first introduced into Brazil via Bahia state, in 1626, by Conde de Miranda, which explains the vernacular name in Brazil - *"fruta do Conde"*. It was later taken to the Philippines and Asia via the West Indies (Antilles) and the Cape of Good Hope (Popenoe, 1974 a; León, 1987).

In India, there is a very large, diverse population of sugar apple, and its commercial importance is so great that some botanists have considered it to be a native fruit of that country (León, 1987). However, this is a secondary centre of diversity, created during the last 500 years. Some of the arguments used by those who favour an Asiatic origin for this species include: the occurrence of common names for it in Sanskrit; the existence of large, apparently wild populations in several parts of India; and the presence of carvings and wall-paintings, maybe representing the fruit, in the ruins of ancient Muttra and Ajanta temples (Popenoe, 1974 a). In Asia, it grows not only in India, but also in south China, where it is known as fan-li-chi, or foreign lichi.

Safford, cited by Popenoe (1974 a), suspected that the name *"ata"* is not of American origin. He said that it may be from the Malayan name *"atis"*, meaning heart, and that it was carried to Mexico from the Philippines in early colonial days. Coronel (1994) cites the vernacular name *"atis"* in the Philippines.

In Cuba, the sugar apple ranks with mango as one of the favourite fruits and it is common in other islands of the West Indies. In the USA, it grows successfully in southern Florida but has never been grown to fruiting size in California (Popenoe, 1974 a).

Sugar apple and cherimoya have been hybridized and produced a new fruit called atemoya. The crosses were made by P.J. Webster in 1907 in Florida, for the USDA. However, crossing occurred naturally in the field in Australia in 1850 and again in Palestine in 1930 (NRC, 1989). The hybrid is in commercial production in Australia (where it is confusingly called custard apple), as well as the USA, Israel, South Africa, the Philippines and numerous parts of Central and South America. This hybrid is preferred because there appear to be no pollination difficulties. Nonetheless, major selection programmes from diverse seedling progenies have not been vigorously pursued in any major production area.

Chapter 4. Major and Minor Production Areas

A. C. de Q. Pinto

Statistics on minor fruits, such as *Annona* species, are unavailable in many countries, and where reported they often lack reliability, uniformity and continuity. Generally, production data relates only to plantation or orchard crops grown for sale for international markets, e.g. banana, grape and mango. Production of minor fruits from scattered trees used mainly for home consumption is not collected.

Some developed countries, such as Spain and Australia, have produced a body of technical knowledge on cherimoya production, which has contributed to better international marketing by these countries. Consequently, cherimoya is well known commercially, and has good production and export performance, so that it is more important in the external market and world consumption than soursop and sugar apple. These latter species have their major production areas in developing tropical countries, and they are produced mainly for internal markets, principally for consumption as fresh fruit or for processing. The custard apple and wild soursop, the less important annonas, have the smallest areas of production.

4.1 Major Production Areas

The estimated production area of cherimoya in the world in 1994 was 13,500 ha and, considering an average yield of 6 MT/ha, the total production was estimated as 81,000 MT. In Chile, the average production of cherimoya has been estimated at 25 MT/ha, which is 4 times higher than the world average (PROCIANDINO, 1997).

Commercial cherimoya production occurs mainly in Spain, Peru and Chile. Smaller production areas occur in some countries of Central America, Mexico, Israel and the USA (California).

Spain is considered the most important cherimoya producer in the world, with a cultivated area of 3,266 hectares in 1999 (Guirardo *et al.*, 2001, cited by Scheldeman, 2002). Granada is the major producing province, representing *ca.* 90% of the total area of cherimoya in Spain (Farré and Hermoso, 1997). However, Agustin (1997) commented that the production area of cherimoya in Spain was 1800 ha, which is approximately 55% of that reported by Guirardo *et al.* (2001) in the year of 1999. Up-to-date data show a total cultivated area of 3,090 ha of cherimoya in Spain, with 99% under irrigation, which suggests a total production of approximately 29,000 MT (Gómez, G.B., Embassy of Spain in Brazil, July 2000, personal communication).

Peru had an area of 1975 ha in 1998 producing 14,606 MT and a yield of 7.4 MT/ha. The Nor Oriental del Marañon is the most important producing province with 665 ha of cultivated cherimoya (Vargas, A.I., Oficina de Información Agraria del Peru, July 2000, personal communication).

Chile had 785 ha in production in 1996 (Agustín, 1997). In 1998, 1,152 ha were reputed to be in production (Furche, C., Director of the Oficina de Estudios y Politicas Agrarias del Chile - ODEPA, July 2000, personal communication), which represents a 68% increase in two years.

Carlos Furche indicated that in the same year (1998), Peru had an area of 1,800 ha, Bolivia 1,000 ha, Ecuador 700 ha and Australia 500 ha Crane and Campbell (1990) and Grossberger (1999) commented that California had 100-120 ha of cherimoya, with an estimated production of 453 MT in the 1989-90 season. Crane and Campbell (1990) also noted that Thailand, the Dominican Republic and Costa Rica were important exporters to the USA.

Soursop is cultivated in many tropical areas in countries such as Angola, Brazil, Colombia, Costa Rica, Cuba, Jamaica, India, Mexico, Panama, Peru, USA (Porto Rico), Venezuela and S.E. Asia (Pinto and Silva, 1996). There is a dearth of production data for most of the South, Central and North American countries, except Mexico, Venezuela and Brazil, which seem to be the major producing countries of this species.

Mexico is the most important soursop producing country in the Americas and in 1990 had an area of 598 ha, with production of 4,087 MT. Rebollar-Alviter *et al.* (1997) estimated the cultivated area in Mexico at 4,890 ha in 1996, which means that in six years the cultivated area had increased nine fold. On the other hand, Hernández and Angel (1997) stated that the Mexican area planted to soursop in the same year was equivalent to 5,915 ha with a production of 34,900 MT, easily the largest in the world. However, the yield/ha had decreased from 6.8 MT/ha in 1990 to 5.9 MT/ha in 1996. Nayarit, with approximately 380 ha, is the most important province for soursop production in Mexico.

Venezuela had a cultivated area of 3,496 ha in 1987, with a total production of 10,096 MT. Zulia is the most important producing state (Diego, 1989).

Brazil, with approximately 2,000 ha, has an estimated production of 8,000 MT of fruits per year (average of 4 MT/ha), almost totally devoted to the internal market. Because of its climatic conditions, the Northeast is the major production region, representing around 90% of the total production of soursop. Recent government support for the development of agroindustry on small farms (1 to 5 ha), through processing fruits by freezing pulp, and making jellies, syrups and ice creams, has promoted the expansion of soursop production in Brazil, especially in the Northeast. Ceará state, in the Northeast, with an estimated area greater than 500 ha (Bandeira and Sobrinho, 1997), is the most important producer of soursop in Brazil, largely because many juice industries operate in that region.

The cultivated area of soursop in Peru was estimated at 443 ha in 1998, with a total production of 3,262 MT and a yield of 7.4 MT/ha (Dr. Antonio Isaias Vargas, Oficina de Información Agraria del Peru, July 2000, personal communication). Although Venezuela and Brazil have larger production areas than Peru, this country has a larger yield/ha.

Although sugar apple production data are scarce, the information collected shows that the potential for expanding the sugar apple market is high in many countries. This species is grown commercially in the West Indies and Dominican Republic, the USA (Florida), the Middle East, India, Malaysia and Thailand (Crane and Campbell, 1990). Although it is still considered a backyard fruit used mainly for domestic consumption in the Philippines, this country's production is considered one of the largest in the world. The Bureau of Agricultural Economics of the Ministry of Agriculture reported that in 1978 there were 2,059 ha of sugar apple in the Philippines, with a production of 6,262 MT of fruits. Western Visayas (975 ha with 1,844 MT) and Southern Tagalog (390 ha with 1,302 MT) were the largest producing regions (Coronel, 1994).

In Brazil, sugar apple production is concentrated in Alagoas and São Paulo States. The area of production of sugar apple in Alagoas State appears to have increased greatly, since it was estimated at 500 ha in 1995 (Albuquerque, 1997), and 814 ha in 1996 (Dr. Eurico Lemos, Federal University of Alagoas-UFAL, July 2000, personal communication). This increase was due to increasing demand in the north-eastern market. São Paulo State had, in this same year, approximately 240,000 sugar apple and atemoya trees (Piza Jr. and Kavati,1997), which is an estimated production area of 480 ha and has been expanding. Like soursop, the development of agroindustry and the reasonable price of fresh fruits have encouraged sugar apple growers to expand cultivated areas. Currently, the sugar apple and atemoya areas are moving into north-eastern and northern Minas Gerais State, mainly to the major irrigation projects, where small fruit growers produce excellent fruits and sell them to retailers in the Brasilia and Belo Horizonte markets.

4.2 Minor Production Areas

Several factors impede the production and marketing of the lesser known annonas, and scattered cultivation and harvesting from the wild continues, e.g., wild soursop in Africa and custard apple in Brazil. Other important factors are management of pollination, pests and diseases, financial support for growers, highly seasonal harvesting period, organoleptic quality, short shelf-life, other commercial opportunities and, finally, marketing. Each minor production area is limited by one or more of these factors.

Carlos Furche (Diretor of the Oficina de Estudios y Politicas Agrarias del Chile - ODEPA, July 2000, personal communication) indicated that Israel, with 50 ha, represents one of the important countries with minor production of cherimoya. Palacios Rangel and Cano Garcia (1997) state that there was a small area of cherimoya in Mexico (31 ha in 1990).

Portugal (Madeira) had an area of 85 ha of cherimoya in 1996 (Nunes, 1997). This area was very important in supporting Portuguese demand for this fruit. In Italy, an area of 30 ha under cherimoya has been reported, located in the coastal part of Calabria (Monastra, 1997).

There are no official statistics on the production areas of cherimoya in Brazil, although Paraná, São Paulo and Minas Gerais States have small areas with appropriate microclimates and altitudes above 1,400 m. Generally, these cherimoya areas are cultivated by fruit growers of European origin settled in Brazil. Bonaventure (1999) stated that cherimoya and atemoya occupy an area of 80 ha in Brazil. However, the cultivated area of atemoya in Northeast of Brazil is expanding very quickly. The reason for increasing the area planted to cherimoya and atemoya is their excellent organoleptic qualities, which make these fruits ideal for export.

In Mexico, sugar apple was produced in an area of 12 ha, with a total production of 73 MT, in 1990, and an estimated yield of 6 MT/ha. Egypt is also a representative of the minor areas of production, since the total acreage of cherimoya and sugar apple in that country in 1991 was 50 ha, with yield of about 170 MT of fruit (Mansour, 1997).

There are no data on cultivated areas and production of custard apple and wild soursop. Custard apple is grown in small backyard orchards or harvested from the wild in most of its North, Central and South American distribution, while the wild soursop is found scattered as wild or dooryard plants in many

African countries. Custard apple has been widely spread around the tropics and has become a prized backyard plant in many parts of Africa.

In India, sugar apple is cultivated in rain-fed orchards mainly in Maharashtra, Gujarat, Andhra Pradesh, Karnataka, Madhya Pradesh, Uttar Pradesh, Bihar, Assam and Orissa (Singh, 1992) and in the 1980s the area was estimated to be 44,100 ha (Pareek, 1985). Few of the plantings are commercial except for areas of Gujarat. Most fruits come to market from semi-wild forests of the Deccan Plateau where sugar apple has gone wild.

4.3. Demand

(see also section 12.2)

There has been little market research on international fruit markets for annonas. The experience with cherimoya and the sale of improved types (swollen skin, round shape, good flavour, juiciness, low seed content, resistant to bruising and adequate packing: NRC, 1989) shows small but steady increase in demand in Chile, Argentina, Portugal, Spain, the USA, the UK, France and Japan.

Chapter 5. Ecological Factors

M. C. R. Cordeiro and A. C. de Q. Pinto

5.1 Physiography and climate

The Annonaceae contains species which are mostly tropical and subtropical, although some species can be grown in temperate climates (Donadio, 1997; Silva and Silva, 1997). In general, the annonas grow at a range of altitudes, and those with the widest adaptation to altitude are also those with the widest adaptation to latitude. No photo-period responses have been reported (Nakasone and Paull, 1998).

Most annonas do not adapt to low temperatures. However, highland species, such as cherimoya, wild soursop and, to some extent, custard apple, are better adapted to cold weather than the lowland soursop and sugar apple.

Heavy shading reduces fruit set in annonas. Consequently, appropriate pruning and spacing are very important and should be adjusted to each species (see Chapter 10). Rainfall influences the efficiency of pollination (Nakasone and Paull, 1998), generally reducing it significantly when rains occur during peak flowering periods.

Wind is a factor that effects annona cultivation, often severely, as it can reduce humidity around the stigma and reduce pollination. Wind can also break branches, especially if laden with fruit, and fruits are sensitive to dry winds (Nakasone and Paull, 1998). Cherimoya, for example, is reported to be especially sensitive to dry winds, which can cause fruit loss (Belotto and Manica, 1994).

Cherimoya is reported to grow at altitudes between 900 and 2500 m in its natural range (Popenoe, 1939; Zayas, 1966; Fouqué, 1972; Belloto and Manica, 1994) on plateaus and in mountain valleys in subtropical areas with a dry, cool climate (the Andes in Peru), and is cultivated mostly in dry, cool regions (Fouqué, 1972). Because it is adapted to high altitudes, it can grow and yield well in the subtropics - cherimoya is cultivated around the Mediterranean (Spain, Italy, Egypt, Israel), and southern coastal California and Portugal, as well as in South Africa, Argentina and Chile. In Spain, it is cultivated along the southern 'Sun coast', especially in Malaga and Granada. Cherimoya is now cultivated between latitudes 37° North and 37° South (Bonaventure, 1999).

Cherimoya is not adapted to high humidity regimes and it is reported that the dry season favours fruiting (Popenoe, 1939). In Mexico, the cherimoya is cultivated in three types of climate: (A)C(m)(w), (A)C(w2) and (A)C(w), in the Köppen climate classification system. The first is considered subtropical, with a high rainfall regime in the summer (mean of 1692 mm/year in the summer and greater than 5% of this in winter); the other two types are considered subtropical, but with less abundant rainfall (1,047 to 1,182 mm/year in summer and less than 5% of this in winter) (Agustín and Angel, 1997). Water stress just before flowering can increase flower production (NRC, 1989).

The best temperatures for cherimoya cultivation are 18 to 22°C in the summer and 5 to 18°C in the winter (Belotto and Manica, 1994; Nakasone and Paull, 1998). Consequently, it is considered to be tolerant of relatively low temperatures (but is less hardy than avocado or orange: NRC, 1989), and needs chilling periods (Nakasone and Paull, 1998). It is sensitive to high temperatures.

Soursop is cultivated from sea level to 1,200 m altitude (Zayas, 1966; Pinto and Silva, 1994) and between latitudes 27° North and 22.5° South. Its northern extremes include southern Florida (USA), Culiacan, Chiapas, Veracruz and Yucatán (Mexico), Cuba, and the south of China, while it's southern extreme is in central Brazil.

Soursop is the most tropical annona (Popenoe, 1939; Nakasone and Paull, 1998) and is cultivated mainly in tropical moist regions, classified as A in the Köppen system (Pinto and Silva, 1994). All months have average temperatures greater than 18°C and annual precipitation exceeds 1500 mm. Tropical wet (Af) climates have year round precipitation with minor monthly temperature variations (less than 3°C). Tropical monsoon (Am) climates have annual rainfall equal to or greater than Af, but concentrated in the 7 to 9 hottest months, with water deficits in the dry season. Soursop probably originated somewhere in these climate types. Tropical savanna (Aw) climates have an extended dry season during the winter, with less than 1,000 mm precipitation during the wet season (Ayoade, 1991).

In Brazil, soursop is cultivated in warm and humid to semi-arid climates (the latter with rainfall near 1,000 mm/year), but only fruits if irrigated in the semi-arid regions (Pinto and Silva, 1994). The mean temperature in the semi-arid winter is greater than 18°C. Nakasone and Paull (1998) reported that 15 to 25°C is the minimum temperature range for good growth, while Belotto and Manica (1994) reported that the temperature range for its establishment is 18 to 29°C. Soursop is reported to be cultivated between 21 and 30°C and is susceptible to abrupt changes in temperature, especially if they go below

12°C (Pinto and Silva, 1994). Consequently, even though the literature is variable, it is clear that soursop is sensitive to colder temperatures. Additionally, it does not tolerate dry, cold winds. It is the least hardy of the annonas (NAS, 1975).

Soursop is reported to require high light intensity to grow (Villachica, 1996), although the wild populations reported by Cavalcante (1976) in Amazonia are apparently shade tolerant. This contrast suggests that it is a completely domesticated species, as proposed by Clement (1999).

Custard apple is the most widely cultivated annona at low to medium elevations (0 to 1,500 m) (Popenoe, 1952). It grows between latitudes 25° North and South, and is reported to be found in almost all tropical areas of the world (Zayas, 1966; Nakasone and Paull, 1998).

Custard apple cultivation is possible in both humid and semi-arid climates (Popenoe, 1952), although it is reported to prefer humid climates (Fouqué, 1972). The average temperature recommended for custard apple cultivation is not reported anywhere, but Fouqué (1972) affirms that it is sensitive to long periods of cold.

Wild soursop is adapted to various altitudes, being cultivated from 0 to 1,800 m in Kenya and from 0 to 2,400 m in other parts of East Africa (FAO, 1983). Wild soursop is still essentially restricted to Africa, between latitudes 22.5° North and 22.5° South. It appears to have adaptation to very low to moderately high rainfall regimes, occurring generally in areas with 600 to 1,200 mm (but 716 to 2,029 mm in Tanzania; FAO, 1989), while across Africa requirements are for more than 600 mm annual rainfall. It can withstand a relative humidity as low as 44% at midday. The best temperatures for wild soursop growth are between 16°C and 30ºC (FAO, 1983).

Sugar apple is usually cultivated in the lowlands, although in Cuba it is reported in cultivation up to 900 m (Zayas, 1966). Sugar apple is a lowland tropical or marginally subtropical species, growing between latitudes 22.5° North and South.

Sugar apple is native to the warmest and driest places in Central America but is also reported yielding well in humid regions (Popenoe, 1952). It is also frequently reported in cultivation in semi-arid climates, such as north-eastern Brazil (Belotto and Manica, 1994). It is relatively drought-tolerant and does not fruit well in high rainfall regimes (Nakasone and Paull, 1998).

Sugar apple is more adaptable to low temperatures than soursop and more tolerant of high temperatures than cherimoya (Belloto and Manica, 1994).

Fouqué (1972) reported that this species is also sensitive to long periods of cold.

5.2 Soil

Soil characters are extremely important for annona cultivation, the most important factor being drainage. No annona grows well in soils with drainage problems. High water content in the soil causes root diseases (Nakasone and Paull, 1998). In general, annonas are not too demanding of soil type (Nakasone and Paull, 1998), but produce better in fertile, well aerated, well drained, deep soils rich in organic matter (Zayas, 1966).

The best soil pH for cherimoya growth is around 6.0 to 6.5 (Villachica, 1996). In Mexico, the best physical/chemical composition for cherimoya cultivation was pH 6.5, with an organic matter content of 6.2%, nitrogen of 0.25%, phosphorus of 2.8 ppm, and potassium of 0.79 meq/100 g (Agustín and Angel, 1997). Cherimoya grown in soils which are poor in calcium, phosphorus or rich in aluminium does not produce well.

Soursop prefers deep soils with good aeration (Melo *et al.*, 1983; Ledo, 1992) and can be grown on a wide variety of soil types. Pinto and Silva (1994) reported the best soil pH to be 6.0 to 6.5, while Zayas (1966) reported that it is between 6.0 and 7.5, and Belotto and Manica (1994) reported that it is between 5.5 and 6.5.

Custard apple is well adapted to unfavourable soil conditions. It can grow in soils with pH 5.0 to 8.0. Because of this high tolerance to variable soil types, it is reported to be a good rootstock for cherimoya and soursop (Popenoe, 1952; Zayas, 1966).

Wild soursop occurs in a variety of soil types (FAO, 1983), but no precise information on limiting conditions is available. FAO (1989) mentions its occurrence on coral rocks dominated by sandy loam soils (Tanzanian coast), stony and ferruginous soils, and gravel banks. It is noted for regenerating on areas that have been burnt, taking advantage of the nutrient flush. As a component of natural or semi-natural vegetation, it occurs in grasslands, thickets and open woodlands.

Sugar apple grows on a wide range of soils from sandy to heavy clays. It is relatively shallow-rooted and can tolerate salinity to a certain degree. It is typical of stony soils along rivers, along the coast and on fallow land, as well as on hills and slopes (Von Maydell, 1986).

5.3 Phenology

Flowering and fruiting seasons differ among annonas, depending upon the geographic location and climate where they are cultivated. Phenology is important for planning management, harvesting and commercialisation. In general, the period from pollination to fruit maturity averages 5 to 6 months.

Annonas adapted to the highest latitudes or altitudes (like cherimoya) are described as responding to typical seasonal regimes (autumn, winter, spring and summer). In general, winter is the colder and drier season, and summer the warmer and wetter one. Most annonas, however, are cultivated in tropical areas, where temperatures do not vary very much and the seasons are divided into rainy and dry seasons (see Table 5.1).

The fruiting season of cherimoya in Spain (37° North) occurs at the end of the dry season (September to October). It is less frequent, but possible, to harvest it in the wet season (November to December) (Farré and Hermoso, 1997). On the other hand, in Mexico (22.5° North), cherimoya flowering and fruiting occur in dry and wet seasons (flowering: February to May and fruiting: March to October), respectively. Fruit development takes around 6 months (Agustín and Alviter, 1996).

Although soursop tends to flower and fruit continuously, there are fruiting seasons. The fruiting season in Florida (25° North) occurs in the wet season (June to September) (Mowry *et al.*, 1941). In Mexico, flowering occurs in the dry season (December to January) and fruiting continues into the wet season (May to June). In Mexico, a second flowering can also occur in June to July (wet season) with fruiting from November to January (dry season). In Brazil (Brasília at 15° South), flowering occurs in the wet season (November to February) and fruiting during the beginning of the dry season (April to July). In Puerto Rico and the Caribbean region (15-20° North), the soursop fruiting season extends from February and March (dry season) to September (wet season), with a peak in the wet season (June to August) (Bueso, 1980). This annona requires around 6 months for fruit development (Pinto, A.C.Q., Embrapa Cerrados, July 2003, personal communication).

Custard apple matures in Florida during late winter and early spring (dry to wet season) (Mowry *et al.*, 1941). In Mexico, its flowering occurs in the transition from the wet to the dry season (August to November) and fruiting is in the dry season (March to April).

In Tanzania (5° South), wild soursop flowers during the beginning of the wet season (October to December), and along the coast in the wet season (December to February), while fruit maturity occurs during the rainy season (the peak of rain is in April) (FAO, 1983). In western and eastern Tanzania, fruiting takes place in the wet season, in western Tanzania from December to March and in eastern Tanzania from March to May.

In Florida, the sugar apple fruiting season begins in mid summer (wet seson); its ripening is irregular, lasting 3 months (Mowry *et al.*, 1941). In the Philippines (15-20° North), fruiting occurs during the beginning of the rainy season (summer). In India (10-22.5° North), fruiting also occurs in the wet season (August to mid September) and can occur from October to November (the end of the wet season) (Coronel, 1994). In Mexico, flowering occurs at the end of the dry season (March to May) and fruiting at the end of the wet season (September to November). In Brazil (Brasília), flowering occurs at the end of the dry season (March to May) and fruiting in the wet season (December to January). In Brasília, flowering can be induced in the wet season (December) and to fruiting in the dry season (May) (Pinto, A.C. de Q., Embrapa Cerrados, July 2003, personal communication).

Table 5-1. A quick reference guide to monthly rainfall (mm) in some important *Annona* production areas

Location	**Species grown**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Spain (Málaga)	Cherimoya	203	203	178	229	152	76	25	25	76	203	229	229
Florida (Miami)	Soursop, sugar apple, custard apple	51	53	61	76	150	224	152	198	216	178	79	46
Caribbean (Puerto Rico)	Cherimoya, soursop, sugar apple, custard apple	76	56	58	94	155	112	114	135	135	140	147	119
Mexico (Mexico City)	Cherimoya, soursop, sugar apple, custard apple	8	5	13	20	48	107	130	122	109	43	15	8
India (Mumbai)	Sugar apple, cuatard apple	0	0	0	0	13	566	650	488	356	89	5	0
Ecuador (Quito)	Cherimoya	114	130	152	175	124	48	20	25	79	130	109	104
Peru (Lima)	Cherimoya	0	0	0	0	0	3	5	3	3	3	0	0
Brazil (Brasilia)	Soursop, sugar apple	553	457	457	305	152	50	50	76	203	406	533	610
Tanzania (Dar-es-Salaam)	Wild soursop	71	64	130	269	183	33	28	25	28	48	84	94

During the wet season the average precipitation is 203 mm in Málaga, 159 mm in Miami, 114 mm in Puerto Rico, 4 mm in Lima, 83 mm in Mexico City, 471 mm in Brasilia, 130 mm in Quito, 310 mm in Mumbai and 128 mm in Dar-es-Salaam.

Chapter 6. Properties

M. C. R. Cordeiro and A. C. de Q. Pinto

6.1 Chemical properties

Leaves, roots, bark, fruits and seeds of annonas contain numerous bioactive chemical substances, such as acetogenins, alkaloids, terpenes, flavonoids and oils. At least some acetogenins have insecticidal, cytotoxic, antitumoral, antifeedant, antibacterial, immuno-suppressant, pesticidal or antihelminthic properties (Rupprecht *et al.*, 1990). Alkaloids, terpenes and flavonoids are potentially useful in medicine. A list of some of the chemical compounds present in annonas is given in Appendix A.

Acetogenins isolated and characterized from different annonas have monotetrahydrofuran (MTH) or bis-tetrahydrofuran (bis-THF), with adjacent and nonadjacent bis-THF systems, in their structures (Cortés *et al.*, 1993 a, b; Duret *et al.*, 1994). These substances can be extracted from seeds using ethanol, methanol or petroleum ether (Rupprecht *et al.*, 1990).

Cherimoya: At least 6 types of acetogenins have been identified in cherimoya roots (Cortés *et al.*, 1993 b; Duret *et al.*, 1994) and some of them exhibit cytotoxic and antiparasitic activities. Three alkaloids have been identified from the leaves and stem (Fresno and Cañavate, 1983). The stems also contain acetogenis, amides, kauranes, purine and steroids (Chen *et al.*, 1998). Ethanol extracts of cherimoya seeds also have bioactive acetogenins (Cortés *et al.*, 1993 a, b; Sahpaz *et al.*, 1996; Chen *et al.*, 1999) and alkaloids (Fresno and Cañavate, 1983). Moreover, cherimoya seeds have oils containing oleic (43%), linoleic (35%), palmitic (12%), stearic (8%), linolenic (1%) and traces of arachidic acids (Lizana and Reginato, 1990).

Soursop: Roots, stems and leaves of soursop have different kinds of acetogenins. Some of them have antitumoral activities and act preferentially against human cancer cell lines (Wu *et al.*, 1995 a, b, c; Zeng *et al.*, 1996; Kim *et al.*, 1998 a, b). Acetogenins found in soursop leaves and stems are used to prepare extracts that have insecticidal activities. These compounds are similar to anonins and muricins (Pinto and Silva, 1994). Additionally, biogenetic intermediaries of acetogenins are found (Gleye *et al.*, 1997). In soursop seeds there are amyloids (Kooiman, 1967), acetogenins (Myint *et al.*, 1991; Roblot *et al.*, 1993; Philipov *et al.*, 1994; Pinto and Silva, 1994; Wu *et al.*, 1995 b; Rieser *et al.*, 1996; Yu *et al.*, 1998), and unsaturated and saturated fatty acids (Bueso, 1980; Castro *et al.*, 1984; Pinto and Silva, 1994). The main types of unsaturated fatty acids found in soursop seeds are oleic (41%), linoleic (33%) and palmitoleic (2%) acids, together making up 76% of total fats. The saturated fatty acids are palmitic (19%) and stearic (5%), together making up 24% (Castro *et al.*, 1984; Pinto and Silva, 1994).

Custard apple: In custard apple leaves and stem bark there are acetogenins that have cytotoxic activity and potential use in cancer treatments (Hisham *et al.*, 1994). Custard apple seeds have bioactive acetogenins (Chang *et al.*, 1998), diterpenoids, alkaloids and n-fatty acyl tryptamines as structural components (Maeda *et al.*, 1993). Diterpenoids are represented by kaurane and kaurene types (Maeda *et al.*, 1993). Dopamin is also present in seeds (Maeda *et al.*, 1993). In fruits, there are essential oils which account for their characteristic perfume and flavour. In stem and root barks there are amino acids and ent-kaurenoids (Fatope *et al.*, 1996).

Wild soursop: The most important chemical constituents found in leaves of wild soursop are aliphatic ketone, alkanes, alkanols, fatty acids, flavonoids, sterols, monoterpenoids and sesquiterpenoids (Langason *et al.*, 1994; You *et al.*, 1995). Unidentified bioactive substances found in wild soursop leaves reduce the feeding activity of insects (Abubakar and Abdurahman, 1998). There are also alkaloids, such as aporphine and (-) roemerine, with cytotoxic activity (Cassady, 1990). These enhance the cytotoxic response mediated by vinblastine in multidrug resistance to KB V1 cells and interact with P glycoproteins (You *et al.*, 1995). Seeds also contain cytotoxic acetogenins (Sahpaz *et al.*, 1996).

Sugar apple: Sugar apple leaves are rich in aporphines (Salluja and Santani, 1990) and fruits contain diterpenoids. Bark contains acetogenins (Chao-Ming *et al.*, 1997; Hopp *et al.*, 1997; 1998). Squamotacin (similar to bullatacin) and molvizarin acetogenins have cytotoxic activity against prostate tumour cell lines (Hopp *et al.*, 1996). Fatty acid composition of seeds is: stearic acid (9.3%), oleic acid (37%), linoleic acid (10.9%), arachidic acid (3.3%) and isoricinoleic acid (9.8%) (Leal, 1990). The seeds also contain terpene hydrocarbon essential oils, such as alpha pirene, beta pirene, limorene, beta farnesene and trans orimene (Leal, 1990).

Sugar apple seeds are also rich in acetogenins, diterpenes and saponin (Salluja and Santani, 1990; Li *et al.*, 1990; Nonfon *et al.*, 1990; Mukhopadhhyay *et al.*, 1993; Chao-Ming *et al.*, 1997; Hernández and Angel, 1997). The most important acetogenins are anonins or anonacins: asimicin, annonastatin, bullatacin, bullatacinone and squamocin. These substances have toxic effects when eaten by insects and can inhibit insect growth, development and reproduction. The cytotoxic anonins cause 70% mortality of *Aedes aegypti* with a concentration of only 10 ppm. They act by inhibiting respiration (Londershausen *et al.*, 1991 a, b). Asimicin is effective against insect pests, such as *A. aegypti, A. vittatum, A. gossypii, Colliphora vicina, Epilachna varivertis, Tetranychus urticae*, and the nematode *Caenoharbiditis elegans*. This compound has 256 known isomers, of which bullatacin is the most toxic (Li *et al.*, 1990). Bullatacin causes 80% mortality of *A. aegypti, A. gossypii* and *Diabrotica undecimpunctata* when in concentrations of 1, 10 or 24 ppm, respectively. Another powerful isomer is bullatacinone (Hernández and Angel, 1997). Some of these acetogenins could be used as insect repellents (Hernández and Angel, 1997).

6.2 Pulp properties

Annona pulps are useful foods because they contain proteins, fatty acids, fibre, carbohydrates, minerals and vitamins (Bueso, 1980; Leal, 1990; Lizana and Reginato, 1990). However, annona fruits do not contribute many calories to the diet (Kalil *et al.*, 1979).

Nutrients in the diet are important because they have many biological functions, such as providing energy and matter for growth, and regulating biological reactions. These functions are modulated by the quality and quantity of the carbohydrates, lipids, proteins, minerals and vitamins in food. Nutrients are divided into protectors and non-protectors. Protector nutrients are essential to protect organisms against pathogens, while non-protector nutrients provide only calories. Milk, meat and egg (principally because they are rich in proteins), and vegetables and fruits (mainly because they are rich in minerals and vitamins) are examples of foods that provide protector nutrients (Evangelista, 1992).

The most important factors for a healthy diet are: (1) nutrients must be ingested in sufficient quantity and quality to provide nutritional and caloric balance. Sex, age and physical activity effect requirements for nutrients. For example, a 65 kg person, with strong physical activity, needs 4,000 kcal/day in the diet, while a person with strong intellectual activity needs only 3,000 kcal/day. (2) The balanced diet must provide a harmonious combination of proteins, carbohydrates, lipids, minerals and vitamins. For example, a normal person (with normal activity) needs 10-15% proteins, 25-35% lipids and 50-60% carbohydrates in the diet (all percentages are related to total caloric intake per day). So, if we consider that 1 g of protein, lipids or carbohydrates gives 4, 9 and 4 kcal, respectively (in a 2,800 kcal diet), the total diet must have approximately 70-105 g protein, 77-103 g lipids and 350-420 g carbohydrates to be well balanced. Animal or plant protein, calcium and vitamin D are also very important, but plant proteins do not have all the essential amino acids for human diets (Kalil *et al.*, 1979).

The nutritional value of annonas is not very high because their nutrient content is not high, contrary to some assertions in the literature. The carbohydrate content is reasonable and explains why some authors have referred to annonas as being fruits with high caloric value. Although the pulp is not nutritionally important, it is flavourful and is reasonably rich in minerals and vitamins, making it an agreeable input to a healthy diet.

Cherimoya, soursop and sugar apple are the most widely consumed species and, consequently, more is known about their nutritional composition. The chemical-nutritional content of custard apple is only reported by Wu Leung and Flores (1961) and Zayas (1966). Even less is known about the chemical-nutritional content of wild soursop, except for its high content of vitamin C and moderate levels of minerals (FAO, 1988). Known chemical composition of 4 species is shown in Table 6.1 and should be referred to as an adjunct to the text below.

Cherimoya is commonly eaten fresh as a dessert fruit. It can also be pureed and used as a sauce. In Chile, it is commonly used for ice cream. The flesh is white, melting in texture, and moderately juicy. The flavour is sweet and delicate, suggestive of pineapple and banana. The edible portion corresponds to 60% of the fruit weight. The physical-chemical analysis of the pulp varies among varieties and according to the horticultural practices and the climate where it is cultivated. In general, the pulp carbohydrate content is high, while acidity is low (Table 6.1).

The sugar content represents a mix of fructose, glucose (11.75%) and sucrose (9.4%). The fibre combines cellulose, hemicellulose, lignin and pectic substances. The degree of ripening does not interfere in this proportion, suggesting that fibre content is determined early in ontogeny. The protein percentage is reported to be the highest among commercially important annonas (Popenoe, 1974 a), but this is not very important nutritionally. Various volatile hydrocarbons, such as esters, alcohols, carbonyls and other compounds, are responsible for pulp flavour and aroma (Idstein *et al.*, 1984). These compounds could be used to flavour processed foods based on annonas. The vitamin A content is low, but it is a good source of thiamine, riboflavin and niacin (NRC, 1989).

Soursop pulp is considered to be aromatic and exotic, and is consumed mostly after processing into cold beverages or sometimes fresh. The edible portion constitutes 67.5% of total fruit weight (Bueso, 1980). The characteristic flavour of this fruit is produced by amyl and geranyl caproic acids (Bueso, 1980; Pinto and Silva, 1994). The processed pulp is used to prepare juices and ice creams (Pinto and Silva, 1994). In Cuba, the pulp is processed to prepare an alcoholic drink called *champola* (Popenoe, 1974 b). The most important sugars are fructose (1.8%), glucose (2.3%) and sucrose (6.6%). The most common acid in its pulp is citric, with some malic and, less commonly, isocitric acid. Soursop fruit contains vitamins A and B_5. Also, it is the only annona with tannins in its pulp (Castro *et al.*, 1984). It was suggested that pectin in the fruits could become an important by-product (NAS, 1975), but this has not been developed.

Custard apple flesh is creamy yellow, rich and sweet, with low acidity (Wester, 1913). However, its flavour is not considered comparable to that of cherimoya or sugar apple. Wu Leung and Flores (1961) reported that the edible part of custard apple is 45%, of which 78.6 g/100 g is water, which is similar to Zayas' (1966) report. As in other annonas, other components are of low to moderate nutritional importance.

Wild soursop flesh is scant, but sweet and aromatic (Wester, 1913). It has a white pulp and a pleasant pineapple-like odour (FAO, 1983). No physical-chemical composition data were reported in the literature available to us.

Sugar apple pulp is slightly granular, creamy yellow or white, sweet, with a good flavour and low acidity (Mowry *et al.*, 1941). It is considered the sweetest of the annona fruits (FAO, 1990) and is generally consumed fresh as a dessert fruit. The edible portion is 28-37% of the total fruit weight; seeds correspond to 31-41% and rind to 23-40% (Leal, 1990). The carbohydrates present in the pulp are fructose (3.5%), sucrose (3.4%), glucose (5.1%) and oligosaccarides (1.2-2.5%).

Table 6-1. Chemical composition of 100 g of edible pulp of cherimoya, custard apple, soursop and sugar apple fruits

Components	Cherimoya	Custard apple	Soursop	Sugar apple
Water (g)	77.3±3 (74.6-83.3)	75.8±2.8	81±2.5 (77.9-81.7)	72.6±2.4 (68.6-75.9)
Proteins (g)	1.6±0.6 (1.0-2.9)	1.85±0.05	1±0.55 (0.69-1.7)	1.6±0.8 (1.2-2.4)
Lipids (g)	0.3±0.2 (0.1-0.5)	0.35±0.15	0.6±0.3 (0.3-0.8)	0.4±0.3 (0.1-1.1)
Carbohydrates (g)	18.42±4 (11.7-22.0)	18.7	17.25±0.1 (16.3-18.2)	19.6±1 (18.2-26.2)
Fibre (g)	1.64±0.5 (1.0-2.0)	2.55±0.35	0.86±0.1 (0.78-0.95)	1.4±0.6 (1.1-2.5)
Total acidity (g)	0.58±0.19 (0.39-0.77)	-	1.0±0.3 (0.7-1.3)	0.1
Ash (g)	0.7±0.1 (0.6-1.0)	0.95±0.15	0.61±0.2 (0.4-0.86)	0.7±0.1 (0.6-1.3)
Energy (calories)	68.6±13.4 (56-101)	75	65±5 (64-71)	96±10 (86-114)

Components	**Cherimoya**	**Custard apple**	**Soursop**	**Sugar apple**
Calcium (mg)	27.14±5 (21.7-34.0)	24	15±7 (8.8-0.22)	26.2±6 (17-44.7)
Phosphorous (mg)	35.2±18 (30.2-47.0)	26	28±1 (27.1-29)	42±14 (23.6-55.3)
Iron (mg)	0.6±0.2 (0.4-0.8)	1.0	0.7±0.1 (0.6-0.82)	0.8±0.5 (0.3-1.8)
Vitamin A (mg)	-	Traces	14.45±5.45 (8.9-20)	0.005±0.001 (0.004-0.007)
Vitamin B_1 (mg)	0.09±0.03 (0.06-0.12)	0.07	0.07±0.01 (0.06-0.077)	0.1±0.01 (0.10-0.11)
Vitamin B_{12} (mg)	0.12±0.2 (0.11-0.14)	0.12	0.08±0.035 (0.05-0.12)	0.13±0.05 (0.057-0.167)
Vitamin B_5 (mg)	0.8±0.2 (0.6-1.02)	0.7	1.2±0.3 (0.89-1.52)	0.9±0.3 (0.65-1.28)
Ascorbic acid (mg)	11.5±5.5 (4.3-17)	30	19.4±3 (16.4-22)	37.38±4.62 (34-42.2)
Tannins (mg)	±0	±0	85.30	±0

Sources: (Wu Leung and Flores, 1961; Zayas, 1966; Bueso, 1980; Castro *et al.*, 1984; Leal, 1990; Lizana and Reginato, 1990). Means ± standard deviations.

Chapter 7. Uses

M. C. R. Cordeiro, A. C. de Q. Pinto and S. R. M. de Andrade

7.1 Food products

In general, annonas are consumed as fresh fruits, but they are also widely used in semi-processed and processed products, especially desserts. As world demand for exotic flavours and healthy foods expands, the use of annona fruits is also likely to expand.

The cherimoya fruit is consumed mostly fresh, generally chilled and often with salt and lemon. Fruit pulp is often mixed with wine, milk (to make milk shakes) and yoghurt, processed into ice cream and sherbet, and baked into cookies and pastries (Bueso, 1980; Lizana and Reginato, 1990; Leal, 1990; Bonaventure, 1999). Most of these preparations, and others, can be made at home (Ibar, 1986).

Soursop fruits are occasionally consumed fresh or more commonly made into juices, ice creams (Pinto and Silva, 1994) or sherbets (Popenoe, 1974 b). Most people consider it to be too acid for eating fresh, but it is esteemed for making refreshing drinks (Mowry *et al.*, 1941), nectars, ice creams and similar foods. Nectar (sweetened pulp) can be prepared and used after dilution with 3 parts of water. In Java, Indonesia, fruits of soursop are added to soup (*sajoer*).

The flavour of custard apple pulp is considered to be poor and hence of little commercial value (Popenoe, 1974 a), although it is a popular backyard fruit and attracts children. Chilling of this fruit, as well as other annonas, improves the flavour (Mowry *et al.*, 1941).

Wild soursop fruits are sold in local markets in Africa. The fruit has a pineapple-like odour and sweet taste (FAO, 1983). It keeps for only a few days. It is used in sherbets, ice creams and for making drinks (FAO, 1988).

The sugar apple is consumed as a fresh dessert fruit, or used for preparing juice and ice cream. In the latter case, it should not be pasteurised or cooked, but simply blended into the semi-solid cream just before freezing (Sturrock, 1959). Leal (1990) reports that it can also be used to make wine, as can cherimoya.

7.2 Industrial food uses

Cherimoya is widely consumed in a processed form. Industrial processing depends on development of freezing techniques for pulp preservation. In a simple freezer, frozen cherimoya can be successfully preserved for 120 days. For freezing, the fruits should be peeled, preferably with stainless steel knives or by chemical peeling with caustic soda (20%). The pulp or fruit slices should be bagged in polyethylene prior to freezing and sugar can be added if desired (Lizana and Reginato, 1990). Additives, such as EDTA, ascorbic acid and citric acid, preserve against oxidation.

Soursop is the other annona of which the pulp or nectar can be frozen, processed and used industrially (Beneto *et al.*, 1971). It is perhaps the best annona for industrial processing and commercialisation because of its exotic taste and agreeable aroma. The processed pulp can be preserved by pasteurisation or freezing (Zayas, 1966) and conditions for these processes and storage have been developed. The quality of the processed product depends on total sugars and ascorbic acid retention, low acidity, viscosity and presence of pectinesterase activity. The final product should have an agreeable flavour and a good consistency. Temperatures of 93°C and 107°C decrease the quality in unsweetened and sweetened frozen soursop puree, respectively (Bueso, 1980). The high temperatures and exposure also influence pectinesterase activity and ascorbic acid retention. Moreover, soursop fruit composition differs among varieties (Pinto and Silva, 1994) and cultural treatments. Hence, it is necessary to work out the best conditions for each variety in each production environment.

Several authors have reported on soursop pulp or nectar processing, freezing and canning (e.g., Sánchez-Nieva, 1953; Payumo *et al.*, 1965). Bueso (1980) reported that fruits should be picked by hand, washed with chlorinated water and peeled by hand. The edible pulp should be extracted from the fruit using a blender, a pulper or dispersed in a sugar syrup. At this stage, care should be taken not to mix peel with pulp or to break the seeds, as these are dangerous because of the presence of bioactive compounds (see Chapter 6). After extraction, the pulp is strained through a screen. Sánchez-Nieva (1953, in Bueso, 1980) commented that extraction of the pulp should be done quickly so as to avoid aeration and oxidation.

Holanda *et al.* (1980) reported that the fruit should be processed after selection and further maturation (3-5 days depending on temperature) in an acetylene acid maturation chamber at 12.5-16°C and 80% relative humidity (RH), before finally being weighed and washed with 0.5% potassium sorbic acid. Fusagri (1982) demonstrated that 12.5°C is the best temperature to mature and store soursop fruits; at this temperature the fruits are preserved for up to 5 days. After maturation, the fruits are selected again, peeled and the pulp separated mechanically.

Pulp can be pasteurised at 85°C and nectar at 90.6°C. Both can then be stored in cans for a year at 29.4°C (Bueso, 1980). More recently, Umme *et al.* (1997) established that the best conditions for pasteurisation of soursop pulp are a pulp : water mixture of 2:1, 78.8°C for 69 s at pH 3.7. Under these conditions, the inactivation of pectinesterase enzymatic activity is maximized and ascorbic acid is preserved, which helps to maintain quality.

Frozen soursop puree can be stored for 400 days at -23°C (Bueso, 1980). To prepare this puree, the sugar content should be adjusted to 45-59°Brix; with 45°Brix, ascorbic acid retention is higher in the pasteurised puree. Ascorbic acid should be added to the pasteurised puree at a rate of 0.5-1.5 g/0.45 kg; this improves the retention of the nectar's flavour and serves as an anti-oxidant to control polyphenol oxidase-mediated pulp darkening of the fruit juices (De Oliveira *et al.*, 1994). The sweetened or unsweetened frozen nectar can be preserved by pasteurisation. Unsweetened nectar can be pasteurised at a temperature of 90.6°C, while higher temperatures give inferior final products. The same is observed for sweetened nectars. While higher temperatures reduce pectinesterase activity they also increase ascorbic acid retention.

Another industrial application involves the extraction of essential oils present in soursop pulp. These oils, such as esters of aliphatic acids, have potential to improve the flavour of processed fruit products (Jirovetz *et al.*, 1998).

Sugar apple pulp can also be processed and frozen. Its industrial processing is less important than that of cherimoya and soursop, but it is used to prepare drinks, fermented liquors and ice creams (Prasada and Rao, 1984). For this purpose, the fruits should be peeled and cut by hand, and the seeds extracted from the pulp. The pulp is heated for 3 min at 70°C, stored in jars and then double boiled for 15 min at 95°C. Sealed jars can be stored at 27°C for 150 days, during which time the acidity and total reducing sugar concentrations increase and ascorbic acid content decreases. A similar study was done on the nectar prepared with acclimatised (in an ethylene chamber at 16°C and RH 80%) and non-climatized (at room temperature for 72 h) fruits. Before the pasteurisation process, the pulp was adjusted with water, sugar and citric acid (pulp 1 kg, water 2.51 kg, sugar 0.37 kg and citric acid 1 g) (Leal, 1990). The same pasteurisation process was used for the pulp (for 3 min at 70°C, stored in jars and then double boiled for 15 min at 95°C). After 150 days of storage the only observed change was an increase in total sugars by the end of the first month and the complete loss of vitamin C content (Leal, 1990).

7.3 Medicinal uses

Various plant parts are also widely used in folk medicine, because of the bioactive compounds (mainly acetogenins, alkaloids and flavonoids) found in the roots, leaves, bark, fruits and seeds (listed in Chapter 6 and Appendix A). Acetogenins are potential anti-cancer treatments, as they have cytotoxic effects (Chang *et al.*, 1993; Cortés *et al.*, 1993 b). Flavonoids present in the seeds, roots, bark, stems and fruits are potential chemo-preventive agents, given evidence that they decrease tumour incidence (for a review, see Cassady, 1990). Appendix B provides a summary of the known uses, the most important of which are discussed below.

When a herbal product finds widespread use as a medicine, particularly for primary health care of people with little access to modern health services, it is important that natural sources are not over collected and depleted. Cultivation becomes an imperative, as does the standardization of herbal preparations (Bajaj and Williams, 1995), and there is some evidence that this is occurring for *A. squamosa* as an anti-bacterial herb (Anjaria, 1989). In Brazil, the National Sanitary Vigilance Agency (ANViSa) has recently required both evidence of bioactivity and lack of toxicity for medicinal plants used as phytopharmaceuticals. The latter requirement is especially important in annonas, given the toxicity of many of the bioactive compounds.

Cherimoya roots have aporphine alkaloids, such as roemerine, annonaine and dehydroroemerine.. These have relaxant effects, provided by the blockage of calcium movement across the cell membrane through voltage-operated channels and disruption of the alpha-1 adreno-receptors connected to the receptor-operated channels (Chuliá *et al.*, 1995). Ethanol extracts of cherimoya seeds are used in folk medicine for their insecticidal and anti-parasitic activity (Bories *et al.*, 1991). The dark-yellow resin extracted from the seeds contains substances that dilate pupils, intensify photophobia, cause dryness of the mouth, burning of the throat, nausea, vomiting and other symptoms resembling the effects of atropine remedies (Lizana and Reginato, 1990). In Mexico, the powder of two seeds from a fruit, mixed with water or milk, is a potent emetic and cathartic remedy (Lizana and Reginato, 1990). Seeds contain a reddish oil and caffeine. Flowers of cherimoya are used to flavour snuff in Jamaica but whether this is used medicinally is not clear.

Some soursop root acetogenins are known to have cytotoxic effects (Gleye *et al.*, 1998): panatellin, uvariamicin IV, uvariamicin I, reticulatacin, reticulatacin 10-one and solamin. The bark contains alkaloids. The leaves have essential oils with parasiticide, anti-diarrhoea, rheumatological and anti-neuralgic properties (Moura, 1988). Boiled water infusions of leaves have anti-spasmodic, astringent, gastric properties (Calzavara *et al.*, 1987; Khan *et al.*, 1997), help treat diabetes and gastric upsets (Calzavara *et al.*, 1987), and are used in kidney ailments (Duke, 1970). The cooked flowers and petals are used for healing eye inflammations; the treatment requires 2-3 washes a day (Calzavara *et al.*, 1987).

Immature soursop fruits have medicinal properties against dysentery, cankers, diuretic, scorbutic, anti-thermical processes, skin diseases, rashes, fever, malaria, peptic ulcers, colic and oedema (Khan *et al.*, 1997). The peel from immature fruits has constituents that act against atonic dyspepsia, diarrhoea and chronic dysentery; it is astringent and provokes vomiting (Calzavara *et al.*, 1987). The acid pulp is used to heal foot parasites and icteric liver diseases (Calzavara *et al.*, 1987). The fruit also has properties that act on the biliary vesicle (Calzavara *et al.*, 1987). The seeds have anti-spasmodic and anti-parasitic properties (Moura, 1988; Bories *et al.*, 1991; Philipov *et al.*, 1994). They contain amyloids, oleic acid and steroids (Kerharo and Adam, 1974; Asolkar *et al.*, 1992).

Wild soursop roots, leaves and bark are also used in folk medicine (FAO, 1983). The roots are used to treat cancer, convulsions, venereal disease, diarrhoea, dysentery, fever, filariosis and male impotency, and have anti-neoplasic and anti-protozoal activities (Fatope *et al.*, 1996). The leaves are used for diseases of the eye, stomach and intestines (Philipov *et al.*, 1995; You *et al.*, 1995). Alcoholic leaf extracts have anti-spasmodic and relaxant activity on the smooth muscles, anti-ulcer activity against indomethacin induced ulcers and reduce the effect of stress on ulcer induction. These effects are produced by various compounds, including flavonoids, alkaloids, tannins and saponins (Langason *et al.*, 1994). Moreover, the leaves contain compounds that have insecticidal effects and are used to control insect pests (Abubakar and Abdurahman, 1998). The bark is utilized as a vermifuge and snakebite treatment (Philipov *et al.*, 1995). The stem bark contains 4-ent-kaurenoids that have cytotoxic activity against tumour cell lines (Fatope *et al.*, 1996). Other wild soursop uses in folk medicine include treatments for pain of the chest, swelling and trypanosomiasis (You *et al.*, 1995; Fatope *et al.*, 1996), and treatment of convulsions in children and against cancer.

Sugar apple has many alkaloids, such as aporphine, roemerine, norcorydine, corydine, norisocorydine, glaucine and anonaine in different parts of the plant (Kowalska and Puett, 1990). The roots are used to treat acute dysentery, depression and spinal marrow diseases, while leaves have been used in cases of prolapse of the anus, sores and swelling (Chao-Ming *et al.*, 1997). Tea made from the roots is highly purgative, while when it is made from the leaves is mildly laxative (Leal, 1990). It has a tonic effect on the digestive tract (Leal, 1990). Ethanol extracts of the bark appear to have anti-tumour activity (Hopp *et al.*, 1996, 1997, 1998). The leaves have an alkaloid, higenamine, and this is a cardiotonic active principle (Wagner *et al.*, 1980).

Sugar apple fruits contain 16-b, 17-dihydroxykauran-19-oic acid, which has demonstrated anti-HIV activity (Wu *et al.*, 1996). Seed extracts are very poisonous and have insecticidal properties (Pandey and Varma, 1977; Qadri and Rao, 1977; Hernández and Angel, 1997); saponin, extracted from the seeds, haemolyses red blood cells and is toxic to fish (Salluja and Santani, 1990). In India, the extract of the seeds is used to provoke abortion by tribes in Madhya Pradesh State (Salluja and Santani, 1990), often combined with leaves of *Plumbago zeylanica*. Constituents of the leaves and tender stems are itemized in Asolkar *et al.* (1992).

The folk and modern medicinal uses of the annonas are clear, but this chapter should not be used for self-medication, as the toxic properties of most of these compounds can have undesirable side effects. Caparros-Lefebvre *et al.* (1999) showed that the alkaloids present in the leaves, bark and seeds of annonas, when consumed for their sedative and hypnotic effects in the French West Indies, are responsible for inducing neurotoxic effects with symptoms of Parkinsonism. Hence, any medicinal use of the annonas should only be carried out with medical guidance.

7.4 Other uses

The annonas have a number of other non-medicinal important uses for their chemical constituents. The acetogenins with insecticidal properties, present in roots, stems, leaves and seeds, can be prepared domestically as powders or by extracting them with water, acetone, ethanol, petrol ether, ethylic ether or hexane solvents. These extracts can be very potent insecticides, even in diluted form, and proper protection should be used when handling. An oil can also be extracted from seeds and used as an insecticide (Hernández and Angel, 1997). The seeds of sugar apple yield an oil suitable for soap making, and the cake can be used as a manure (Mishra *et al.*, 1979, Salunkhe and Desai, 1984).

Wild soursop bark can be used to produce a yellow or brown dye (in Uganda) and its wood is used for making tool handles (FAO, 1983). As is the case with many woody species in areas of subsistence agriculture, the plant is multi-purpose. The leaves and young shoots are used as vegetables, the flower buds are used to flavour foods and the bark is used for rope making. Sugar apple prunings are valuable for thatch in India because they are not attacked by white ants (Singh, 1992).

In general, the annonas offer potential for agroforestry, although this potential is seldom exploited. The presence of annonine in the leaves, stems and other parts make the plants bitter to goats or cattle. Aiyelaagbe (1994) reported on a system that improved the productivity in a cashew-coconut system in Kenya and which could also be adopted for annona production. However, care should be taken for annona production as the plants do not perform well under low light intensity conditions, which may be created with combined planting.

Lastly, various species can be used as rootstocks to which other desirable species can be grafted. Since *A. reticulata* can withstand diverse ecological conditions and survive long dry periods, it is very useful as a vigorous rootstock. *A. diversifolia* also has a similar ecological amplitude, but has been less widely tested.

Chapter 8. Genetic Resources

F. R. Ferreira and A. C. de Q. Pinto

8.1 The annona genepool

Annona species are widely distributed and their genetic resource conservation has achieved a degree of world-wide attention. Until recently, the centres of diversity of *Annona* seemed to contain inexhaustible supplies of genetic materials for plant breeding. However, these genetic materials have been changing rapidly as a result of genetic erosion in both cultivated and wild annonas. Human pressure on natural ecological systems, leading to the destruction of wild species, and the introduction of improved new clonal varieties, which have replaced many landraces, has promoted the loss of the genetic variability that had accumulated over a period of thousands of years of natural evolution and human directed domestication (Ng, 1991).

Chromosome numbers among *Annona* species do not vary significantly. Kessler (1993, cited by Scheldeman, 2002), reported that most of the *Annona* species present a chromosome number of 2n = 2x = 14 or 16, except for *A. glabra* which is a tetraploid species.

The most important cultivated *Annona* species not treated in this book include: ilama or annona blanca (*A. diversifolia* Saff.) from Central America and Mexico; pond apple or alligator apple (*A. glabra* L.) from Tropical America and West Africa, cultivated as a medicinal plant rather than a fruit (Scheldeman, 2002). This author also mentioned mountain soursop or cimarrona (*A. montana* Macfad), soncoya or negro head (*A. purpurea* Moc. et Sessé), and posh té or cawesh (*A. scleroderma* Saff.), all three of which are from Central America. *A. diversifolia*, *A. montana* and *A. muricata* are quite similar morphologically, and they can be cross-grafted with reasonable compatibility. Along with the cross-fertility of *A. cherimola* and *A. squamosa* there are clearly many aspects of species relationships that are by no means well studied yet (George *et al.*, 1999).

There are very extensive areas in which diversity of numerous species has been observed (Table 8.1), which suggests that certain specific regions need targeted exploration. These include the mid-elevation valleys of the Andes, many parts of Brazil, Mexico, Guatemala, Honduras and the Antilles.

Table 8-1. Centres of origin and diversity of some *Annona* species

Species	Centres of Origin
A. aurantiaca	Brazil (Mato Grosso, Goias and Minas Gerais)
A. cacans	Brazil (Savannah regions)
A. cherimola	Andean valleys of Ecuador, Peru and Chile
A. coriacea	Brazil (Mato Grosso do Sul) and Paraguay
A. crassifolia	Brazil (São Paulo, Goias and Bahia)
A. diversifolia	Southwestern Mexico, Guatemala and El Salvador
A. furfuracea	Brazil (Mato Grosso, São Paulo, Goias and Minas Gerais
A. glabra	Central America, Antilles, Ecuador, Brazil
A. longifolia	Mexico (Jalisco)
A. longipes	Mexico (Veracruz)
A. montana	West Indies, Antilles, tropical South America
A. muricata	Antilles, tropical America
A. mutans	Southern Brazil, Paraguay, Northern Argentina
A. paludosa	Guyana (Savannah regions)
A. purpurea	Southern Mexico and Central America
A. reticulata	Antilles, tropical America
A. salzmannii	Brazil (Pernambuco)
A. scleroderma	Southern Mexico, Guatemala
A. senegalensis	East Africa
A. spinescens	Brazil (Piauí, Bahia, Goias)
A. spraguei	Panama
A. squamosa	Antilles, tropical America
A. testudinea	Guatemala, Honduras
A. xespertonium	Brazil (Bahia)

A. senegalensis is widespread in sub-Sahalian tropical Africa but nothing is known about patterns of variation. A related smaller species, *A. stenophylla* Engl. & Diels, occurs in Botswana, Namibia, Zimbabwe and Malawi, and is a seasonal staple for bushmen (FAO, 1983).

Diversity is still to be found in most of the areas where annonas are backyard crops. In these agroecosystems, diverse seedlings are raised and fruit quality varies considerably. Commercial production using propagation by budding or grafting onto local rootstocks is rare.

The conservation of genetic resources requires both *in situ* and *ex situ* conservation. *In situ* refers to the preservation and protection of genetic resources in their natural habitats (Lloyd and Jackson, 1986), while *ex situ* conservation is the preservation of genetic resources outside of natural habitats.

8.2 *In situ* conservation

The establishment of protected natural areas constitutes one of the principal strategies for *in situ* conservation of wild populations, allowing for their continued evolution. The major criteria to select areas by genetic reserves are diversity, intrinsic fragility, vulnerability, and high degree of endemism with current and potential use. Generally, *in situ* conservation is practised in pre-established protected areas, where inclusion of significant *Annona* genetic diversity is a random event, rather than planned. Nonetheless, conservation areas throughout the Americas and in central-eastern Africa should be surveyed for the presence of *Annona* populations, both wild populations of the species discussed in this book, and wild species and populations of other annonas. However, *in situ* conservation is not always possible or acceptable (Ndambuki, 1991).

In situ conservation also includes on-farm (including backyard) conservation. Incentives could be given to large and small farmers, and to indigenous peoples, to continue cultivation using traditional agricultural methods. Ideally, agro-ecosystems should be preserved in their totality and should be evaluated comprehensively.

The economic environment of the farm household determines the degree of genetic diversity used in its agricultural system (Goeschl, 1998) and, consequently, the amount available for on-farm conservation. The causal link between market conditions and conservation efforts on-farm offers scope for policy interventions, such as deliberate changes in economic parameters. Goeschl (1998) suggests both market and non-market incentives, the latter directed at the individual farm situation.

In Tocantins State, northern Brazil, the Brazilian Corporation for Agricultural Research (EMBRAPA) has started a project with the Kraô, an indigenous group, to encourage the conservation of their genetic resources, especially on-farm genetic resources. The first step of this project is to carry out a survey of species occurring in this area. Ferreira and Bustamante (2000) commented that ethnobotany can help to establish new alternatives for conservation and use of genetic resources via on-farm conservation, including for *Annona* species. No other references have been found on the *in situ* conservation of *Annona* species.

8.3 *Ex situ* conservation

Ex situ conservation includes various strategies, such as seed storage, *in vitro* culture and field genebanking. *Annona* seeds show an orthodox response to desiccation and exposure to sub-zero temperatures. Cherimoya seeds tolerate desiccation to 4.8% moisture content, while soursop seeds tolerate desiccation to 5% moisture content. The seeds of sugar apple tolerate desiccation to 1.5% moisture content, and no viability loss occurred during 6 months of hermetic storage at -20°C (Hong *et al.*, 1996). These authors suggest that *Annona* seeds can be conserved in conventional seed genebanks under conditions of 18°C or less, in airtight containers at a seed moisture content of 5 ± 1%.

In vitro culture techniques can be used for collecting, exchange and *ex situ* conservation of species that produce seedless fruits, as well as for vegetatively propagated plants, including annonas. *In vitro* storage can be done by using slow growth techniques, when medium-term preservation is sufficient, or by cryopreservation in liquid nitrogen at -196°C, if the need is for long-term preservation. Both techniques present great advantages for germplasm conservation. *In vitro* culture also offers the possibility of eliminating pathogens, and thus conserving and exchanging germplasm under disease free conditions. Despite their potential, *in vitro* conservation techniques are currently used to a limited extent only. This is due principally to the lack of research to develop protocols for each species (Ashmore, 1997). Although several papers have appeared on annona tissue culture (Rasai *et al.*, 1995; Lemos and Blake, 1996; Padilla, 1997; Castro *et al.*, 1999; Encina *et al.*, 1999; Lemos, 2000), a great deal of work remains to be done on development of methods for *in vitro* propagation for germplasm conservation of *Annona* species.

Emphasis on *in vitro* research should be placed on conserving specific clonal material which is well documented. Much of the range of variation can be conserved using seed storage, and this is more cost-effective than attempting large *in vitro* programmes. Despite the availability of seed and *in vitro* conservation techniques, in practice the majority of *Annona* genetic resources are stored in field genebanks, also called clonal repositories or collections of living plants, which face higher risks of disease, human error and environmental hazards than other conservation techniques (Ferreira, 2001). These collections seem to be mainly breeders' collections, and are rarely representative of the range of *Annona* variability that needs to be conserved.

There is an urgent need to survey and collect wild materials, primitively cultivated forms and varieties of *Annona* species. However, primary emphasis needs to be on improving the agronomic and economic yields of each species in the range of habitats where they are grown.

A total of 1,741 germplasm accessions of eleven identified species, one interspecific hybrid and various *Annona* spp. are documented (IPGRI, 2000), with a surprisingly low percentage of duplication across the 67 institutional collections in 34 countries (Table 8.2). Due to their commercial importance, the three species with the largest number of accessions are *A. cherimola*, *A. muricata* and *A. squamosa*.

Considering that almost all conserved *Annona* germplasm is maintained in field collections, which are subject to abiotic and biotic stress conditions, such as flooding, drought, pathogen or insect infestations, the low percentage of duplication is a matter of considerable concern. The first step to remedy this has been taken by the Spanish government, in co-operation with IPGRI, through the establishment of a cherimoya genebank in Peru (Coppens d'Eeckembrugge *et al.*, 1998). Besides this cherimoya genebank, Ecuador is establishing an *Annona* collection on the same basis as the Peru genebank (G. Coppens d'Eeckembrugge, Cali, 2001, personal communication). Other actions are needed, since these two actions only target cherimoya.

A global strategy for collecting, evaluating and conserving germplasm needs to be thought out and implemented. This is particularly important since *Annona* collections are scarce in most of the major areas of diversity, such as Honduras, Mexico and the Antilles. In addition, the need of long-term financial commitment for germplasm banks, especially field genebanks of fruits in their centres of diversity, is important. It was observed in Amazonia, for example, that various collections were in advanced stages of deterioration. In part, this is due to a lack of breeders using the collections, although these collections are valuable as sources of genetic materials for testing in different areas or for exchanging among countries even if breeders are not locally available (Arkcoll and Clement, 1989).

Table 8-2. Number of *Annona* accessions in germplasm collections around the world

Species/Country	*che*	*div*	*ret*	*squ*	*mur*	*mon*	*pur*	*gla*	*pit*	*cin*	*scl*	*A.che x A.squ*	*spp*	No. Collections	Total Accessions
Australia	10	1	3	1	4	-	-	-	-	-	-	22	-	3	41
Brazil*	2	-	9	92	124	3	1	5	-	-	-	5	16	11	257
Cameroon	-	-	4	1	4	-	-	-	-	-	-	-	-	1	9
Costa Rica	24	1	4	1	67	1	5	2	1	-	-	2	4	5	112
Cuba	2	-	6	5	9	1	1	1	-	2	-	-	2	2	29
Cyprus	4	-	-	-	-	-	-	-	-	-	-	-	-	1	4
Ecuador	218	-	1	1	5	-	20	-	-	-	-	-	-	5	245
El Salvador	-	23	4	-	30	-	2	2	-	-	-	-	-	1	61
France	4	-	2	4	13	-	-	-	-	-	-	2	-	1	25
Germany	1	-	-	1	1	-	-	-	-	-	-	-	-	1	3
Ghana	-	-	1	1	1	-	-	-	-	-	-	1	-	1	4
Grenada	-	-	-	2	-	-	-	-	-	-	-	2	-	1	4
Guatemala	-	3	6	-	4	-	5	8	-	-	2	-	1	1	29
Honduras	-	1	-	-	1	-	1	1	-	-	1	-	1	2	6
India	-	-	-	-	-	-	-	-	-	-	-	-	10	1	10
Israel	-	-	-	-	-	-	-	-	-	-	-	-	20	1	20
Jamaica	-	-	-	1	1	-	-	-	-	-	-	-	9	2	1
Malawi	-	-	-	-	-	-	-	-	-	-	-	-	3	1	3
Mexico	3	-	-	1	-	-	-	-	-	-	-	-	-	1	4
Panama	-	-	-	-	13	-	-	-	-	1	-	-	-	2	14
Papua New Guinea	-	-	-	-	-	-	-	-	-	-	-	-	4	1	4

Species/Country	*che*	*div*	*ret*	*squ*	*mur*	*mon*	*pur*	*gla*	*pit*	*cin*	*scl*	*A.che x A.squ*	*spp*	No. Collections	Total Accessions
Peru	62	-	-	-	9	-	-	-	-	-	-	-	-	5	71
Philippines	-	-	11	43	7	-	-	-	-	-	-	8	14	2	83
Portugal	7	-	-	-	-	-	-	-	-	-	-	-	-	1	7
Saint Lucia	-	-	-	-	2	-	-	-	-	-	-	-	-	1	2
Seychelles	-	-	-	-	5	-	-	-	-	-	-	-	-	1	5
South Africa	11	-	-	-	-	-	-	-	-	-	-	-	-	1	11
Spain	291	-	-	1	-	1	-	1	-	-	-	5	-	1	299
Sudan	-	-	-	7	-	-	-	-	-	-	-	-	-	1	7
Suriname	-	-	-	-	3	-	-	-	-	-	-	-	3	2	6
China	7	-	1	1	1	1	-	1	-	-	-	3	-	1	15
Tanzania	2	-	-	-	2	-	-	-	-	-	-	-	-	1	4
USA	-	3	17	13	263	-	-	2	-	-	-	-	31	4	329
Venezuela	-	-	-	-	7	-	-	-	-	-	-	-	-	1	7
Total	648	32	69	176	576	7	15	43	1	3	3	50	118	67	1741

Source: IPGRI, 2000; *Updated by authors; *che = A. cherimola; squ = A. squamosa; div = A. diversifolia; ret = A. reticulata; mur = A. muricata; mon = A. montana; pur = A. purpurea; gla = A. glabra; pit = A. pittieri; cin - A. cinerea; scl = A. scleroderma; spp = Annona spp.*

Chapter 8. Genetic Resources

Chapter 9. Genetic Improvement

A. C. de Q. Pinto and S.R.M. de Andrade

9.1 Introduction

Although restricted to only a few species, principally cherimoya, improvement programmes of annonas have made great contributions by producing important cultivars with good yields and fruit quality, and that more closely meet consumers' demands. The development of new cultivars is not a simple task. In many cases the major constraints are agronomic, as well as the lack of prolific cultivars to start improving.

9.2 Cytogenetics and genetic aspects

The chromosome numbers of cherimoya, custard apple, soursop and sugar apple are 2n = 14 to 16 (Nakasone and Paull, 1998; George and Nissen, 1992; Koesriharti, 1992). Although there is some variation in chromosome number, they are all diploids, 2n = 2x. The chromosome number of wild soursop is not reported. This slight variation in chromosome number may explain the ease or difficulty of interspecific hybridisation and grafting, and warrants further work to determine if intra-specific variation also exists. Some related species, e.g., *A. glabra*, are known to be tetraploid (Kessler, 1993, cited by Scheldeman, 2002).

Generally, cross-pollination between annonas is conducted primarily to determine compatibility for increasing fruit set (Nakasone and Paull, 1998) and occasionally for new hybrid development. Samuel *et al.* (1991, cited by Nakasone and Paull, 1998) commented that crosses among soursop and other annonas, such as cherimoya, ilama, custard apple or sugar apple, have not been successful. This may reflect the genetic distance between soursop and the others. However, there is a dearth of information on species' relationships, so this is a topic that needs to be researched.

The extensive morphological diversity, much of it genetically based, within all *Annona* species (Page, 1984) not only offers great potential for breeding, but also lowers the possibility of easily selecting a cultivar with all the possible desirable characters. Considerable variation exists among cultivars and seedlings of cherimoya, but sugar apple and soursop are reputed to be less variable (George and Nissen, 1992; Pinto and Silva, 1996).

The influence of *Annona* rootstocks on scion behaviour is also quite marked, and genetic variability within seedling rootstock lines and between different rootstock species induces wide variability in scion performance (Page, 1984). This kind of genotype and environment interaction requires much more study than it has received to date.

Seedling populations of some *Annona* species, such as sugar apple and soursop, are known to be rather uniform (George and Nissen, 1987). There are some growers using seedlings in commercial orchards in Brazil (Pinto and Ramos, 1999). Since annonas are considered out-crossing species (George and Nissen, 1987; Scheldeman, 2002) with high degrees of heterozygosity and do not generally produce true-to-type seedlings, commercial orchards should be clonally propagated to avoid possible influence of genetic variability. However, little has been done to identify and characterize the diversity in any of the *Annona* species.

9.3 Characteristics of annona ideotypes

There are several characters that are considered important in a superior commercial cultivar of an *Annona* species (Table 9-1). According to Mahdeem (1990), the most important characteristics of an ideotype, especially of cherimoya, are the following: a) vigorous and prolific plants, compatible with one or more rootstocks, regular-bearing, resistant to cold and dry conditions, as well as to pests and diseases; b) architecture of the canopy with acceptable form, which does not need pruning, and which is easy to harvest; c) abundant flowers with fertile pollen, and which attract insect pollinators; d) out-of-season fruit harvest for specific locations; e) fruit with symmetrical form, high natural fruit set, hard skin resistant to pests and diseases, as well as with long post-harvest life; f) excellent fruit quality with regards to flavour, with fine, fibreless and firm pulp texture, and a low number of free seeds in the pulp. Each species will have a slightly different ideal type, due to their inherent biological differences.

9.4 Breeding programme

Wester (1913) was the first scientist to realize the possibilities for genetic improvement of annonas and initiated breeding programmes in Florida and in the Philippines. However, he faced a lot of limiting factors and because he evaluated only a small number of progenies, no new cultivars were selected at that time.

9.4.1 Limiting factors and major constraints

Climate and soil are the factors with greatest influence on the variation in growth, fruit set, fruit size and quality of commercial annonas. They represent the main constraints in the establishment of an *Annona* breeding programme, since they directly influence response via the genotype-environment interaction.

Rainfall and high humidity during the peak flowering season greatly enhance fruit production of most annonas by preventing desiccation of stigmas, prolonging their receptive period and increasing fruit set and early fruit growth (Nakasone and Paull, 1998). The sugar apple is the contrast, as it is probably the most drought-tolerant species, and it grows, but produces poorly, where rains are frequent. This is shown by the fact that sugar apple does much better in northern Malaysia, where dry periods occur, than in the southern part, which has year-round high moisture (Nakasone and Paull, 1998). This climatic adaptation of sugar apple to semi-arid conditions is confirmed by Coronel (1994). Sugar apple's deciduous growth habit contributes to its drought resistance, as it does not have any leaves during most months of the dry season. In contrast, soursop grows and produces very well under high rainfall conditions in the Amazon region. However, both sugar apple and soursop grow and produce very well in the semi-arid conditions of north-eastern Brazil, with very low rainfall, but they both require irrigation. Given these good responses to environmental control, breeding of sugar apple and soursop have a greater likelihood of success under semi-arid conditions.

Temperature is also a limiting factor, mainly for the tropical annonas, soursop, custard apple, sugar apple and wild soursop, since low temperatures (< 14°C) may damage or even kill young trees, although adult plants may show some tolerance. Poor pollination is frequent in all species when high temperatures (> 30°C) and low RH (< 30%) occur, even with hand-pollination (Nakasone and Paull, 1998). These authors also comment that cherimoya is more tolerant to low temperature (7-18°C) and soursop is the least tolerant (15-25°C). Therefore, improvement of cherimoya would be better in the northern hemisphere (temperate and subtropical regions) and soursop, like the other annonas, in the southern hemisphere under tropical conditions.

Shading of the generally vigorous annona trees can greatly reduce fruit set. Therefore, pruning and spacing are cultural practices that need to be adjusted for enhancing fruit set in any breeding programme. No photoperiod responses have been reported in annonas, so this factor can safely be ignored.

It is very common to observe trunk and stem breakage of soursop and sugar apple trees due to winds. Tree shaking may also be partially responsible for collar-rot by allowing penetration of pathogens, and the fruit skin is easily damaged by rubbing and exposure to drying winds (Marler *et al.*, 1994). Control of fruit drop can be improved by windbreaks and under-tree sprinkling to raise RH above 60% (Nakasone and Paull, 1998).

All *Annona* species can grow in a wide range of soil types, from sandy soils to clay loams. However, they prefer rich, well-drained soils, and breeders have the additional advantage of avoiding root-rot diseases in seedling populations.

A small population of pollinator insects may limit fruit set of open pollinated annonas. The morphology and fragrance of flowers suggest that natural pollination is done by certain species of Coleoptera beetles (Coronel, 1994; Pinto and Silva, 1996). Low numbers of pollinator insects coupled with slow anthesis (flower opening) impede insect visits. Consequently, there is often very low fruit set from natural pollination, varying from 0% in some cherimoya orchards (Gardiazabal and Cano, 1999) to 26% in some soursop orchards (Pinto and Ramos, 1999). In contrast, the same authors obtained 26% and 73% fruit set by using hand pollination on cherimoya and soursop, respectively. Due to protogyny, hand pollination is useful in breeding programmes, since breeders can select the parents to be crossed and may also improve a full-sib progeny population more quickly than a half-sib one.

Apart from cherimoya, germplasm banks that contain *Annona* species are rare throughout the world (see Chapter 8), which is a limiting factor for selecting and crossing among elite cultivars. The length of the juvenile period is also a limiting factor for genetic improvement. Generally, the juvenile period lasts until the third year. Therefore, if one considers three years of seedling and fruit evaluations as a minimum requirement, the release of an F1 cultivar is only possible six years after the cross.

Seedling rootstocks of annonas are generally derived from heterogeneous open-pollinated plants; hence, it is often difficult to fix specific characters in a short period. Early maturity, better fruit appearance and long post-harvest life for tropical annonas, and in the subtropics, greater cold tolerance, are objectives for cherimoya breeding (Nakasone and Paull, 1998).

9.4.2 Breeding objectives

The first objective that the breeder has in mind is the determination of the specific characteristics that are important for the new cultivar - the ideotype (Table 9-1). These characteristics may help a breeder to select parental groups to be used in an annona breeding programme, in order to obtain desirable progenies. These progenies may not have all desirable characteristics, but at least will have those most important to growers, retailers and consumers. For instance, a sweet sugar apple cultivar with long shelf life fruits (> 5 days), which is important from a consumer’s viewpoint, may not be selected, if it presents low yield (< 20 kg/tree/year) and fruit weight lower than 400 g (Table 9-1), since no grower will plant this cultivar.

Indeed, yield is always an important trait in cultivar development for any crop species (Fehr, 1987 b) and annona is no exception. However, genetic improvement for yield is the most difficult and expensive of all breeding objectives, due to the complex nature of its inheritance and the numerous environmental factors influencing the trait. The different yield responses of the various *Annona* species and cultivars, such as soursop (Pinto and Silva, 1996) and cherimoya (Gardiazabal and Cano, 1999), in the same region, prove the complexity of the genotype-environment interaction.

Quality is another important characteristic for the improvement of annonas, as important or sometimes more so than yield, since market value is based on the fruit's appearance and its organoleptic characteristics. A complicating factor is that quality standards may not be the same for all markets. In cherimoya, a skin without protuberances above the carpel walls may be preferable, since this diminishes the susceptibility of the fruit to mechanical damage (Gardiazabal and Cano, 1999). Small, sweet soursop fruits are recommended for the fresh market, while large acid ones are more suitable for the processing industry (Pinto and Silva, 1996). However, ripe fruits become soft and perishable, with subsequent rapid fermentation. Besides the difficulty to determine a correct harvest point, handling and processing procedures have to be adapted to this postharvest problem. Therefore, it is difficult to produce fresh soursop fruits for export to distant markets without resolving this postharvest impediment.

Table 9.1. Main characteristics of cherimoya, soursop and sugar apple ideotypes (adult plants).

Characteristic	Cherimoya	Soursop	Sugar Apple
Plant			
- Vegetative vigor	Medium to low	Medium to low	Medium to low
- Reproductive vigor (yield)	High (> 30 kg/tree/year)	High (> 60 kg/tree/year)	High (> 20 kg/tree/year)
- Bearing	Regular	Regular	Regular
- Rootstock/Scion Compatibility	High	High	High
- Resistance			
Climate (Temperature)	High Temperature (> 22 °C)	Low Temperature (< 18 °C)	Low Temperature (< 18 °C)
Pest and Disease	High	High	High
- Flower Number	Abundant (>150 flowers/tree)	Abundant (>100 flowers/tree)	Abundant (>180 flowers/tree)
- Pollen Fertility (20 °C)	High (> 76%)	High (> 76%)	High (> 76%)
- Harvest	Out-of-Season	Throughout year	Out-of-Season
Fruit			
- Size/Weight			
For Industry	Large / > 650 g	Large / > 2,5 kg	Large / > 400 g
For Fresh Consumption	Medium / 300-600 g	Small / 0,8-2,5 kg	Medium / 300 - 400 g
- Shape	Heart	Conical	Rounded to Heart
- Fruit Set (naturally)	High (> 27%)	High (> 26%)	High (> 25%)
- Skin	Smooth (Impressa)	Short protuberances	Tuberculate
- Pulp	Sweet, fiberless	Sub-acid, low fiber	Sweet, low fiber
- Flavour	Delicate	Sub-acid flavour	Pleasant acidulous
- Seed number/100g of pulp	Low or Absent / < 6 seeds	Low / 10-30 seeds	Low or Absent / < 10 seeds
- Shelf Life (15° to 30°C)	Long (> 10 days)	Long (> 5 days)	Long (> 5 days)
- Transport resistance	High (pulp pressure > 1.5 kg/cm2)	High (not found)	High (not found)

Sources: Anderson and Richardson (1990); George and Nissen (1987); Guardiazabal and Cano (1999); Higuchi *et al.* (1998); Nakasone and Paull (1998); Pinto *et al.* (2001); Scheldeman and Van Damme (1999); Viteri *et al.* (1999).

Breeding for pest and disease resistance is another important part of cultivar development. The soursop cultivar 'Morada' has shown less susceptibility to fruit borer than other cultivars under the environmental conditions of Brazil's Central Region (Pinto and Silva, 1996). Given the stage of domestication of the three principal annonas, it is not surprising that this type of resistance is rare, especially when most annona plantations are monoculture orchards.

Quantitative characteristics, like yield, controlled by numerous major and minor genes, are more difficult to manipulate than qualitative ones. In addition, traits whose expression is influenced by environment are also more difficult to select for than those unaffected by environmental factors. As *Annona* breeding programmes have several objectives, it is the responsibility of the breeder to design cost-effective strategies to select genotypes with the maximum number of desired traits.

9.4.3 Methods and strategies

Most *Annona* species and cultivars differ in environmental adaptation, productivity and fruit quality. Therefore, different conventional methods can be used in their breeding. According to Fehr (1987a), there are three requirements for the development of an asexually propagated cultivar: a) a suitable source of genetic variability; b) evaluation of individuals from the population; c) asexual multiplication of a new cultivar for commercial use.

Introduction of superior genotypes and/or cultivars to establish a germplasm collection is, basically, the first requirement of any breeding programme. This can be complemented by the introduction into the collection of some wild *Annona* species with useful genes, mainly for resistance to diseases. All accessions require comprehensive characterisation and documentation, followed by evaluation and selection.

Several types of populations can be developed by hybridisation, from which superior clones are selected. Nonetheless, most of the existing commercial cherimoya cultivars in Chile and Spain were released after selection and asexual propagation of open-pollinated progenies (Hermoso and Farré, 1997; Gardiazabal and Cano, 1999), so hybridisation is not always necessary, although it can often accelerate a breeding programme. However, breeding (and selection) in cherimoya has been neglected and only a few new cultivars have been developed in the past 20 years, due mainly to the lack of breeding programmes and clear strategies. In contrast, other subtropical and tropical fruit species, such as mango, have been intensively selected and cloned from more than several hundred thousand seedlings over more than 100 years (George *et al.*, 1999), although some progress has recently been made in selecting new cherimoya cultivars.

A very simple but interesting strategy, developed by members of the California Cherimoya Association, is to bring samples of new cultivars to show at their Annual Meeting. This helps to identify new materials that they might want to grow next year (Grossberger, 1999). This strategy has a long history in developed countries, such as the USA, and needs to be more widely adopted in developing countries.

George *et al.* (1999) commented that a major *Annona* breeding programme, funded by the Australian Custard Apple Growers Association, started with the objective of developing high quality seedless cultivars of atemoya (*Annona squamosa* x *A. cherimoya* hybrids). The vernacular name 'custard apple' is usually and wrongly used to refer to *Annona squamosa* by Indian researchers (Pawshe *et al.*, 1997) and to *Annona* hybrids or to *Annona cherimola* by UK and Commonwealth researchers (George and Nissen, 1987, Van Damme and Scheldeman, 1999). Therefore, the reader is advised to carefully identify the origin of articles in order to correctly identify the species which is referred to.

In this breeding programme, the Australian breeders first produced tetraploids, either through gamma irradiation or colchicine, and then crossed these to diploids to produce seedless triploids. There are several other potentially useful methods of obtaining seedlessness in annonas, e.g., a) trying to identify progeny from diploid x diploid crosses with small seed sizes and numbers; b) producing triploids from diploid x tetraploid and tetraploid x diploid crossing, as done in Australia; c) producing triploids through protoplast fusion of diploids and haploids; d) irradiation of budwood to "knock out" genes for seed production; e) crossing of low-seeded parents (as the seed number is an heritable character); f) development of self-incompatible parthenocarpic hybrids; and g) using endosperm culture to get triploids. Not all of these strategies are currently being employed in annona breeding programmes (George *et al.*, 1999).

Progeny of a cherimoya x sugar apple cross produced fruits which were late maturing (spring in Queensland), and appeared to have inherited the flowering and fruiting characteristics of atemoya, with flowering in autumn and fruit maturity in late spring, under the subtropical conditions in that part of Australia. A similar study was carried out by Zill Nursery near Boyton Beach, Florida, and approximately 3,000 seedlings, mainly from interspecific crosses, were planted. Since attractiveness is a key factor in selling fruits, the exciting possibility exists to develop new cultivars with external and internal pink-red colours. Crossing of newly introduced red and pink-skinned atemoya x cherimoya selections to red-skinned sugar apple types selected in Queensland, Australia, is currently in progress (George *et al.*, 1999).

Spain is more focused on germplasm collection and *ex situ* evaluation of numerous acessions (Farré Massip and Hermoso González, 1987, cited by Scheldeman, 2002). Pérez de Oteyza and Farré (1999) reported that the selection of a superior cultivar of cherimoya at the Experimental Station of La Mayora, Spain, is based on the following characters: a) regarding agronomic and commercial parameters - size, format and pilosity on leaves, length and colour of flowers, floral density (number of flowers per one metre of mature stem), susceptibility to fruit fly, season of maturation and harvest, defects on the skin and in the pulp, resistance to fungal attack and seed colour; and b) regarding fruit transport and consumption - type of skin, pulp firmness, taste (sugar content and acidity) and seed index (number of seeds per 100 g of fruit).

In Chile, introduction and selection of cherimoya showed that the new cultivars from Spain were superior, with longer harvest periods and better fruit quality than Chilean cultivars (Gardiazabal and Cano, 1999). Ten cultivars from Spain were evaluated for fruit weight, shape and colour, skin type, number of days post-harvest to reach appropriate ripeness for eating, resistance of pulp to pressure, percentage by weight of fruit components, seed type, number of seeds per 100 g of pulp, sugar and acidity, and taste. The Spanish cultivar ‘Cholan’ showed the highest general rating.

In Mexico, genetic improvement of cherimoya started in 1991, with evaluation of seedlings of local cultivars and evaluation of introduced cultivars from Spain, Chile and New Zealand (Román and Damián, 1999). Characterisation and selection of cherimoya fruits from trees collected in three regions of Michoacán State, Mexico, was done by Agustín (1999). While studying such characteristics as fruit weight, percentage of pulp and seed, fruit soundness, type of skin and earliness, he found great genetic variability among native fruits and proposed this as the basis for developing germplasm for commercial plantations. A very similar strategy has been used in Italy and Portugal (Madeira), with selection and evaluation of promising local types and introduced cultivars (Monastra, 1997; Nunes, 1997).

The methods and strategies used in Madeira to develop superior cultivars of cherimoya were somewhat different. First, the agricultural service surveyed and mass selected local types. Plant behaviour was observed with respect to age, origin, farming practices, pest and disease resistance, organoleptic parameters and so on. At the same time, genetic material was introduced from other countries, especially the USA and Spain, increasing variability and allowing comparison of adaptability, productivity and quality with the local materials. Finally, clonal selection produced four improved cultivars: Madeira, Mateus I, Perry Vidal, and Funchal (Nunes, 1997).

Soursop is still largely propagated by seed, and the progenies can be selected and separated into groups based on acidity and sweetness. Morada, an ecotype introduced into Brazil from Colombia, produces large fruits with an average weight of 3.8 kg, but its fruits have very acid pulp, which is a constraint for the fresh fruit market. A local soursop selection from Bahia State named "ecotype A" produces very small fruits (< 1.8 kg), but has sweet pulp, appropriate for the fresh market. Crossing between these two might produce a medium weight fruit with a commercially acceptable taste. Several genotypes and some related species are used in the soursop breeding work of Embrapa Cerrados, Brazil, from which a clone based on Morada has been released as a reliable option for tolerance to trunk borer (Pinto and Ramos, 1997). At the same time, *A. glabra*, which has dwarf characteristics and good adaptation to damp areas, is being used in a breeding programme for rootstock improvement, since there is acceptable rootstock/scion compatibility between these two species.

Wild soursop has been used for insect control in Africa, since it has significant amounts of secondary metabolites with insecticidal activity (see Chapter 7). However, there is no specific breeding programme to improve this characteristic, although Abubakar and Abdurahman (1998) mentioned a project to prospect, collect and chemically identify wild soursop variation with insect growth-regulating activity in Kaduma State, Nigeria (work at the Department of Biological Sciences, Ahmadu Bello University, Zaria).

9.4.4 Selection and cultivar development

Like any other fruit tree, the type of selection or cultivar development of annonas is strongly influenced by commercial use. Also, the feasibility of using a particular type of selection or cultivar may depend on the nature of the organisations that produce and distribute grafted plants for commercial use, these being much better established in more developed countries. This explains why annona cultivar development concentrates on cherimoya and soursop (and atemoya), and has been carried out only by public institutions. In short, the cost of annona cultivar development is too high compared with the demand for superior grafted material, therefore, only a few private companies or nurseries can afford a breeding program, e.g., Zill Nursery in Boyton Beach, Florida.

Nakasone and Paull (1998) stated that only cherimoya and atemoya have important named clonal cultivars. For other annonas, such as soursop, sugar apple and custard apple, there are some selections and very few named cultivars (Table 9.2).

In California, some old cultivars of cherimoya, such as ‘McPherson’, ‘Deliciosa’ and ‘Bays’, were selected and cloned from seedling plantings (Nakasone and Paull, 1998). Grossberger (1999) stated that cv. ‘White’ is the most important cultivar grown in California because of its large size. However, ‘Booth’, as a very sweet cultivar, and ‘Pierce’, as a cultivar with the best shape for packing, have been cultivated for a long time.

In Peru, considerable work has been done on the development of annona cultivars, but they are not widely known outside Peru. Chile, Spain and New Zealand grow cherimoya, as it is more tolerant of cold temperatures and has more successful self-pollination than atemoya. ‘Reretai’ and ‘Burton’s Wonder’ are the most important New Zealand cultivars while ‘Madeira’, ‘Mateus I’, ‘Perry Vidal’ and ‘Funchal’ are important cherimoya cultivars grown on Madeira island (Nunes, 1997). Numerous cherimoya cultivars have been reported in Spain and Fino de Jete identified as the finest commercial cherimoya cultivar, mainly because of its good postharvest life (Hermoso and Farré, 1997). In Ecuador, there are no single-cultivar orchards of cherimoya; rather most orchards consist of plants propagated by seed. In some cases there are plants grafted onto the local ecotypes known as Jaramillo and Chumina, selected by farmers on the basis of yield and quality (Fuentes, 1999).

There is no well-established breeding programme for custard apple. Nonetheless, a few cultivars have been mentioned, such as ‘Camino Real’, in Guatemala, and ‘Fairchild Purple’ and ‘Young’, in Florida, USA (George *et al.*, 1999).

Soursop is largely planted by seed in most countries, including Mexico and Brazil. Soursop clones are separated into groups, such as acid (for the processing market) and low acid (for the fresh market), or juicy and non-juicy types. Seedling populations of soursop have been established in Mexico, Malaysia and Brazil, permitting the selection of superior clones with better yield and improved processing qualities (Pinto and Silva, 1996; Nakasone and Paull, 1998; Lemos, 2000 b). Morada is a soursop type belonging to the acid group and producing large fruits (average of 3.8 kg), which was introduced into central Brazil in 1980, and has shown high yield and good tolerance to trunk and fruit borers. 'Giant of Alagoas' developed by Lemos (2000 b) is a clonal cultivar selected from seedling of Morada soursop, which shows the same performance as the mother plant. Several soursop selections in the low acid group have been evaluated in Pernambuco State, Brazil, and some of them have given high yields - up to 70 kg/plant/year (Lederman and Bezerra, 1997).

Table 9-2. Some selections and cultivars of cherimoya, atemoya, soursop, sugar apple and custard apple that are currently planted in various countries

Cultivar/Selection	Country of Origin	Cultivar/Selection	Country of Origin
Cherimoya		**Atemoya**	
Alvaro[(1)]	Mexico	African Pride[(1)]	S. Africa/Israel
Andrews[(1)]	Australia	Bradley[(1)]	USA/California
Bays[(1)]	USA/California	Jennifer[(1)]	Israel
Booth[(1)]	USA/California	Kabri[(1)]	Israel
Burton's Wonder[(1)]	New Zealand	Malalai[(1)]	Israel
Bronceada[(1)]	Chile	Nielsen[(1)]	Australia
Campas[(1)]	Spain	Island Gem[(1)]	Australia
Chaffey[(8)]	USA/California	Page[(1)]	USA/Florida
Cholan[(1)]	Spain	Pink's Mammoth[(1)]	Australia
Concha Lisa[(1)]	Chile	**Soursop**	
Cortes II-31[(1)]	Mexico	Morada[(3)]	Colombia/Brazil
E-8[(1)]	Ecuador	Lisa[(3)]	Colombia/Brazil
Fino de Jete[(1)]	Spain	Blanca[(3)]	Colombia/Brazil
Funchal[(2)]	Portugal/Madeira	Giant of Alagoas[(4)]	Brazil/Alagoas
Gangemi[(1)]	Italy	Ibimirim Selection[(5)]	Brazil/Pernambuco
Cherimoya			
Golden Russet[(8)]	USA/California	**Sugar Apple**	
Kempsey[(1)]	Australia	IPA Selections[(5)]	Brazil/Pernambuco

Cultivar/Selection	Country of Origin	Cultivar/Selection	Country of Origin
Leone[1]	Italy	Molate[6]	Philippines
Libby[7]	USA/California	Cuban Seedless[1]	Cuba
Lisa[1]	USA/California	Lobo[7]	Philippines
Madeira[2]	Portugal/Madeira	Noi[7]	Thailand
Mateus I[2]	Portugal/Madeira	Access 6333[7]	Philippines
McPherson[8]	USA/California	Red Sugar Apple[7]	USA/Florida
Mossman[1]	Australia	Mammouth	India
Negrito[1]	Spain	Balangar	India
Ott[1]	USA/California	Sitaphal (red/lal)	India
Perry Vidal[2]	Portugal/Madeira	Borhodes	India
Pierce[1]	USA/California	Britishbaroa	India
Reretai[1]	New Zealand	**Custard Apple**	
Whaley[8]	Australia	Camino Real[7]	Guatemala
White[8]	USA/California	Fairchild Purple[7]	USA/Florida
		Dr.León[7]	USA/Florida
		Young[7]	West Java

Sources: [1]Nakasone and Paull (1998); [2]Nunes (1997); [3]Pinto and Silva (1996); [4]Lemos (2000 b).

India, China and Taiwan have produced a few named cultivars of sugar apple that are propagated vegetatively. In Cuba, researchers developed ‘Cuban Seedless’, which is a seedless cultivar with medium-sized fruits, and another cultivar with low fibre content that is very important for the commercial market (Nakasone and Paull, 1998). In the Philippines, there are 3 forms of sugar apple fruits: (a) a green-fruited seedy form, which is grown in most parts of the country; (b) a purple-fruited seedy form, reportedly introduced from India; (c) and the green-fruited seedless form, which is a recent introduction and whose origin is unknown. The selection of superior strains is aimed in the direction of a green-fruited seedy form (Coronel, 1994). In Petrolina, Pernambuco state, Brazil, some sugar apple growers are producing and commercialising a purple sugar apple type (Plate 1), and northeastern Brazilian consumers – mainly those with higher per capita income – are buying it much more as an exotic fruit, due to its colour, than because of any other characteristic, since taste and shape are similar to standard green sugar apples. Unfortunately, this sugar apple type has not been totally accepted in the market, because most of the consumers think that the purple fruit is already rotten.

9.5 Role of modern biotechnology

9.5.1 Tissue culture

Tissue culture has many uses: a) micropropagation; b) maintenance of germplasm collections; c) embryo rescue; d) development of haploid plants; e) enhancement of variability by somaclonal variation; and f) to prepare explants for transformation methods (Encina *et al.*, 1999; Herrera, 1999). However, for most annona work the main objective is micropropagation, as the conventional methods of propagation are slow and costly, and in some cases, such as with cherimoya, are also inefficient. This appears to be because the morphological potential for rooting of cherimoya is very low (Encina *et al.*, 1999).

Researchers have successfully micropropagated cherimoya, sugar apple, soursop and atemoya. Atemoya clonal propagation was described by Rasai *et al.* (1994). They obtained multiple shoot formation from hypocotyls and nodal cuttings of the cultivar 'African Pride'. The explants were cultivated in MS medium supplemented with BAP, kinetin, biotin and calcium pantothenate. In spite of improved rooting by shoot pre-treatment in liquid MS medium containing IBA, the percentage of rooting was still low (40%) and remains a limiting factor for commercial micropropagation of atemoya.

Benjoy and Hariharam (1992) described plantlet differentiation in soursop. They found a mean of 4.8 shoots per hypocotyl explant growing in an MS medium containing BAP and NAA. However, they reported only relative success in rooting and survival (35%). To improve the system, Lemos and Baker (1998) suggested the use of sorbitol to induce *de novo* shoot development and Lemos and Blake (1996 c) tried galactose and NAA to stimulate rooting. Nonetheless, no commercial protocol is ready for use.

The first haploid plants induced by anther culture in fruit trees were reported by Nair *et al.* (1983) with sugar apple. The availability of haploids is very important for fruit-breeding, because of the long generation intervals, the highly heterozygous nature of most fruit species and the presence of parthenocarpy and self-incompatibility. These researchers obtained callus differentiation, and formation of triploid roots and shoots from sugar apple endosperm (Nair *et al.*, 1986). Their aim was development of seedless fruits, but a complete plantlet was not obtained.

Shoot proliferation of sugar apple was achieved with hypocotyls and nodal cuttings growing in Woody Plant Medium, supplemented with BAP and silver thiosulphate to control leaf abscission (Lemos and Blake, 1994; 1996 a, b). Rooting was obtained when shoots were preconditioned in medium with activated charcoal, and then treated with NAA or IBA (Lemos and Blake, 1996 b). To improve rooting, they used galactose instead of sucrose in the rooting medium. Eighty percent of the plantlets were successfully acclimatized in the greenhouse (Lemos and Blake, 1996 b). This methodology now needs to be transformed into a commercial protocol.

However, the greatest success in annona micropropagation was obtained in cherimoya. Encina *et al.* (1994) described *in vitro* morphogenesis of juvenile cherimoya and achieved a micropropagation system for adult cherimoya materials, obtaining 50% rooting and exceptionally good acclimatisation (Encina *et al.*, 1999). To increase the success of acclimatisation, Azcòn-Aguilar *et al.* (1994) inoculated cherimoya with arbuscular mycorrhizal fungi to improve growth, survival and development of cherimoya produced *in vitro*. Currently they are working on several methodologies (Encina *et al.*, 1999): a) somatic embryogenesis; b) adventitious organogenesis and cellular cultures; c) ploidy manipulation; d) autotrophy induction; and e) genetic transformation. However, the authors did not mention that these methodologies have already been applied commercially.

Although there are numerous experimental protocols for *Annona* tissue multiplication, the final price of the plantlets is still too high for commercial use. Given the potential of this technology, further research is needed to transform experimental protocols into commercial protocols.

9.5.2 Genetic transformation

Encina *et al.* (1999) have started studying genetic transformation of cherimoya, mainly to optimize the protocol for *Agrobacterium* transformation. The objectives are to control ripening, to change post-harvest characteristics, and to provide pest and disease resistances. For other *Annona* species there are no advanced studies.

9.5.3 Molecular markers

Samuel *et al.* (1991) suggested the use of allozymes to study diversity and systematics in Annonaceae. They considered these systems to be efficient for investigations of the origin of polyploids for breeding programmes. A preliminary study, using eleven isoenzyme loci, was developed with five *Annona* species. Strangely, soursop, mountain soursop (*A. montana*), and pond apple (*A. glabra*) presented no variation between or within the populations studied.

Some isoenzymes studies with cherimoya have been carried out. Groups at the University of California (USA) and University of Granada (Spain) studied the variation in isoenzyme patterns of cherimoya cultivars from the USA and Spain. Both groups found sufficient variation to distinguish cultivars and to evaluate cherimoya germplasm (Ellstrand and Lee, 1987; Pascual *et al.*, 1993). This isoenzyme analysis is important, since cultivars have been confused and are widely known by the wrong names. For instance, there is often confusion with the cherimoya cultivar 'McPherson', which is incorrectly identified in Spain (Grossberger, 1999).

In Mexico, Medina *et al.* (1999) used molecular biological techniques to select soursop varieties according to their resistance to fungal diseases. They analysed the electrophoretic pattern of peroxidase isozymes and observed the variation between isoforms of healthy and infected plants. Since these diseases are detrimental to soursop production, the researchers consider these isoenzyme patterns as markers to select healthy and infected individuals, and potentially to identify resistant and susceptible genotypes.

Isoenzyme studies are limited because they are carried out using a relatively small number of loci. RAPDs offer an enormous number of markers covering the whole genome, and is a more powerful technique for genotype identification and germplasm evaluation. Ronning *et al.* (1995) estimated variation between cherimoya, sugar apple and atemoya, and determined the inheritance of these markers in the F1. All fifteen primers used generated repeatable polymorphic patterns, resulting in a very efficient method to distinguish genotypes of *Annona* species.

In short, the recent biotechnological studies, both cellular and molecular, have shown great potential to further annona development, not only to solve problems of mass propagation of superior cultivars, through micropropagation techniques, but also to identify or fingerprint annona cultivars, as well as to determine cultivar parentage, through RAPD markers.

Chapter 10. Agronomy

A. C. de Q. Pinto

10.1 Propagation

Annona propagation commonly includes sexual or seed propagation, and asexual or vegetative propagation. Since both are still important, each will be examined carefully, since the quality of planting materials depends upon a well-prepared plant.

10.1.1 Seed propagation

If seeds are to be used, they should be obtained from selected mother plants, whose characteristics should include high fruit yield, excellent fruit quality and high resistance to pests and diseases (Torres and Sanchéz, 1992; Coronel, 1994; Agustín and Alviter, 1996). Use of seeds bought at market is not advisable because these characteristics can not be observed at first hand.

Annona seeds generally present uneven and irregular germination, which occurs over a long time, making sexual propagation difficult. However, since seeds lose viability in the field, they should be sown as soon as possible after removal from ripe fruits (Coronel, 1994; Nakasone and Paull, 1998). Seed storage tolerance and later germination success vary among *Annona* species (Table 10-1). Seeds dried and held at low temperatures provide more leeway in time of planting (Torres and Sanchéz, 1992).

Table 10-1. Time of storage (days) to assure 90% seed viability, time (days) for germination, germination percentage, seedling age for transplanting and age if used for grafting

***Annona* species**	**Time of Storage (days)**	**Time of Germination (days)**	**Germination (%)**	**Age for Transplant (days)**	**Age for Grafting (days)**
Cherimoya (*A. cherimola*)	50-60	35-45	90-95	70-100	240
Custard apple (*A. reticulata*)	40-50	30-35	90-95	50-60	180
Soursop (*A. muricata*)	30-40	30-40	90-95	60-90	210
Sugar apple (A. squamosa)	40-50	35-50	85-95	90-120	220

Source: Hernandez (1983).

Irregular germination is due to different levels and types of dormancy (Pinto, 1975 a, b; Ferreira *et al.*, 1997; de Smet *et al.*, 1999; Ferreira *et al.*, 1999; Hernández *et al.*, 1999; Moreno Andrade, 1999). Nevertheless, there still exists disagreement about the presence of dormancy in *Annona* seeds and the correct treatments to overcome it. Sanewski (1991) claimed that no dormancy exists, whereas other authors claim the presence of dormancy (Hayat, 1963; Purohit, 1995; Ferreira *et al.*, 1999; Hernández *et al.*, 1999). A possible hypothesis to explain this disagreement among authors is the degree of seed maturity when tested and the fact that dormancy can be induced by environmental factors rather than being innate. Many of the comparisons below do not give data on how the seed was handled and what conditions it was kept in before testing; hence measures of viability and/or germination results may not be truly comparable.

Pre-treatment of *Annona* seeds is very important and can be physical, such as seed scarification and water immersion to reduce or eliminate the impermeability of the seed coat, or chemical, such as gibberellic acid (GA) to counteract endogenous germination inhibitors (Campbell and Popenoe, 1968; Hartmann *et al.*, 1990; de Smet *et al.*, 1999). Duarte *et al.* (1974) found that dry cherimoya seeds treated with GA at 10,000 ppm significantly increased the seed germination to around 70%, compared with 57% for untreated seed, while hot water showed an adverse effect on seed germination (28%). Pittman (1956) suggested that cherimoya seeds must be soaked in water for 3 to 4 days and then sown in warm soil, after which they will start to germinate in 4 to 5 weeks.

Castillo Alcopar *et al.* (1997) found that germination capacity of cherimoya seed varied from 66 to 94% and period of germination varied between 58 and 69 days after p lanting. They found that seed scarification had only a slight influence on germination. Significantly, all physiological responses were genotype dependent. De Smet *et al.* (1999) evaluated germination percentage and rate in cherimoya using different pre-treatments, such as soaking in different concentrations of GA (extreme values of 500 and 10,000 ppm), soaking for different periods (12-72 hours) in distilled water, and chemical scarification with sulfuric acid. They found that GA showed a positive effect on both physiological parameters.

GA is costly and not affordable for most resource-poor cherimoya growers, especially in developing countries. Soaking in distilled water has shown a significant effect on germination, although germination was less concentrated and more irregular over time; nonetheless, it is a cheaper, though less effective, alternative to GA treatment. Another alternative, which also resulted in rapid and high germination of cherimoya seeds, is soaking for 48-72 h in distilled water, or for a shorter time in hot water (92°C) and gradually cooler water (de Smet *et al.*, 1999). Wild soursop (*A. senegalensis*) produces seedlings rapidly when the seeds are scarified (FAO, 1988).

In general, seedlings show variability in plant growth and fruit yield because they are sexually propagated materials. However, soursop seedlings cultivated in the Cerrado region of Brazil, which generally start flowering and producing at the same age as grafted soursop trees, have similar fruit yield and greater longevity (Pinto *et al.*, 2001). In addition, some seed propagated orchards are used as seed sources for the establishment of rootstocks.

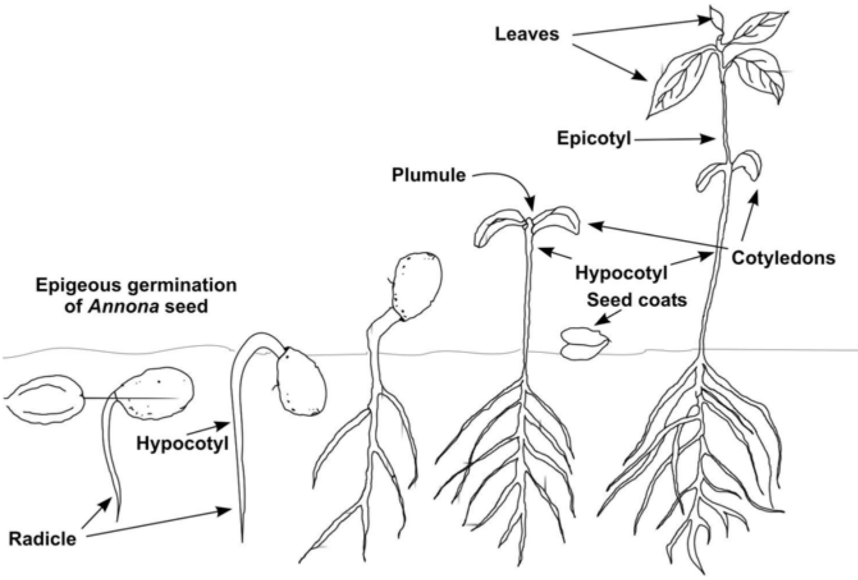
Seeding substrates, especially those with composts, may contain root rot fungi, weed seeds and nematodes, to which most of the annonas species are susceptible, and seedlings may not grow well in their presence. The pre-treated medium should be composed of fine river sand or a mixture of two parts fine sand and one part garden soil (Coronel, 1994) or compost. Therefore, pre-treatment of seeding compost is strongly recommended (Torres and Sánchez, 1992; Junqueira *et al.*, 1996; Kavati and Piza Jr., 1997). Recommendations have included methyl chloride, chloropicrin and other gaseous chemicals (Hartmann *et al.*, 1990); more recently these chemical treatments have been substituted, especially under tropical conditions, by a less expensive and safer treatment called the 'solarization system'. Solarization involves covering compost (thickness of the compost layer should not exceed 30 cm) with a transparent plastic sheet, which allows solar rays to penetrate the medium, thereby increasing the temperature high enough (> 50°C) to kill most problematic soil microorganisms (Plate 2).

The treated substrate is transferred to the germination system used in the nursery. The seeds can be sown directly in perforated black plastic bags (22 cm diameter, 25 cm length and 0.2 mm thick; Pinto and Silva, 1996) or can be sown in seed boxes, seedbeds or other shallow containers, for later transplanting to plastic bags when the seedlings are 8-15 cm tall (Torres and Sánchez, 1992; Coronel, 1994; Agustín and Alviter, 1996; Fuentes, 1999). Seedbeds 1.2 m wide by 4 m long should be prepared, above soil level in order to have good drainage (Fuentes, 1999).

To avoid fungal infection, the seed can be disinfected with a fungicide, such as Zineb, if this is available or can be purchased, applied before sowing. Seeds should be spaced at 1-3 cm apart and 10 cm between rows. They should be sown at about 1-2 cm deep, then covered with a fine layer of soil, which should be compacted gently and watered to saturation (Popenoe, 1974; Coronel, 1994; Fuentes, 1999).

Annona species present epigeous germination. The seed coat must be left to drop naturally without any interference from the nurseryman, to ensure that the plumule and young leaves to emerge without any damage (Fig. 10-1.).

Figure 10-1. Type and sequence of seed germination of annona species



After germination, seedlings grow slowly until they are two to three months of age. At this stage growth accelerates in some annona species, such as soursop, especially during the warmer season. Sugar apple and cherimoya seedlings grow more slowly than soursop seedlings. The best time for grafting of soursop is around 12-13 months after germination. While for budding of sugar apple seedlings, the best time is 15-18 months after germination. Cherimoya seedlings reach the appropriate size for budding or grafting at around 15 months after germination, when the seedling rootstock is about 1 m tall (Scheldeman, 2002). However, the trunk diameter of the seedling is a more appropriate growth measurement to determine the best time for vegetative propagation, which will be explained below.

10.1.2 Vegetative propagation

Due to the generally high variability among seedlings, vegetative propagation of both scions and rootstocks is desirable. To establish an orchard, the grower must evaluate different methods of propagating annonas vegetatively, such as by cuttings, layering, inarching, grafting, budding and micro-propagation, as different species and varieties react differently in each *Annona* growing region.

Seedlings for rootstocks are most effectively kept, in large numbers, in a protected and well constructed nursery with irrigation (Fig. 10-2 and Fig. 10-3), where control of pests, diseases and weeds, as well as seedling fertilization, can be planned and carefully executed. Foliar fertilization should start on 90-day old seedlings and be repeated monthly, before and after grafting, until planting out in the field. A formula that has given good results is composed of 5 g of urea and 15 g of triple superphosphate per litre of water (Torres and Sánchez, 1992). To avoid herbicide phytotoxicity, most annona growers in Brazil control weeds in the nursery by hand once a week, while pests and diseases are monitored daily so as to use a minimum of pesticides for control.

Figure 10-2. A sketch (plan view) of an irrigated nursery for production of grafted soursop and sugar apple trees showing the cement block supports, wires, micro-sprinklers and plastic bags, their distances and characteristics

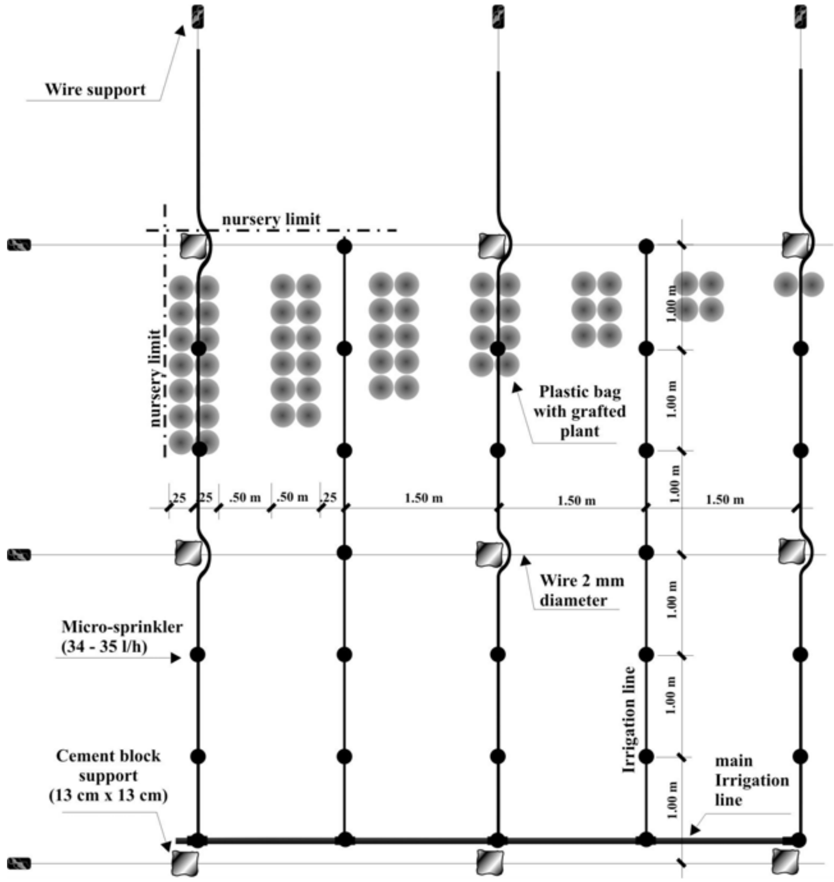
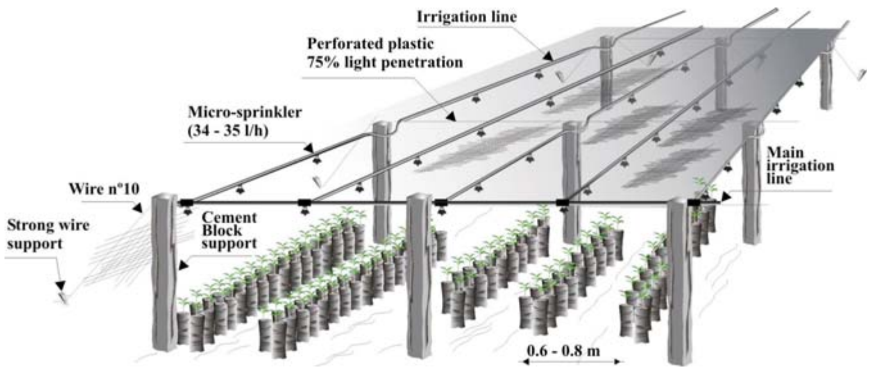


Figure 10-3. A sketch (side view) of an irrigated nursery for production of grafted soursop and sugar apple trees showing the cement block supports, wires, micro-sprinklers and organization of plastic bags, their distances and characteristics



The success of each method varies according to the species grown (Table 10-2) and, in addition, rootstock and scion compatibility has a major influence on the success of vegetative propagation methods among annona species (Table 10-3). Although some species of annonas, such as soursop, can successfully be propagated by cuttings, most are difficult to strike, especially cherimoya. Cuttings of custard apple and sugar apple succeed only with specific cultivars. The experience of the grafter also has a significant influence on the success of the propagation procedure. It should be noted that wild soursop has not been tested in grafting experiments.

Table 10-2. Seed and vegetative propagation methods, commercial recommendations and success for different *Annona* species *

Method	*Annona* Species			
	Cherimoya	**Custard Apple**	**Soursop**	**Sugar Apple**
Genetically (seedling)	Highly variable	Variable	Uniform	Low variability
Commercial Use (seedling)	Not recommended	As rootstock	High; also as rootstock	Regular to good
Stem and tip cuttings	< 25%	Unknown	Successful	Some cultivars only
Root cuttings	Not successful	Unknown	Successful	< 5%
Layering	Unknown	Unknown	Unknown	High if modified technique is used
Air layering	< 5%	Unknown	Unknown	< 8.3%
Budding	> 70%	> 40%	> 40%	> 80%
Grafting	> 70%	> 70%	> 80%	> 70%

Method	*Annona* Species			
	Cherimoya	**Custard Apple**	**Soursop**	**Sugar Apple**
Inarching	Successful	Unknown	Successful	Unknown
Topworking	Unknown	Unknown	Successful	Unknown
Micropropagation	Successful	Unknown	Successful	Unknown

Sources: Bourke (1976); Coronel (1994); George and Nissen (1987); Nakasone and Paull (1998); Torres and Sánchez (1992).
* Information not applicable to wild soursop.

Table 10-3. Rootstock x scion compatibility and the recommended vegetative propagation methods for nine annona species

Rootstock Species	Scion Species			
	A. cherimola	***A. muricata***	***A. reticulata***	***A. squamosa***
A. cherimola	C; budding, grafting	NC; none	Unknown	C; grafting
A. glabra	Unknown	LC; budding	C; budding	C; budding, grafting
Atemoya	C; budding	NC; none	NC; none	C; budding, grafting
A. montana	Unknown	C; grafting	Unknown	Unknown
A. muricata	NC; none	C; budding, grafting	C; budding	LC; none
A. reticulata	C; budding	C; budding, grafting	C; budding	C; grafting
A. senegalensis	Unknown	Unknown	Unknown	Unknown
A. squamosa	LC; none	LC; budding, grafting	C; budding	C; budding, grafting
Rollinia spp.	C; unknown	C; grafting, budding	Unknown	NC; none

C = Compatible; LC = Low compatibility; NC = Not Compatible.

Sources: Duarte *et al.* (1974); Popenoe (1974 a, b); Pinto (1975); Hernandez (1983); Iglesias and Sanchez (1985); Ferreira *et al.* (1987); George and Nissen (1987); Ledo and Fortes (1991); Singh (1992); Torres and Sánchez (1992); Coronel (1994); Pinto and Silva (1996); Bezerra and Lederman (1997); Nakasone and Paull (1998).

Attempts to propagate cherimoya by root cuttings treated with various combinations of benzylamino purine (BAP) and indole butyric acid (IBA) had no success after 4 months, even though some cuttings produced a few roots (George and Nissen, 1987). Hardwood and leafy terminal cuttings of cherimoya taken at monthly intervals and placed in an outdoor rooting bed or under mist conditions, respectively, were treated with 0, 1250, 2500 and 5000 ppm of napthalene acetic acid (NAA). None of the cuttings taken from adult trees rooted, but some leafy terminals taken from one year old plants did, with as much as 25% and 20% rooting with 5000 ppm NAA treatment in December and January, respectively (Duarte *et al.*, 1974). George and Nissen (1987) commented that etiolation of propagation materials has given good results with a high percentage of take in a preliminary study of cherimoya propagation by cuttings. They said that the extra costs involved in producing plants by this method may be compensated for by the higher yields and disease resistance of clonal trees. However, no commercially viable method for vegetative propagation by cuttings exists to date in cherimoya.

Tip cutting propagation has been described for atemoya (*Annona cherimola* x *A. squamosa* hybrid), with greater success when leaves are attached, versus without leaves (George and Nissen, 1987; Hartmann *et al.*, 1990). Atemoya tip cuttings were propagated in mist beds containing a sterilized 50:50 sand:perlite mix and bottom heat with temperatures between 25 and 28°C (George and Nissen, 1980). An important environmental factor influencing tip-cutting success is humidity, since desiccation of cuttings prior to placement in mist beds is a common cause of failure.

In Florida, mature and healthy stem cuttings of sugar apple taken during the dormant period were propagated successfully by Noonan (1953). He used shoots between 0.5 and 1.0 cm in diameter and cut into 13-15 cm lengths, then set them in sand to a depth of 4/5 of their length with one bud exposed above the surface. The cuttings produced roots 25-30 days after planting. Bourke (1976) evaluated propagation of sugar apple by root cuttings and obtained success percentages of less than 5%.

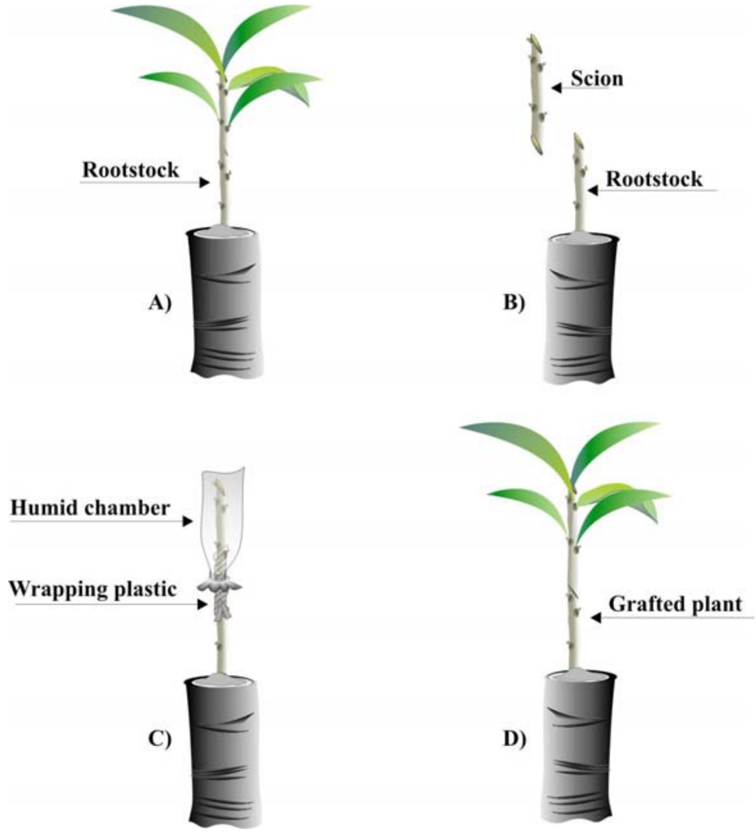
Layering is a type of vegetative propagation by which adventitious roots are produced on a stem while it is still attached to the parent plant (Hartmann *et al.*, 1990). A modified layering technique was used by George and Nissen (1986) with 100% take. They used one year-old cherimoya seedlings and cut them back severely in mid-summer to produce 3-5 juvenile shoots. When the new shoots were approximately 15 cm long, metal growth constrictor rings were placed over each shoot, then a polyethylene sleeve was placed over each shoot and filled with a mixture of 50% sand and 50% sawdust, leaving only the growing points exposed. Excellent root systems were produced 4-5 months later. Marcottage (air-layering) of limbs 1.0-1.5 cm diameter on mature trees of cherimoya cultivar 'Deliciosa', however, was unsuccessful, with less than 5% of marcots rooting (George and Nissen, 1987).

Orchards established with cuttings are more uniform and less expensive to establish than grafted trees, when cutting materials are taken from pruned branches. However, cutting and air-layering methods do not produce taproots and plants are more susceptible to falling over in strong winds, with subsequent damage and orchard loss. Hence, these vegetative propagation methods are not recommended where strong winds are a problem.

Cherimoya, soursop and sugar apple can all be successfully inarched with a high percentage of success (Morton, 1967; Viñas, 1972; Castillo Alcopar, 1997). The inarching method is used to join rootstocks to selected scion cultivars which are otherwise difficult to root or to graft as detached scions, as well as to invigorate weak-growing trees by augmenting their root systems (George and Nissen, 1987). However, this method is much more difficult to work with and it shows a higher cost/benefit ratio compared with the grafting and budding methods.

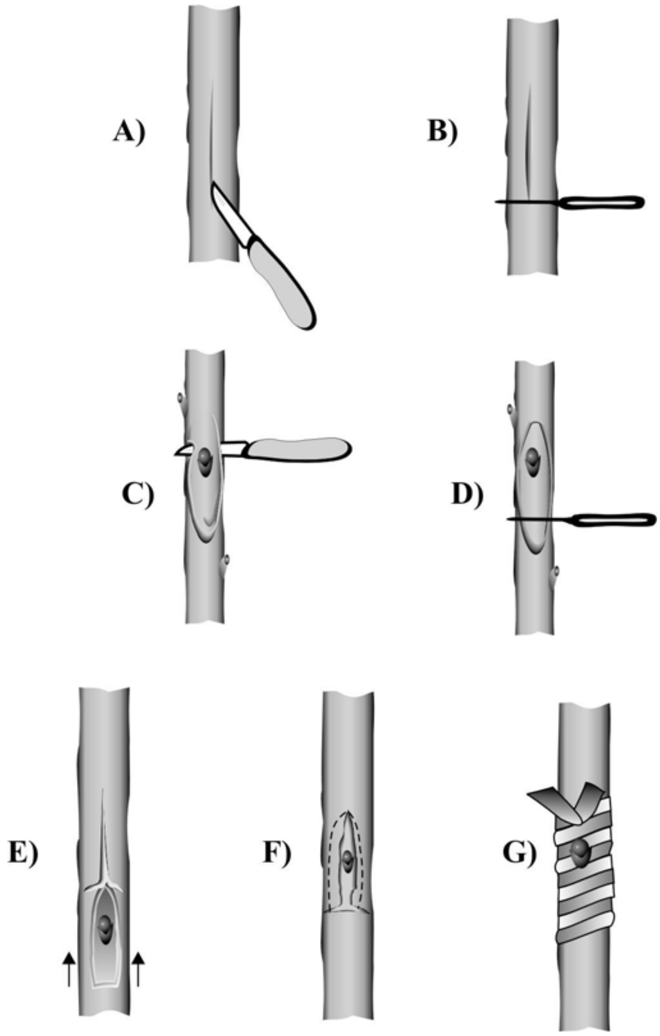
The annonas are easily propagated by budding and grafting, although the success varies among species. In general, grafted plants grow rapidly but do not bear fruit any earlier than seedling stocks. Several authors (Moran *et al.*, 1972; Duarte *et al.*, 1974; George and Nissen, 1987; Torres and Sánchez, 1992; Pinto *et al.* (2001) and Nakasone and Paull, 1998) have described splice grafting (Fig. 10-4), also called cleft grafting, as well as shield-budding and inverted T budding (Fig. 10-5), as the most successful methods for vegetative propagation of annonas. Generally, annonas have shown higher percentage take when propagated by grafting in comparison to other methods, except for sugar apple, which shows a greater success with budding (Table 10.2).

Figure 10-4. Splice grafting: A) annona rootstock; B) scion from selected cultivar and cut rootstock; C) wrapping of scion and rootstock producing a humid chamber with a transparent plastic bag; D) new grafted plant



In Ecuador, grafting of cherimoya takes place 15 months after transplanting, when the seedling rootstocks are 30-40 cm tall and the stem diameter is 0.5 cm, and has up to 90% success (Fuentes, 1999). Four types of grafting (splice, cleft, whip-and-tongue, and crown) and shield-budding were evaluated by Moran *et al.* (1972) with scions of two diameters (0.8-1.0 cm and 1.2-1.5 cm) on cherimoya seedling rootstocks of the same cultivar. They found no differences in percentage take between the two sizes of rootstock, but subsequent growth was better on the thicker rootstock. Both the budding and the four grafting methods led to a success rate of at least 70%. The crown grafts took more quickly, but shield-budding led to superior growth compared to the other methods. However, splice and whip-and-tongue graftings on thick rootstocks were considered to be the best as regards percentage take, subsequent growth and cost (low).

Figure 10-5. Steps of the inverted T - budding technique: A and B) rootstock cut and prepared for budding; C and D) collecting bud from selected cultivar; E and F) insertion of the bud into the rootstock stem; G) wrapping of the bud. Adapted from Hartmann *et al.* (1990)



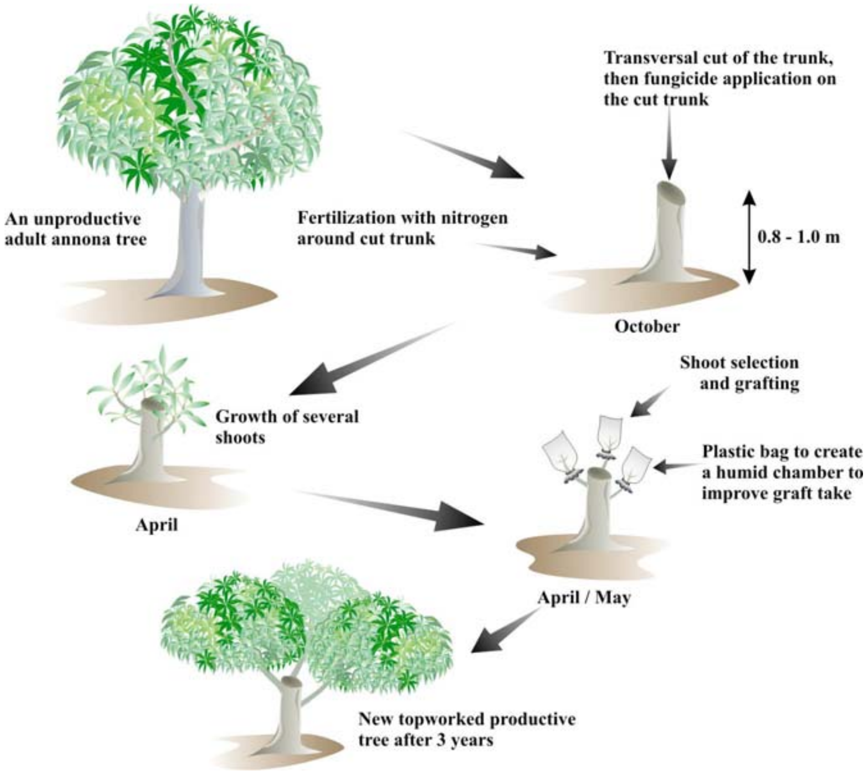
In Colombia, Iglesias (1984, cited by Torres and Sánchez, 1992), used three budding methods (double bud, patch and shield-budding) and two grafting methods (whip and veneer) to propagate soursop on several rootstocks (commercial soursop, a local soursop type called Chocó soursop, custard apple, and sugar apple). The shield-budding method on both soursops as rootstocks showed the highest percentage take, with 83% of success. The graft or bud union should be placed 15-20 cm above ground level (Pinto and

Silva, 1994; Nakasone and Paull, 1998) to avoid long trunks and tall canopies.

Both budding and grafting are better carried out in spring with the start of sap flow (Wester, 1912; Campbell and Phillips, 1983). According to George and Nissen (1986), in the Philippines patch budding of sugar apple is recommended prior to leaf abscission, which occurs during the dry season (November to February).

Occasionally an annona grower may establish an orchard with an unproductive or unpopular cultivar, whose negative results will only show up three years later. He can replace the undesired canopy by using top working methods (George and Nissen, 1987), essentially establishing a new productive orchard with a high quality cultivar without replanting (Fig. 10-6).

Figure 10-6. Steps of the topworking technique used to regenerate an unproductive canopy of an annona tree



A reliable *in vitro* method for propagation of *Annona* species would be of considerable benefit to the annona industry because it would allow rapid clonal propagation of superior yielding and disease resistant varieties, as well as enabling clonal multiplication of superior rootstock material in areas where grafted *Annona* species are required (Rasai *et al.*, 1994). In addition, micro-propagation would facilitate the exchanging of germplasm materials among research centres. However, rapid multiplication with sustained proliferation and *in vitro* rooting has always proved to be difficult.

10.2 Field establishment

10.2.1 Orchard location

The location of an orchard is important as this will influence the quality of the fruit and the potential income generated. There are a number of factors to be considered before investing in the establishment of an annona orchard, or the incorporation of annona trees into existing small holder farming systems.

The climatic conditions of an existing or potential orchard location will determine which species and/or varieties can be grown and their performance under these conditions. The ecological requirements of the annona species highlighted here are detailed in chapter 5 - Ecology.

The soil type is also very important. Although most of the *Annona* species grow on a wide range of soil types, from sands to clay loams, higher yields are attained from trees grown in sandy loam soils. Soils should be free draining as *Annona* species do not grow well in soils with drainage problems and a high water content in the soil can encourage root diseases (Nakasone & Paull, 1998).

Plenty of water for irrigation is essential and proximity to a paved road is also important, especially if the grower is concerned about fruit yield and quality. In addition, proximity to a large market will allow a higher income, principally by saving on transportation costs.

10.2.2 Land preparation

The orchard area must be cleared of shrubs and weeds. Four to six months before ploughing, a soil sample can be taken to determine the lime requirements and soil nutrient levels (Nakasone and Paull, 1998); section 10.3.5. provides the standard methodology for sampling, however the local extension agent should be consulted about sampling methodologies for specific locations. Lime and phosphorus are applied before ploughing and harrowing (see section 10.3.5 for recommendations), although phosphorus can also be applied in the planting pit (Pinto and Silva, 1996; Nakasone and

Paull, 1998). Drainage should be installed at this time to avoid flooding, with either contour or subsurface drains.

On a medium to light texture oxisol, ploughing to a maximum soil depth of 30 cm and harrowing twice should be carried out 1 to 2 months before the wet season to attain the desired soil tillage. This operation will also expose the soil seed bank in order to eliminate most of the undesirable weeds (Pinto and Ramos, 1997).

Depending on the degree of slope, the grower can use one of three types of planting systems: square (Fig. 10-7 A), rectangular or quincuncial (also called triangular) (Fig. 10-7 B). In orchards with slopes greater than 3%, the soil should be prepared along contour lines and the quincuncial system should be used to minimize soil erosion (Figs. 10-8 A and 10-8 C). On the other hand, flat land (with slopes less than 3%) does not need contour line practices, and can use a square (Fig. 10-8 B) or rectangular planting system. Nakasone and Paull (1998) suggest that minimal tillage can be achieved with a 2 m wide cultivated band where the trees are to be planted.

Figure 10-7. Soursop planting systems: A) square and B) quincuncial. Adapted from Torres and Sánchez (1992)

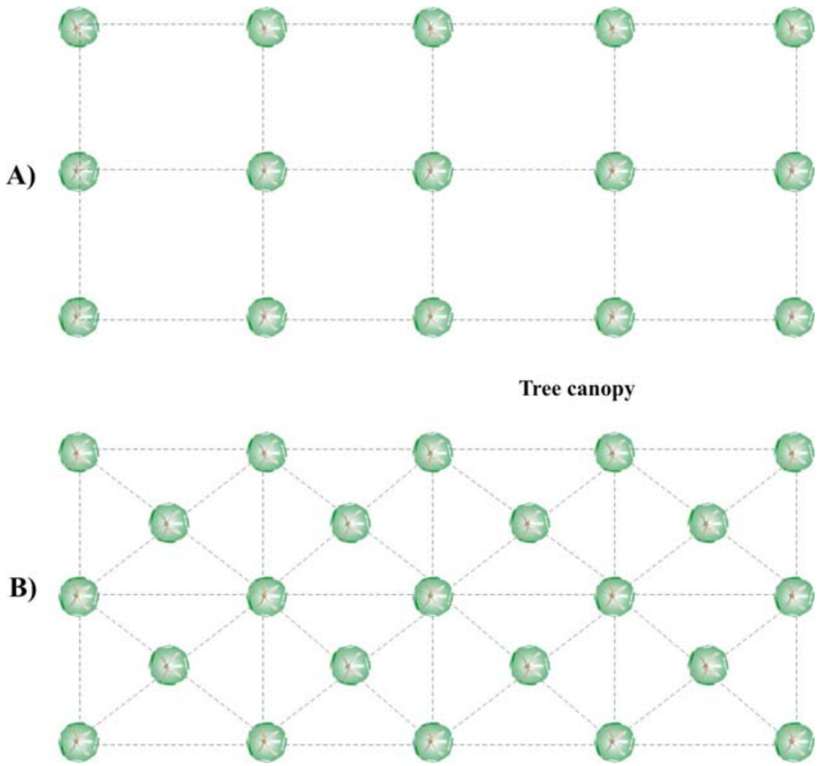


Plate 1. Purple skinned sugar apple is commercialized as an exotic fruit, since its colour makes it look somewhat like a rotten fruit thus limiting its acceptance at consumer market.

Plate 2. A solarization system is used as a pre-planting treatment for germination and seedling growth media to control fungi and nematode attacks.

Plate 3. An intercropping system using sugar apple (main crop) and papaya (secondary crop) can help growers to earn additional income.

Plates 4 and 5. Small plastic containers (e.g. empty film-roll holders) carry pollen (above) and should be kept in the operator's pocket (below), to facilitate hand pollination.

Plate 6. *Annona* fruit borer (above left), seed borer (also called soursop wasp; above right) and trunk borer (below) are the most important annona pests.

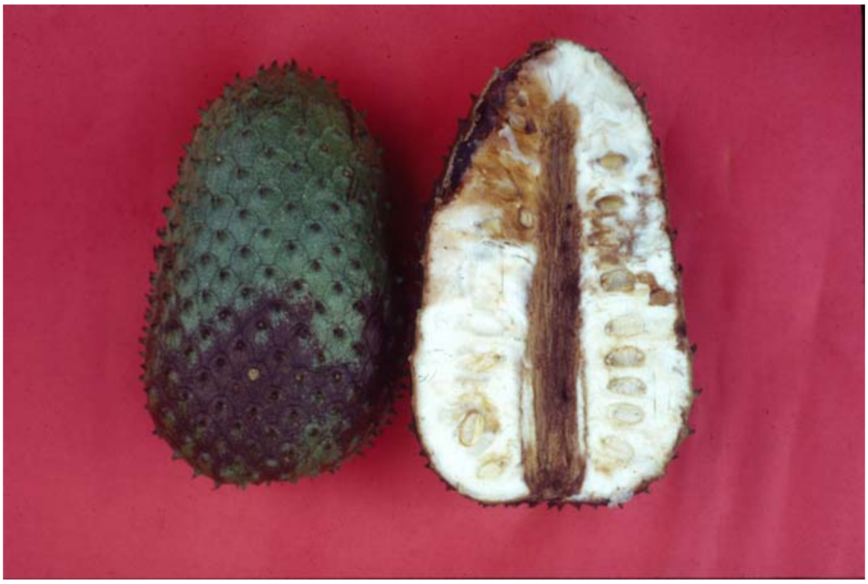


Plate 7. Soursop damaged by brown rot disease caused by the fungus *Rhizopus stolonifer.*

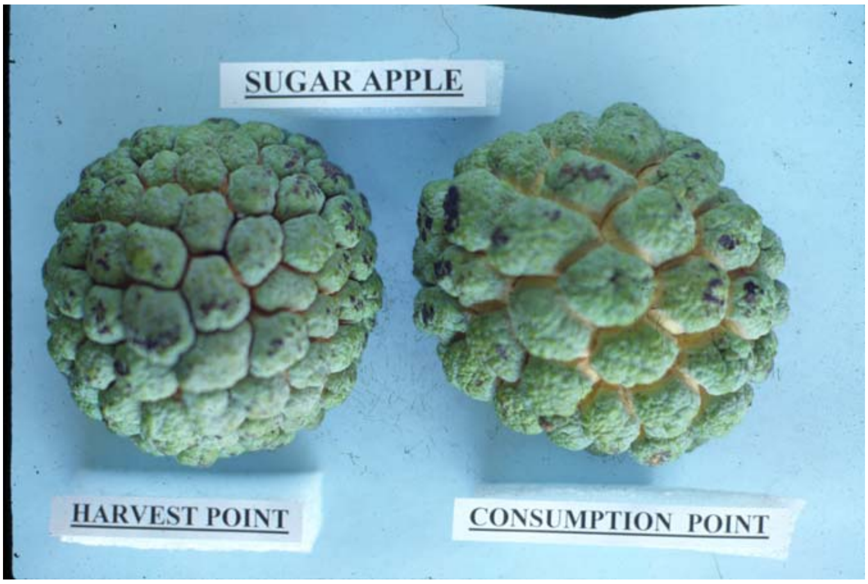
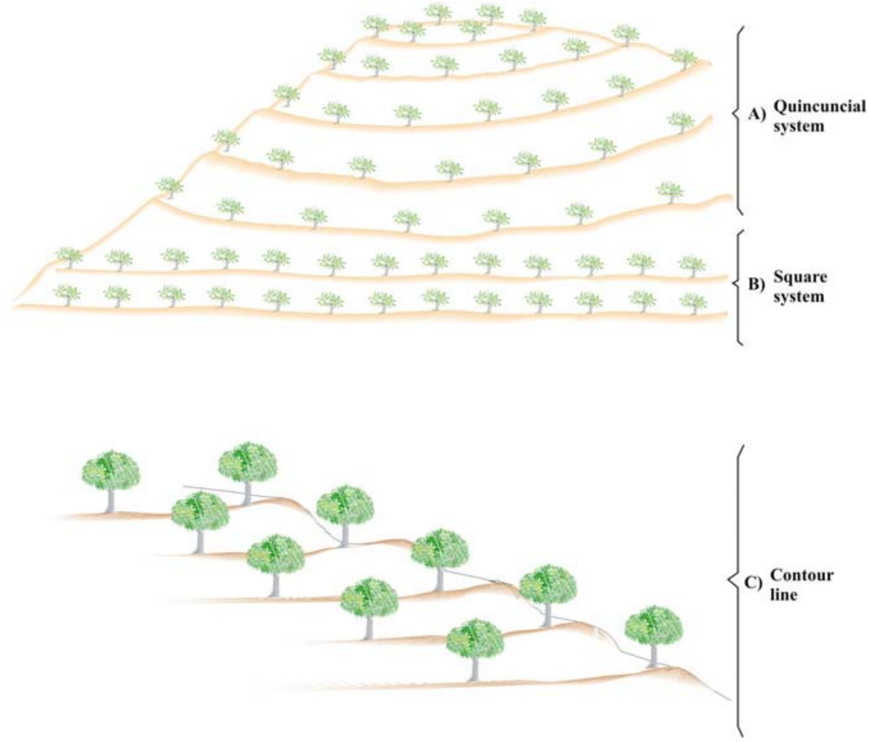


Plate 8. Mature sugar apple fruit at its "harvest point", and fully ripened fruit at its "consumption point".

Figure 10-8. Planting system according to the slope of the land. A) Quincuncial system; B) square system; and C) contour line. Adapted from Torres and Sánchez (1992)



10.2.3 Time of planting

The best time for planting is at the beginning of the wet season, this minimizes frequent watering after planting, especially if there are seasonal dry periods and no irrigation facilities (Torres and Sánchez, 1992; Pinto and Ramos, 1997). When irrigation is provided, planting can be performed in any season, although low air relative humidity can cause leaf dryness and possible plant death. Hence, even with irrigation, wet season establishment is preferable.

10.2.4 Direct seeding

Direct seeding in the field is the traditional method and may still be used on small holder farms, but is not used commercially any more. Although this method can, supposedly, save time and money with nursery management of the rootstock, its cost-benefit ratio is likely to be very high, considering that grafting operations in the field have very low success, obliging the grower to replant the orchard later.

10.2.5 Transplanting and spacing

In general, annona plants are ready for transplanting into the field or for use as rootstocks when they are about 8 to 15 months old, have attained a height from 50 to 100 cm and have at least 4 to 6 mature leaves. Before transplanting, many growers cut the leaves in half, to reduce transpiration, and cut the tip of the main root, apparently to induce production of more lateral roots. Both are empirically developed practices and have not been validated by research.

The plastic nursery bags should be removed and the plant's collar placed at the ground level or, at the most, a few centimetres above the ground level if a planting depression is used to facilitate watering. The young plants should be irrigated as soon as possible after transplanting and they should be supported to avoid wind damage. Also, a mulch should be provided to avoid soil dryness around the newly transplanted materials. Although thick black plastic can be used to cover the area under the canopy of the new annona tree to avoid water loss through evaporation, dried grass or rice husks are much more practical materials; they are also biodegradable and avoid environmental problems, as well as being cheaper and easily found in the field.

Current field spacing ranges greatly among commercial orchards, from 6 x 4 m to 8 x 6 m for cherimoya (George and Nissen, 1992), 4 x 4 m to 8 x 8 m for soursop (Torres and Sánchez, 1992; Pinto and Silva, 1996; Pinto and Ramos, 1997), 3 x 3 m to 5 x 5 m for sugar apple (Coronel, 1994) or 4 x 4 m on poor soil and 5 x 7 m on good soil (Singh, 1992). There is no experimental information on the recommended spacing of custard apple, this is certainly due to the absence of commercial orchards. For wild soursop, 5 x 5 m is recommended (FAO, 1988).

Some authors (Campbell and Phillips, 1983; Nakasone and Paull, 1998) comment that annona spacing also depends upon the rootstock and pruning management. In Florida, narrow plant (4 - 6 m) and row spacing (6 - 7 m) is used for cherimoya; the rows run North-South in a triangular layout, whatever the planting distance used. Narrower spacing is also used for atemoya ‘African Pride’ on sugar apple rootstock and the widest spacing for atemoya ‘Pink's Mammoth’ on cherimoya. In Brazil, soursop spacing varies from 6 x 6 m to 8 x 8 m (Pinto and Silva, 1996), while sugar apple has a wider range of spacing depending on the rootstock vigour, and varies from 6 x 4 m with sugar apple as a rootstock to 8 x 5 m with custard apple as a rootstock (Kavati and Piza Jr., 1997).

10.3 Orchard management

Orchard management can be complex and there is a need to experiment to ascertain the validity of many aspects. Innovation is also needed, e.g. intensive cultural methods, such as trellising or espaliering, require study. NRC (1989) reported that espaliering of cherimoya in Madeira (Portugal) was extremely successful.

10.3.1 Windbreaks

Since most of the *Annona* species are shallow rooting and consequently very susceptible to wind damage, the use of windbreaks is an important orchard practice, particularly during the first three years (George *et al.*, 1987). The windbreak should be established prior to transplanting the annonas into the field. Casuarina (*Casuarina equisetifolia*) has been used in some Brazilian regions as a windbreak, although this species is very competitive for water and is susceptible to natural combustion, thus offering a fire risk. The best option is to consult the local extension service about windbreak species that have proven useful locally, as well as their placement, which depends upon their root distribution, plant height and crown density.

10.3.2 Pruning

Tustin (1997, cited by Castro *et al.*, 1999) stated that pruning is an important cultural practice used to regulate the tree canopy. It influences growth by manipulating the balance between vegetative and fruiting growth (Cautin *et al.*, 1999). Current pruning methods in cherimoya produce shoots with variable levels of vigour.

The literature mentions several types of pruning of annona trees, such as for tree shape, maintenance, rejuvenation and production (also called green pruning) (Torres and Sánchez, 1992; Agustín and Alviter, 1996; Pinto and Ramos, 1997; Nakasone and Paull, 1998; Bonaventure, 1999). However, Alvarez *et al.* (1999) pointed out that there are basically only two types of pruning: for plant formation and for plant production.

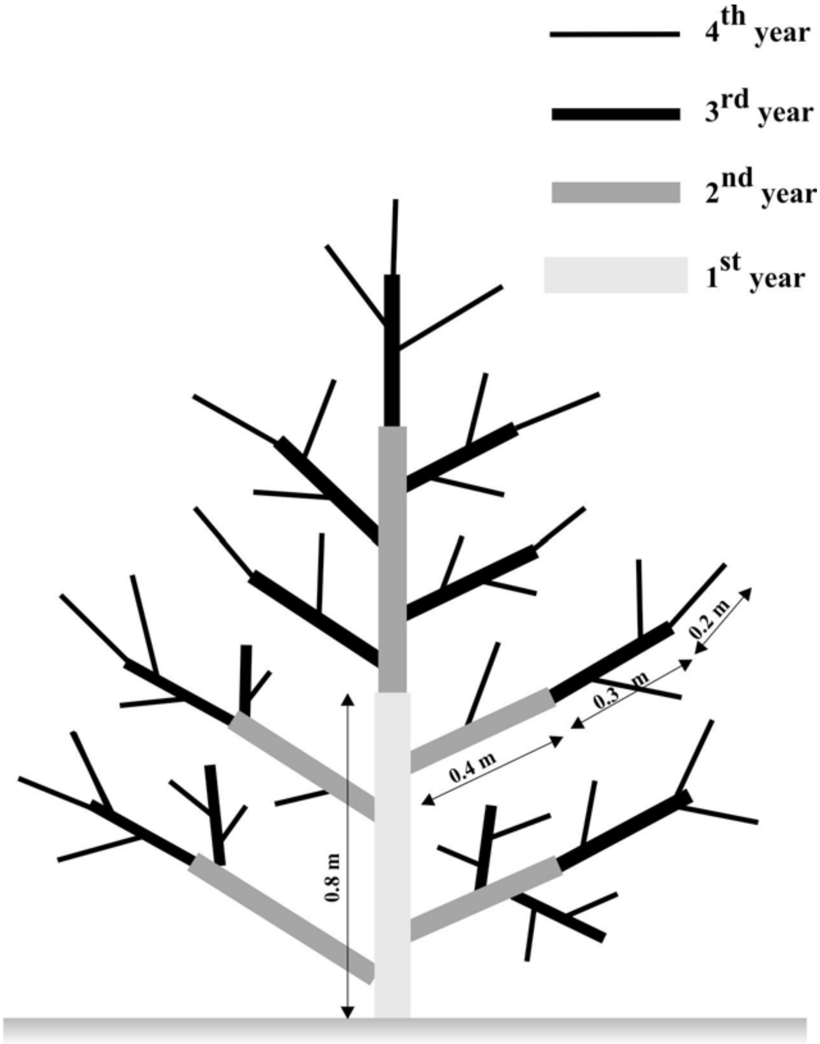
Pruning for plant formation begins in the first year at the same time as the training operation, though this may vary according to the species, and continues until the fifth year after planting out (Agustín and Alviter, 1996). It is necessary to begin training cherimoya trees in the nursery (Nakasone and Paull, 1998), however, soursop and sugar apple produce their branches close to the ground and have a single trunk (Coronel, 1994; Pinto and Ramos, 1997), therefore, they do not require interference at such an early stage.

Pruning has several objectives: a) development of good tree architecture in order to increase yield; b) acceptable aeration and light penetration; c) ease of access for cultural practices, such as artificial pollination, pesticide spraying and harvesting; d) removal of lower limbs (especially those touching the ground) and branches that are rubbing against each other (Torres and Sánchez, 1992; Pinto and Ramos, 1997; Nakasone and Paull, 1998; Bonaventure, 1999).

Anderson and Richardson (1992) described an additional pruning practice that should be carried out during the first 4 years. This involves cutting the single trunk at 80 cm height, to stimulate production of primary branches. In the spring of the second year, the primary branches should be cut at a length of 40 cm to stimulate production of secondary branches. Similarly, in the third and fourth years, the same pruning procedures should be made to the secondary and tertiary branches, however, with 30 cm and 20 cm lengths, respectively (Fig. 10-9). It is important that care be taken during this procedure to ensure that a large number of internal branches do not remain and impede the necessary canopy aeration. Therefore, this type of pruning should be supplemented by an annual pruning through which better aeration of the internal canopy is maintained (Nakasone and Paull, 1998).

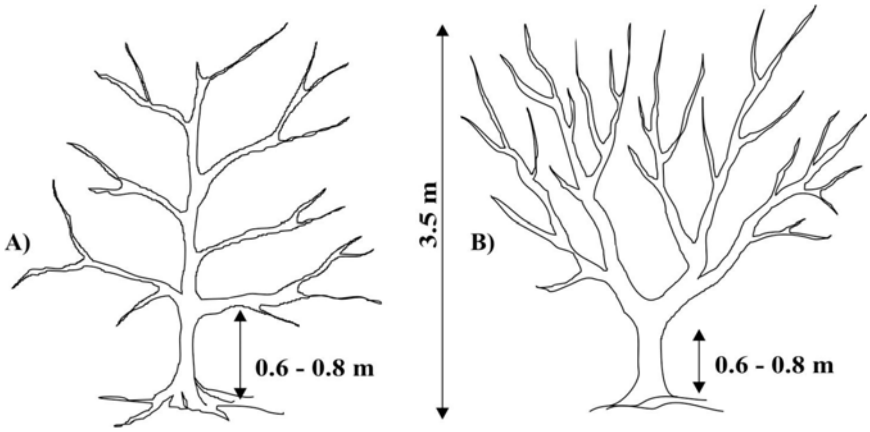
Agustín and Alviter (1996) described different pruning methodologies for cherimoya involving the maintenance of two and three principle branches. Pruning using the two-branch system should begin between the fourth and the fifth month after transplanting. The two principal branches should be selected according to their vigour, and the others should be removed establishing a v-shaped training type (resembling two fingers in an opened position). The three-branch system described by Nakasone and Paull (1998) requires the complete removal of the top part of the tree leaving 90 cm of the main trunk, this encourages the production of lateral branches. Agustín and Alviter (1996) commented that these lateral branches should be at angles of approx. 120° from each other. These new branches should be spaced at 15-25 cm above each other in different directions to develop a good scaffold by the fifth year after planting, when the plant is about 2 m tall (Nakasone and Paull, 1998). The tree can then be allowed to grow naturally while maintaining good aeration.

Figure 10-9. Stylized diagram of cherimoya tree formation with length of the growing branches of subsequent years. Adapted from Anderson and Richardson (1990)



Torres and Sánchez (1992) describe two types of pruning for soursop tree formation, both called 'free canopy shapes': a) pruning to keep a central axis with horizontal lateral branches (Fig. 10-10 A); b) pruning to keep forked branches (Fig. 10-10 B). Branch formation should begin between 60 and 80 cm above the soil, and plant height must be kept to 3.5 m (Fig. 10-10).

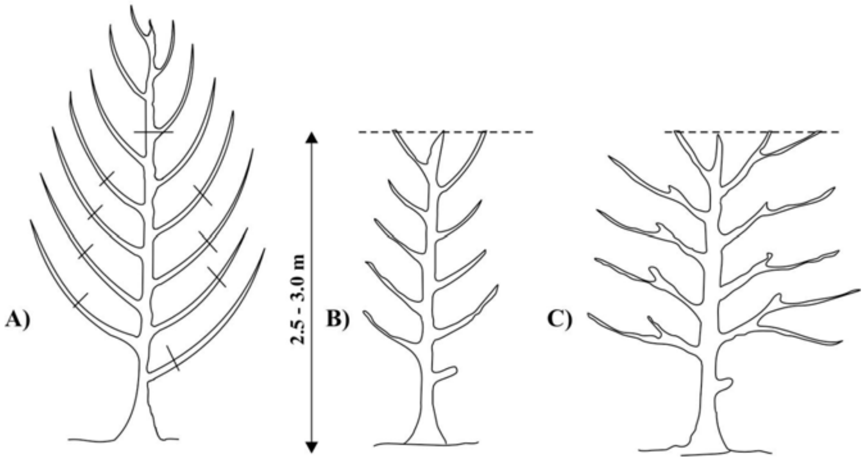
Figure 10-10. Two types of pruning for soursop tree formation: A) by keeping a central axis and horizontal lateral branches; B) by keeping forked branches. Adapted from Torres and Sanchéz (1992)



During the pruning for soursop tree formation it is important to break the apical dominance of branches, in order to promote the growth of new lateral branches; this is followed by another pruning to leave 3 to 4 well distributed new branches, with insertion angles of approx. 30° in relation to the trunk (Torres and Sánchez, 1992). Soursop trees naturally produce a symmetrical canopy well adapted to a central-leader system; therefore, a good alternative for soursop tree formation is to develop a mushroom-shaped tree that is topped at a height of 2.0-2.6 m (Nakasone and Paull, 1998). When the soursop tree is properly trained, little pruning is required, except to thin out poorly placed and weak branches, as well as the annual pruning of the longest branches extending horizontally and vertically (Nakasone and Paull, 1998).

Torres and Sánchez (1992) described pruning for the maintenance and rejuvenation of soursop. Pruning for maintenance is required two to three times a year, preferably after harvesting. It consists of the elimination of undesirable branches, i.e. those which are not productive, dried twigs and dead branches, or those which are diseased; it also includes the elimination of branches above 2.5 m height to avoid excessive growth and alternate yield, and to promote better quality fruits. Pruning for rejuvenation is done in old soursop orchards, where the semi-abandoned tall trees (Fig. 10-11 A) have excessive branching with low yield capacity. All vertical branches are eliminated including the thick lateral and terminal ones (Fig. 10-11 B), in order to attain a plant height of 2.5-3.0 m, then training the new lateral branches into horizontal positions at a later date (Fig. 10-11 C).

Figure 10-11. Pruning for rejuvenation of a soursop tree: A) canopy of an old soursop tree before pruning; B) pruning of lateral and terminal branches; C) training of lateral branches into horizontal positions. Adapted from Torres and Sánchez (1992)



Pruning is not usually carried out on sugar apple trees in arid regions, except to remove unproductive old branches (Singh, 1992). No information is available for custard apple. Methods of pruning have not been worked out for wild soursop, but the trees respond well to coppicing (FAO, 1988).

Pruning for plant production is very common in cherimoya and sugar apple (Agustín and Alviter, 1996; Bonaventure, 1999). However, the literature does not mention pruning for production in soursop (Torres and Sánchez, 1992; Pinto and Ramos, 1997). The position of the bud may be the reason for this, since soursop has its lateral buds in the leaf axil while cherimoya and sugar have subpetiolar buds ('buried buds') in the base of the swollen leaf petiole (Nakasone and Paull, 1998).

Leaf shed in cherimoya and sugar apple generally occurs prior to the elongation of the 'buried buds', so that mechanical removal of leaves, by stripping, or chemical removal, with urea or ethephon, will release these buds (George and Nissen, 1987). However, this technique is not recommended for soursop. Bonaventure (1999) describes this method as 'green pruning' and affirms that it is very important in cherimoya. He mentions the two most important types of green pruning: the first type to reduce excessive vegetation; and the second to separate the two or three new leaves, followed by removal of the apical bud with the finger nail. According to this author, it is possible to promote late production by using green pruning.

George *et al.* (1987) commented that chemical pruning by defoliation of cherimoya and sugar apple trees is necessary for cultivars exhibiting strong apical dominance, since light fruiting-pruning may not be sufficient to release many buds from induced dormancy. They also commented that a range of defoliants have been investigated, but a mixture of 250 g urea and 1 g ethephon, plus wetting agent, in 100 litres of water has been most successful. Two defoliation periods are possible: a) at 5 to 10% bud-break, when the new shoots are about 3 to 5 cm long; and b) at mid season (first week of January in Australia), applied to non-bearing trees, usually 2 to 3 years of age.

Pruning for production of sugar apple is very important, since bearing sugar apple trees seem to deteriorate, in terms of fruit production, faster than any other annona (Coronel, 1994). The heading back of the branches at the onset of dormancy to rejuvenate sugar apple trees will result in resumed production after 2 years (Coronel, 1994). Dormancy of sugar apple buds depends on the climate. In south-eastern Brazil, dormancy is due to low temperatures between May and July, while in the semi-arid areas of the north-eastern region it is due to strong drought (water stress) during several months (Kavati and Piza Jr., 1997).

In Thailand, sugar apple trees are rejuvenated every year to produce new fruiting shoots. This operation consists of removing all small shoots and heading back larger shoots to about 10-15 cm long (Coronel, 1994). This operation is carried out during the dry season, just prior to shedding of the leaves; the plants are then irrigated to promote new shoots and irrigation is continued until the rainy season starts. This is the same procedure as in north-eastern Brazil.

The pruning for production of sugar apple should begin with 1-year-old branches by cutting them back to 10 cm and leaving 120-150 branches per tree (Nakasone and Paull, 1998); flower initiation will then begin at the basal end of the new growing branch. In China and Taiwan, normal fruit pruning occurs in January/February, with harvesting from July to September. However, a summer pruning with fruit thinning (June-October) can lead to harvesting from October to March, effectively increasing the fruit availability. The highest winter fruiting occurs when summer sprouts are pruned as compared to pruning non-fruiting shoots or pruning in late May. In India, light pruning is carried out on budded plants. In São Paulo, Brazil, the summer pruning is from January to March with harvest from August to October, since the late pruning (after March) can promote flowering during periods of low temperature, leading to reduced fruit set (Kavati and Piza Jr., 1997). There are no such problems in north-eastern Brazil, since high temperature, low precipitation and irrigation stimulate successful fruiting of sugar apple, which is managed by pruning.

10.3.3 Orchard maintenance, intercropping and cover-cropping

In most annona orchards, weeds were traditionally eliminated by using hand tools, such as mattocks. Nowadays, this practice has been substituted by herbicides in commercial orchards. In Spanish cherimoya orchards the herbicides most commonly used are simazine or terbumeton mixed with terbuthylazine as pre-emergence treatments, and glyphosate or a mix of paraquat and diquat as post-emergence treatments (Farré *et al.*, 1999). The irrigation system is often used to apply the pre-emergence herbicides. However, phytotoxicity may occur after herbicide application.

Mulching is a very common maintenance system used mainly during the first years after planting, since it has a number of positive effects. These include improved distribution of humidity in the soil, reduction of evaporation losses, avoidance of crust formation on the soil, increased development of healthy feeder roots improving efficiency of fertilizer use (Farré *et al.*, 1999; George *et al.* 1987), and reduction of weed infestations. As consumers demand chemical-free fruit, mulching will become increasingly more important. In practice, dried grass is a practical and cheap material to be used for mulching.

Annonas can be grown as a mono-crop in high density orchards or as an intercrop among larger fruit trees, such as mango and citrus (Ochse *et al.*, 1994), or on small holder farms. Even as the main crop, the space between sugar apple trees may be planted with other fruit crops, such as papaya, which is a common practice in north-eastern Brazil (Plate 3). It is also possible to intercrop annonas with annual field or vegetable crops to earn additional income from the land during the first 2-3 years before annona production.

The establishment of perennial leguminous or other cover crops, such as beans, can provide not only additional income, but also avoid soil erosion and improve the physical structure of the soil. Short grass can be used as a cover crop in the first 12 months after transplanting (Nakasone and Paull, 1998), although fertilization needs to be modified to supply two crops instead of one. A wild peanut (*Arachis pintoi*) is currently being tested at Embrapa Cerrados Agricultural Research Centre, and has so far been very successful. Cover cropping may become more important as consumers demand chemical-free fruit.

10.3.4 Flowering, pollination and fruit set

Annona flowers are hermaphrodite; both female (carpels) and male (stamens) organs are in the same flower. However, the female part matures before the male, which is known as dichogamy of the protogynous type. According to Mansour (1997), there is a short period of stigma receptivity after anthesis, which is 2-3 h in dry weather. Natural pollination is carried out mainly by insects, such as Coleoptera (beetles), but is ineffective in several countries (Saavedra, 1977; Pinto and Silva, 1996; Grossberger, 1999). In Chile, insects rarely visit a cherimoya flower which suggests that entomophilous pollination plays only a secondary role in this species (Saavedra, 1977). Cherimoya is a native species in Chile and should have co-evolved insect pollinators if it were important.

Although dichogamy and the low population density of pollinator insects are important limiting factors to successful natural pollination, the effect of climate and pollen viability seem to interfere greatly with the response to both natural and artificial (hand) pollination. The effects of these factors may result in fertilization failure of all or several ovules, resulting in small or asymmetrical fruits, which obviously affects yield and commercialisation (Saavedra, 1977). Most annonas flower when atmospheric humidity is low (Saavedra, 1977), suggesting the importance of humidity in drying out the stigmas and lowering pollen germination.

Anthesis (flower opening) is most common in the morning or in the evening, indicating that it is favoured by low temperatures (Mansour, 1997). Studying the problem of fruit set on custard apple in Dhawar, Egypt, Farooqi *et al.* (1970) found that flower opening occurs from early morning until noon and that the stigma is more receptive at this time on the first day, giving about 90% fruit set. Thereafter, receptivity decreases gradually, resulting in minimal fruit set (8%) on the fifth day.

Pollen germination of cherimoya has been found to be optimal at 20-25°C, which is the same temperature required for good fruit set in the orchard (Rosell *et al.*, 1999). Higuchi *et al.* (1998) studied the effects of warm (30/25°C) and cool (20/15°C) day/night temperatures on fruit set and growth in potted cherimoya under greenhouse conditions. They found that fruit set at warm temperatures was very low, and ascribed this response to both pollen and stigmatic damage from heat stress. In Madeira island, the best climatic conditions for cherimoya self-pollination are temperatures equal to or above 22°C, with relative humidity of 70-80%, whereas temperatures below 22°C with RH above 90% reduce pollination success (Nunes, 1997).

The stage of flowering phenology, pollen maturity and viability are factors that affect fruit set and yield of *Annona* species. In New Zealand, Richardson and Anderson (1996) compared fruit set at different flowering times by using hand pollination methods in individual trees as main plots and time of pollination on 20 flowers as sub-plots. They found that cherimoya pollination is more successful at the beginning of the flowering period (January), with a total yield of 34.8 kg/tree, than at the end of the flowering period (February) with a total yield of only 0.1 kg/tree. It was also observed that pollen viability varied from 20 to 50% and seediness increased from 11 seeds/fruit at the beginning to 59 seeds at the end of the flowering period. In Chile, Saavedra (1977) found that the first flowers of cherimoya to open gave poorer fruit set with hand pollination than the later ones, probably because the majority of the pollen grains at the beginning of flowering were still in the tetrad stage, with thick walls and full of starch; at this stage, the pollen has a low viability and, consequently, gives a low fruit set.

Grossberger (1999) commented that when pollen is used within 1-2 h of its collection, more than 80% fruit set is generally obtained, as assessed by fruit set two weeks after pollination. When pollen was stored for 12 h in a standard refrigerator, fruit set fell to about 65% and to 35% after 24 h. This would suggest that old pollen results in a low percentage of fruit set, even using a brush or blower, which are appropriate tools for hand pollination. Fruit set by hand pollination ranges from 44.4 to 60% depending upon the species, while fruit set from open pollination is always less than 6% (Mansour, 1997). Hand pollination is the only certain strategy to ensure commercial production, since it guarantees significantly higher production and better fruit quality than open pollination. Cogez and Lyannaz (1996) compared natural and hand pollination in two sugar apple cultivars: ‘Thai Lup’ and ‘New Caledonia’. Natural pollination had 0% and 3.6% success in ‘Thai Lup’ and ‘New Caledonia’, respectively, while hand pollination success was 100% in ‘Thai Lup’ and 90-93% in ‘New Caledonia’. When intravarietal and intervarietal pollen was combined with hand pollination, the success rate was 90.9% and 92.6% success, respectively, in New Caledonia. Pinto and Ramos (1999) obtained 26% fruit set with natural pollination of soursop in the Brazilian Cerrado conditions (Brazilian savannah), while fruit set was 73% when hand pollination with a paint brush was used.

Allogamous hand pollination is also effective with cherimoya. Duarte and Escobar (1998) applied self pollen on cherimoya cultivar Cumbe in El Zamorano, Honduras, as well as cultivar Bronceada, in the morning (6-8 h) and in the late afternoon (16-18 h). The highest fruit set (46.4%) was obtained with cross pollen, as compared with 30.3% and 23.1% with self pollen applied in the morning and in the afternoon, respectively. Fruit set was also better at the beginning of the flowering period.

The success of hand pollination depends on the technique, as well as the species and conditions. Economically effective hand pollination of cherimoya was carried out for the first time in California by Dr. Schroeder in 1941 (Grossberger, 1999) and to date the technique has varied little. Several authors (Agustín and Alviter, 1996; Mansour, 1997; Bonaventure, 1999; Grossberger, 1999) have described the hand pollination technique as follows. The cherimoya flowers that will serve as the pollen source are gathered and held in a small paper bag until the pollen is shed. The operator should remove the 3 petals of the external whorl of freshly opened flowers that will be pollinated. The 3 petals of the internal whorl are then held open with one hand, while, with the other, the pollen is applied onto the pistils with a small camel hair brush, using several back and forth strokes. Pollen can also be blown onto the pistils with special blowers (e.g., the Aluminum Hand Blower, Technes Industry, São Paulo, Brazil; Bonaventure, 1999). A small cylindrical plastic container (such as those used for rolls of film: Plate 3) is an important tool used by soursop growers of the Brazilian Cerrados to carry pollen, which can be kept in the operator's shirt pocket (Plate 5), leaving the grower's hands free to execute the hand pollination.

Hand pollination of cherimoya is generally practiced in the morning or the afternoon as it is too warm and dry at midday and a lower fruit set is obtained (Grossberger, 1999). Similarly, in soursop, pollination should be practiced in the morning, preferably around 9 am and approximately 19 h after the collection of the pollen donor flowers (Pinto and Ramos, 1999). The donor flowers should be collected from the terminal portion of the branch, since these flowers generally present low fruit set themselves (Torres and Sánchez, 1992; Pinto and Ramos, 1999).

Hand pollination is considered to be time-consuming and costly (Nakasone and Paull, 1998). Attempts have been made to substitute hand pollination by growth regulators to enhance fruit set. Experiments carried out by Yang (1988, cited by Nakasone and Paull, 1998) indicated that fruits grow very slowly and with less fruit drop when indole-acetic acid (IAA) and naphthalene acetic acid (NAA) are applied, while gibberellic acid (GA) promotes adequate fruit set and growth rate. Saavedra (1979) found that the application of either NAA or GA can stimulate some production of seedless fruits weighing 200-300 g, but only GA significantly enhanced fruit set and stimulated growth of seedless fruit. However, GA can also induce severe cracks in fruit rinds before harvest. Therefore, hand pollination is still the most effective strategy to increase production and quality of fruit.

Fruit thinning is necessary to regulate crop load and to maintain fruit size, especially for high yielding annona cultivars (George *et al.*, 1987). The thinning operation involves the removal of misshapen fruit and thinning of fruit clusters, both of which improve the quality of the remaining fruit for market.

10.3.5 Nutrition and fertilization

Planting and Juvenile Phases

The establishment of a fertilization programme should be based on the nutrient uptake by the target species (Mengel and Kirkby, 1987; Torres and Sánchez, 1992; Hermoso and Farré, 1997). In establishing orchards, the preliminary fertilization (especially of phosphorous) and soil pH correction of the field should be based on soil analysis. Sufficient sub-samples, for instance 25 per hectare for phosphate and potassium, should be collected in order to obtain a representative sample (Mengel and Kirkby, 1987). Soil sub-samples should be taken from the 0-40 cm soil layer, by walking a zig-zag in the area, a mixture of these sub-samples should then be prepared and a 200-300 g composite soil sample sent off for nutrient analysis (Pinto and Silva, 1996; Bonaventure, 1999).

The fertilization of the planting pit varies according to the species and the soil nutrient levels. In Venezuela, 250 g of NPK 10-10-15 or 10-15-15, and 5 kg of manure is a common recommendation for soursop planting pits (Araque, 1971). *Annona* trees are sensitive to low soil pH and this should be to pH 6.0 if necessary, using either dolomite or calcitic lime before planting out.

For wild soursop, which has not yet reached orchard status, fairly general recommendations on fertilizers are available: compound NPK + Mg at rates of up to 100 g/tree every 3 months (FAO, 1988). Similarly on sugar apple in India, fertilizer can be applied at the start of the monsoon at the rate of 250 g N and 125 g P and 125 g K per tree (Anon., 1981).

Fertilizer rates and timing need to be adjusted according to the tree age and the species. Ibar (1979) describes the fertilization schedule for cherimoya orchards during the juvenile period (from 1st to 3rd year) according to tree age (Table 10-4). However, the schedule for fertilization of the vegetative phase would be much more accurate if the amount of fertilizer applied were based on the soil nutrient content (Table 10-5 and Table 10-6) (Silva and Silva, 1997).

Table 10-4. Recommendation of NPK fertilization for cherimoya in Spain based on tree age after planting during the first three years of orchard establishment

Age after planting (years)	Nitrogen (of N/plant)	Phosphorus (of P_2O_5/plant)	Potassium (of K_2O/plant)
0-1	240	120	120
1-2	360	180	180
2-3	480	240	240

Source: Ibar (1979).

Table 10-5. Recommendation of P and K for soursop trees of different ages according to the amount of N fertilization applied (g/plant) and levels of P_20_5 and K_20 in the soil analysis in the semi-arid region of Brazil

Tree Age	N	g of P_2O_5/plant			g of K_2O/plant		
		Phosphorus in the soil (µg/cm³)			Potassium in the soil (µg/cm³)		
		0-10	11-20	> 20	0-45	46-90	> 90
0-1 year	40	-	-	-	60	40	30
1-2 years	80	80	60	40	80	60	40
3-4 years	120	120	80	60	120	80	60
> 4 years	180	120	80	40	180	120	60

Source: Silva and Silva (1997).

Table 10-6. Recommendation of P and K for sugar apple trees of different ages according to the amount of N fertilization applied (g/plant) and levels of P_20_5 and K_20 in the soil analysis in the semi-arid region of Brazil

Tree Age	N	g of P_2O_5/plant			g of K_2O/plant		
		Phosphorus in the soil (µg/cm³			Potassium in the soil (µg/cm³		
		0-10	11-20	> 20	0-45	46-90	> 90
0-1 year	50	-	-	-	70	40	20
1-2 years	100	80	60	40	60	40	20
3-4 years	120	120	80	60	120	80	60
> 4 years	180	160	120	80	200	140	80

Source: Silva and Silva (1997).

Besides soil analysis, leaf tissue analysis has been accepted as a way to understand nutrient uptake conditions from the soil (Mengel and Kirkby, 1987) and should be used during the juvenile phase of plant growth. The most appropriate methodology for collecting annona leaves for analysis depends on the tree's age, the position of the leaves in the canopy and the period for sampling. Cherimoya leaves should be collected from intermediate branches during the fruiting period or late in the harvest season (Gonzalez and Esteban, 1974). Collection of the third and fourth leaf pairs from the intermediate branches of the canopy in the four cardinal points is the most appropriate for foliar analysis of soursop (Laprode, 1991). Soursop leaves should be 8-9 months old and should be collected from intermediate branches of healthy plants, free of pesticide residues prior to analysis (Pinto and Silva, 1996). A sample of 4 leaves per tree from each of 25 randomly selected plants in the orchard, totalling 100 leaves, is required for complete tissue analysis. Several authors (Avilan, 1975; Sadhu and Ghosh, 1976; Navia and Valenzuela, 1978; Silva *et al.*, 1984) have reported a range of nutrients in normal and deficient leaves of cherimoya, soursop and sugar apple (Table 10-7), which serve as a guide for annona plant deficiencies.

Table 10-7. The average normal and deficient levels of macro and micro-nutrients in leaves of cherimoya, soursop and sugar apple

Species	N%	P%	K%	Ca%	Mg%	S%	B ppm	Fe ppm	Zn ppm
Cherimoya (1)									
a) Basal leaves									
Normal	1.90	0.17	2.00	0.80	0.25	-	-	215.0	23.0
Deficient	0.72	0.09	1.00	0.25	0.04	-	10.0	140.0	12.0
b) Apical leaves									
Normal	2.91	0.17	1.95	0.60	0.26	-	-	125.0	29.0
Deficient	0.90	0.10	1.00	0.15	0.05	-	6.0	40.0	20.0
Soursop (2)									
Normal leaves	1.76	0.29	2.60	1.76	0.20	-	-	-	-
Deficient	1.10	0.11	1.26	1.08	0.08	-	-	-	-
Soursop (3)									
Normal leaves	2.5-2.8	0.14-0.15	2.61	0.82-1.68	0.36-0.38	0.15-0.17	35.0-47.0	-	-
Deficient	1.3-1.6	0.06-0.07	2.64	0.45-0.81	0.07-0.08	0.11-0.13	6.0-14.0	-	-
Sugar Apple (4)									
Normal leaves	2.8-3.4	0.34-0.34	0.87-2.47	-	-	-	-	-	-
Deficient	1.9-2.8	0.17-0.19	0.75-1.66	-	-	-	-	-	-

Sources: (1) Navia and Valenzuela (1978); (2) Avilan (1975); (3) Silva *et al.* (1984); (4) Sadhu and Ghosh (1976).

Gazel Filho *et al.* (1994) found the following variations in the normal macronutrient contents (%) of different soursop varieties: N: 1.99 - 2.04; P: 0.12 - 0.14; K: 1.49 -1.52; Ca: 1.20 - 1.52; Mg: 0.19 - 0.22. Most of these macronutrient contents do not fall inside the range presented in Table 10.7, which demonstrates that several other factors, such as soil, variety, climate etc., influence nutrient contents in living plant tissues (Mengel and Kirkby, 1987), potentially interfering in the orchard fertilization program.

Fruit size, colour, shape and taste are quality characteristics affected by nutrient deficiencies (Mengel and Kirkby, 1987). Undurraga *et al.* (1995) reported rates of 4.14-6.72 kg of N (as urea) applied to individual cherimoya cv. 'Concha Lisa' trees in Colombia, resulted in the lowest soluble solids contents and fruit pulp firmness values, and the highest titratable acidity values. This suggests that N application at or above 4.14 kg per cherimoya tree impairs the storage quality and organoleptic properties of the fruits.

Annona fruits have a high demand for potassium, and to avoid serious symptoms of potassium deficiency (especially those related to fruit production and quality), potassium content in leaves should be maintained above the suggested critical level of 1.0% (Torres and Sánchez, 1992; Silva and Silva, 1997). Torres and Sánchez (1992) recommended a guide for nitrogen, phosphorus and potassium (Tables 10-8, 10-9 and 10-10) for adult soursop trees based on the age and the nutrient content of the soil in Colombia, for orchard fertilization.

Table 10-8. A guide for nitrogen fertilization (g of N/tree/year) for adult soursop trees in different regions of Colombia, according to age and nutrient content in the soil

Region	Organic Matter (%)	Tree Age		
		3 years old	3-6 years old	6 years old
Intermediary Valley	3	45-70	80-110	110-135
	3-5	30-45	50-80	80-110
Atlantic Coast and Oriental Plains	3	50-80	90-120	120-140
	3-5	30-50	60-90	90-120
	5	20-30	30-60	60-90

Source: Torres and Sánchez (1992).

Table 10-9. A guide for phosphorus fertilization (g of $P_2 0_5$/tree/year) for adult soursop trees in different regions of Colombia, according to age and nutrient content (ppm) in the soil

Region	P ppm	Tree Age		
		3 years old	3-6 years old	6 years old
Inter Andean Valley	20	45-60	60-110	180-240
	20-40	20-45	30-60	120-180
	40	0-20	0-30	60-120
Atlantic Coast and	15	60-80	75-130	140-360

Region	P ppm	Tree Age		
		3 years old	3-6 years old	6 years old
Oriental Plains	15-30	30-60	45-75	180-240
	30	0-30	0-45	90-180

Source: Torres and Sánchez (1992).

Table 10-10. A guide for potassium fertilization (g of K_2O/tree/year) of adult soursop trees in Colombia, according to tree age and potassium (meq/100 g of soil) content in the soil

Content of Potassium (meq/100 g of soil)	Tree Age		
	3 years old	3-6 years old	6 years old
0.20	40-60	60-90	90-130
0.20-0.40	20-40	40-60	60-90
0.40	0-20	0-40	6-60

Source: Torres and Sánchez (1992).

The observation of deficiency symptoms, as a field analytical technique, is a fast and low cost method. When used with soil and leaf analyses it is very important for determining the nutritional status of annonas. The main general physiological characteristics and symptoms of deficiencies on annona trees are discussed below, following Avilan (1975), Navia and Valenzuela (1978), Mengel and Kirkby (1987), Torres and Sánchez (1992) and Silva and Silva (1997).

Nitrogen - When the supply of N from the roots is inadequate, N from the older leaves is mobilized to feed the younger parts of the plant. Symptoms of nitrogen deficiency on cherimoya seedlings start at 40 days after sowing, with reduction of the plant and leaf sizes. The progression of the deficiency promotes an intense yellowing of the leaf and then its abscission. In soursop, the seedling shows a reduction in height, and leaf yellowing and abscission occur more quickly than in cherimoya. The leaf blade also shows a green-yellow chlorosis and changes texture. Symptoms of nitrogen deficiency in sugar apple seedlings are irregular bud development and lack of branches. The leaves are small and show dusty spots; abscission occurs later.

Phosphorus - In cherimoya seedlings, deficiency symptoms become evident 60 days after sowing. Irregular chlorosis occurs in the basal leaves and most show a darker green colour. As the deficiency develops, the leaves become small and irregular in shape, coffee coloured spots develop on the blade, then abscission occurs in these affected leaves. Deficient soursop plants only grow 50% as fast as fertilized plants and the leaves show a necrosis on the blade edges. Sugar apple seedlings also show reduced growth with thin shoots and their leaves develop abnormal brown spots at their apices and on the blade edges.

Potassium - Due to its great mobility, potassium moves from old organs to new ones easily. In general, deficient plants do not have the ability to transport carbohydrates produced in the leaves to the other plant organs. Potassium deficiency in cherimoya seedlings appears at 50 days after sowing, and shows intermediate symptoms that are between phosphorus and nitrogen deficiency. Brownish spots start from the apex and basal parts of the leaf blade, and gradually coalesce. In soursop, the leaf symptoms appear in the 8th month after sowing with a reduction in size and an abnormal yellowing, then leaf abscission. Sugar apple trees show retarded growth and dryness of the apical leaves. Deficient plants may flower, but there will be no fruit set. A high content of K induces Mg and Zinc deficiencies.

Calcium - Calcium is an immobile nutrient and its deficiency affects the zones of intense growth first. The symptoms of calcium deficiency in leaves of cherimoya seedlings appear after 30 days. New leaves show interveinal chlorosis. At 70 days, the apical meristem of cherimoya dies and the leaves stop growing and become twisted. In the leaves of soursop seedlings, calcium deficiency occurs later than in cherimoya (120 days), although the symptoms are similar. The best ratio of Ca:Mg is 3:1, a higher ratio can increase Mg deficiency.

Magnesium - The first symptoms of deficiency are generally shown in the oldest leaves because Mg is a mobile nutrient. In cherimoya seedlings this begins at 50 days. An interveinal chlorosis then starts to become visible in the new leaves. In soursop, chlorosis is progressive, turning the leaves necrotic.

Sulphur - This nutrient has low mobility, both in the plant and in the soil, especially in soils with low organic matter content and high C/N ratios. Therefore, the first symptoms of sulphur deficiency occur in the young leaves. The new leaves of cherimoya seedlings are notably smaller than the old ones after 75 days of sulphur deficiency, and the new leaves present an overall yellowing. Similar symptoms are also detected in the leaves of soursop seedlings.

Boron - Similar to calcium, this nutrient is immobile; therefore, the first symptoms of boron deficiency occur in young leaves. In cherimoya seedlings the leaf symptoms appear after 70 days. The upper leaves turn intense green, with some chlorosis. At 140 days, leaf chlorosis becomes more intense. Symptoms are similar on the leaves of soursop seedlings.

Iron - Like calcium and boron, iron is relatively immobile and the first symptoms occur in the young leaves. The initial symptoms are partial chlorosis (yellowish green), then the leaf blades become totally yellow, except over the veins.

Zinc - Plants suffering from zinc deficiency often show chlorosis in the interveinal areas of the leaf. These areas become pale green, yellow, or white. Unevenly distributed clusters of small, stiff leaves are formed at the top of the young shoots; this symptom is known as rosette or little-leaf.

Adult Tree Phase

Physiologically, the fruits act as a sink for nutrients. Nutrient analysis of leaves however gives different results from fruits. A new methodology has recently been tested using fruits as the source of material for nutrient analysis in adult mango trees. Although, in practice, this method is not frequently used yet, it would be a useful additional test, together with soil and leaf analyses.

The quantity of nutrients removed from the soil by fruit trees depends on the species, the variety and the yield (Kirkby and Mengel, 1987). Guirado (1999) observed that a cherimoya orchard with a population density of 156 plants/ha and a yield of 89.7 kg of fruits per tree extracted the following amounts of nutrients per kg of harvested fruit: 6.8 g N; 0.3 g P; 2.7 g K; 0.6 g Ca; 1.9 g Mg. Fruit production of soursop however, is more demanding and extracts larger amounts of macronutrients from the soil than cherimoya, except for N, Ca and Mg. (Figures are given in Tables 10-11 and 10-12).

Table 10-11. Removal of macronutrients (kg) per tonne of soursop and sugar apple fruits produced

Macronutrient	Soursop		Sugar Apple	
	Avilan *et al.* (1980)	Silva *et al.* (1984)	Silva *et al.* (1984)	Silva *et al.* (1991)
N	2.97 kg/t	2.70 kg/t	7.17 kg/t	4.94 kg/t
P	0.53 kg/t	0.54 kg/t	0.58 kg/t	0.25 kg/t
K	2.53 kg/t	3.60 kg/t	5.19 kg/t	5.31 kg/t
Ca	0.99 kg/t	0.26 kg/t	0.45 kg/t	-
Mg	0.15 kg/t	0.24 kg/t	0.46 kg/t	-
S	-	0.27 kg/t	0.27 kg/t	-

Sources: Avilan *et al.* (1980), Silva *et al.* (1984).

Table 10-12. Removal of micronutrients (g) per tonne of soursop and sugar apple fruits produced

Macronutrient	Soursop	Sugar Apple
Fe	8.03	18.48
Cu	1.65	2.68
Mn	2.71	3.26
Zn	3.71	6.95
B	2.75	3.12

Source: Silva *et al.* (1984).

Fertilizer should be applied to adult annona trees in the area under the outer third of the canopy (Pinto and Silva, 1996; Pinto and Ramos, 1997). Fertilization by foliar spraying is very important to supplement a soil fertilization programme during the period before flowering and harvesting to improve the fruit quality. Commercial liquid fertilizers can be applied 2-3 times a year (Torres and Sánchez, 1992; Pinto and Silva, 1997). Cherimoya trees are sensitive to boron and zinc deficiencies, therefore, boron at 2.0 g/m^2 should be applied to the ground area below the canopy. Spraying of 0.1% of zinc sulphate, applied at monthly intervals, will correct any zinc deficiency. In addition, boron and calcium sprays during flowering and early fruit set may be beneficial in reducing the incidence of internal fruit browning (Torres and Sánchez, 1992; Undurraga *et al.*, 1995; Hermoso and Farré, 1997; Bonaventure, 1999).

Fertilization with easily leachable nutrients, such as N and K, should be split into three or more applications during the year. Fertigation techniques (application of fertilizers through the irrigation system) is the best recommendation for this multiple application practice, providing a quicker and more controlled response than soil surface application; this practice also promotes a higher yield and fruit quality. However, there are no scientific results published on this technical issue which can confirm the recommendation for annonas.

Organic cultivation of annona trees is a recent practice with no conclusive studies to identify scientifically acceptable recommendations for production. However, an increasing number of growers are reducing the use of agrotoxins and increasing the use of organic or biological products to improve fruit quality for market. Today, the foliar application of microorganism mixes (commercially named as EM-4 and EM-5), as well as a bioactivators (commercially named Aminon-25), seem to enhance plant metabolism and functions, such as photosynthesis and carbohydrate distribution, and give good results in terms of yield and fruit quality of organically grown cherimoya (Bonaventure, 1999). Further research results are expected to appear on this subject in the coming decade, due to the increasing consumer demand of pesticide-free and organic produce.

10.3.6 Irrigation

The selection of the appropriate irrigation system is directly related to three main factors: technical, economic and human (Silva *et al.*, 1996), within which, there are several critical aspects. Water management (availability in quantity and quality) and its infiltration, slope of the land, plant phenology and climate are technical aspects. For instance, the sprinkler irrigation system should be used in areas where water is not a limiting factor and where slopes are not greater than 16% (Nunes, 1997). The use of sprinkler irrigation also has certain restrictions, especially regarding its use during the period of pollination and fruit set, since it can impede visits of pollinator insects and provoke the abscission of small fruits. Market prices of the irrigation system, costs of installation and maintenance, and financial resources are some of the economic aspects to be considered. Finally, the quality of the labour which will operate the irrigation system is the most important human aspect involved (Silva *et al.*, 1996).

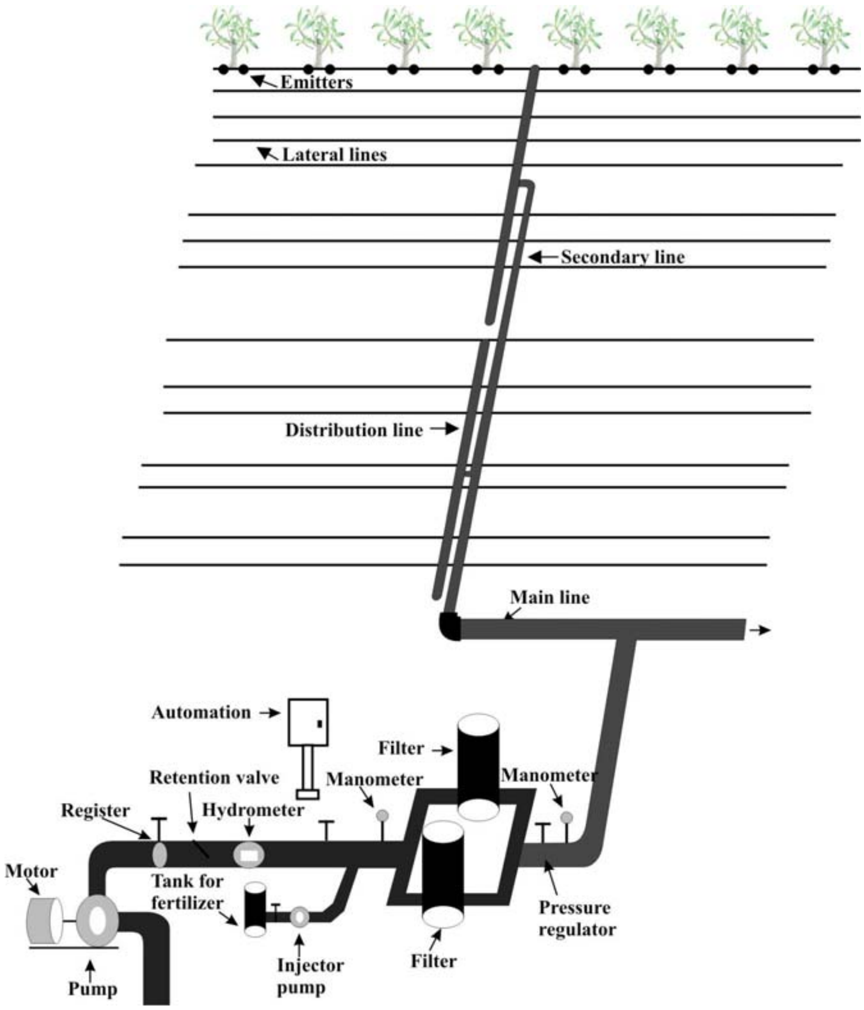
The cost of buying and installing the irrigation system is generally the first critical aspect influencing any decision; therefore the cheapest irrigation system is often chosen. However, the price is not necessarily related to the efficiency. For example, the gravity flow of surface water through furrows and flood irrigation are the cheapest systems; however, water distribution is seldom uniform, leading to poor efficiency in the orchard as a whole (Santos, 1997). In Spain, flood irrigation is used only in orchards situated in river-bottoms (Farré *et al.*, 1999). In north-eastern Brazil, furrow and flood systems are considered old-fashioned, and have been substituted by drip and micro-sprinkler irrigation.

In many areas, water has become very expensive; thus it is necessary to minimize costs by not over-irrigating. Drip and micro-sprinkler irrigation systems decrease costs and increase the efficiency of water use and management (Nunes, 1997), as well as improving fertilizer use and management, resulting in higher yields and better fruit quality. These localized irrigation systems are, nowadays, the commonest methods used on annona trees in north-eastern Brazil. A good irrigation scheme must be designed before orchard establishment. Bucks and Davis (1986) outlined a typical scheme for establishment of a drip irrigation system in the field (Fig. 10-12).

The shape and size of the 'wetted bulb' or area of soil moistened by the system, which will be filled with tree roots, depends on the type and size of emitter, the volume of water applied, and the structure and texture of the soil (Santos, 1997).

A drip irrigation system should be used in areas where water is very limited, e.g., in arid zones (Rungsimanop *et al.*, 1987; Singh 1992). This system has several advantages, such as decreasing the loss of water through evaporation, reducing weed infestation and the negative effects of increased salt concentration (Silva *et al.*, 1996). An enormous disadvantage however, is the need for filters, which are sometimes obligatory because of poor water quality. The filters eliminate, or at least minimize, the possibility of system obstruction by suspended materials; without filters there is usually a considerable increase in cost of maintenance.

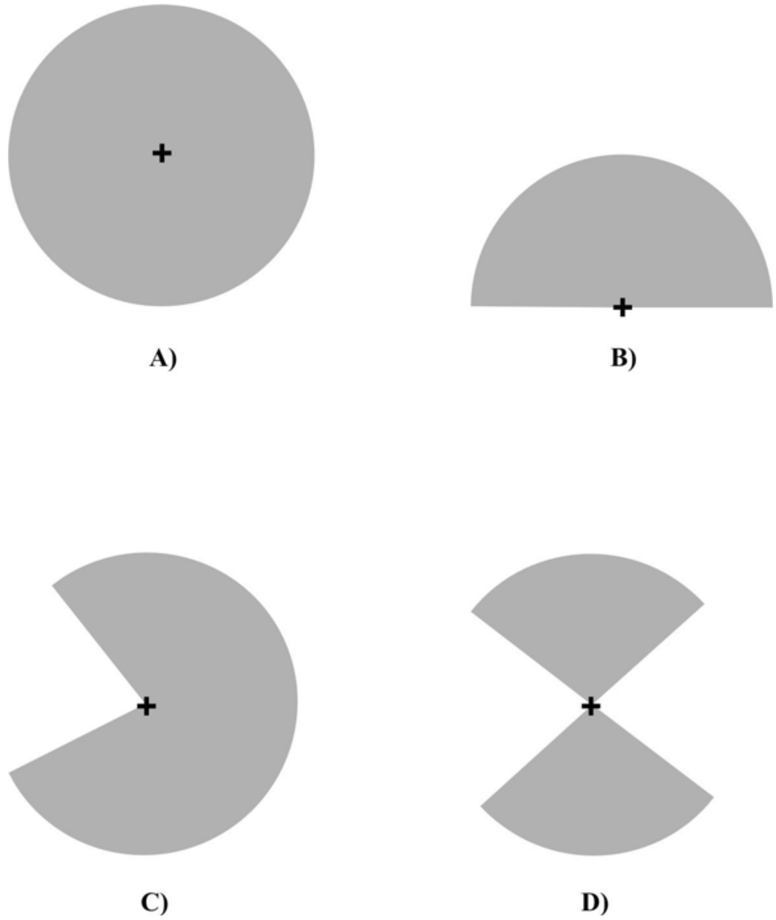
Figure 10-12. A typical scheme for establishment of a drip irrigation system in the field. Adapted from Bucks and Davis (1986)



Micro-sprinkler irrigation is also recommended for areas where water is limited. Like drip irrigation, this system allows more efficient water utilization. Micro-sprinkler irrigation is more appropriate for perennial crops, like annonas, which are established at low density per hectare and have large root systems. James (1988) comments that there are several types of micro-sprinkler emitters that are differentiated based on their water distribution patterns (Fig. 10-13). *Annona* growers in Brazil prefer the single micro-sprinklers with 300° of water distribution, or two micro-sprinklers with 180° each, so that they don't moisten the tree trunks and encourage infectious fungal or bacterial diseases. When selecting a micro-sprinkler system additional parameters must be considered, such as the emitter outlet and its sprinkling radius, as well as the intensity of water application through the radius (Santos, 1997). In general, micro-sprinklers have fewer problems of obstruction in the emitters than drip irrigation (Santos, 1997).

Farré *et al.* (1999) conducted a study to compare the drip, micro-sprinkler and spray irrigation systems with respect to the area moistened under the canopy and the planting density. They concluded that with 313 cherimoya trees/ha (spacing of 8 x 4 m) 1,800-2,000 drippers/ha (6 drippers/tree) were frequently used. With the advent of low-density spray irrigation below the canopy, larger areas have been irrigated in Spain with better results. An irrigation schedule of 24 to 25 litres/tree and 6 drippers of 4 litres/h results in 20% of the area moistened to more than 25 cm depth, while one micro-sprinkler of 25 litres/h wets 12 m^2, resulting in approximately 40% of moistened area. Unfortunately the study did not investigate the variation in the parameters with different soil types, which is very important in understanding the formation of the wetted bulb.

Figure 10-13. Water distribution (degree of opening) of different micro-sprinklers that can be used in annona orchards. A) Type 360°; B) Type 180°; C) Type 300°; D) Type 280°. Adapted from James (1988)



Whatever the perennial crop, there is a need to establish a strategy to determine when and how much water must be delivered to the tree. To determine the need for water, the evaporation of water must be measured and then compared to a pre-established evapotranspiration coefficient of the crop in that region. The evapotranspiration coefficient is determined by using climatic variables, such as solar radiation, temperature, relative humidity (RH) and wind velocity (Pinto and Silva, 1994). A formula to calculate the irrigation requirement for sugar apple in Brazil's semi-arid northeast is based on the averages of air temperature and RH (Santos, 1997). The amount of water to be applied during each irrigation event depends on the amount of water per tree and number of trees per orchard unit. In addition, the time taken to apply the required amount of water depends on the number of emitters per tree and their outlet volumes. If the watering calculations suggest a time that is longer than 3 hours, it is recommended that the irrigation be split into 2 or 3 applications to avoid excessive wetness around the root system and loss of water due to percolation (Santos, 1997). Irrigation at night avoids evaporation losses. Growers should seek expert advice on developing any irrigation strategy.

Water quality is as important as the amount of water and the time of its application. The presence of certain nutrients, such as calcium, can precipitate phosphates and provoke clogging of the emitters (Pinto and Silva, 1994). The presence of sodium in irrigation water can cause concern, as this can result in salinization, especially in shallow soils without drainage systems. Needless to say, salinization is extremely detrimental to plant growth and fruit yield. Irrigation water containing NaCl, $CaCl_2$ or $CaC0_2$ causes depressed growth rate and reduced dry weight of all annona trees, especially above 3,000 ppm (Galila *et al.*, 1991, cited by Mansour, 1997), leading to leaf burn and defoliation of the seedling leaves. High boron and chloride contents in irrigation water also promote phytotoxicity and injury to the leaves and fruits (Pinto and Silva, 1994).

10.3.7 Pest and disease management

Annona trees are attacked by a large number of insect pests and numerous diseases. Peña and Bennet (1995) described 296 species of insects associated with annonas, although many of them are not economically important. Nava-Díaz *et al.* (2000) reported that, world-wide, 106 insects, 91 fungi, 5 nematodes, 2 bacteria and 1 virus have been recorded attacking *Annona* species. In Venezuela, Marin Acosta (1973) described 27 species of pests attacking annona trees. A full biological description of each pest, with management information, would be a very difficult task with limited applicability here, therefore only the major and regionally important secondary pests and diseases will be described below. Pest and disease control in commercial orchards has traditionally relied on the use of chemical products. With increasing awareness of the human and environmental hazards in pesticide use, alternative methods of control are suggested. In small scale plantings, the potential for rapid increase in pest or disease incidence is less, and the capability to monitor any outbreak is easier.

10.3.7.1 Pests

Major and minor insect pests attacking annonas are described by numerous authors (Melo *et al.*, 1983; George *et al.*, 1987; Bustillo and Peña, 1992; Oliveira *et al.*, 1992; Torres and Sánchez, 1992; Agustín and Alviter, 1996; Junqueira *et al.*, 1996; Pinto and Silva, 1994; Nakasone and Paull, 1998; Nava-Díaz *et al.*, 2000) in many countries and ecological regions (Table 10-13) with different levels of economic damage and cost of management control.

Table 10-13. Major and selected minor insect pests of *Annona* species

Common Name	Specific Name	Affected Plant Parts	Country/Region
Major Insect Pests			
Annona moth	*Cerconota anonella*	Seeds and fruits	Universal
Cherimoya seed borer	*Talponia batesi*	Seeds and fruits	Mexico, Peru, Spain
Atis moth borer	*Anonaepestis bengalella*	Fruits	Philippines
Wasps (wasp)	*Bephratelloides maculicollis* and *B. cubensis*	Seeds and fruits	Several countries/regions
Borers (trunk borer)	*Cratosomus bombina, Heilipus catagraphus*	Trunk and branches, base of the trunk	Mexico, Brazil
Flies (fruit flies)	*Anastrepha obliqua, A. ludens, Ceratitis capitata, Bactrocera dorsalis* and *B. tryoni*	Fruits	Peru, Mexico. Colombia, Ecuador, Spain, Peru, Australia, New Zealand
Mealy bugs	*Planacoccus citri, Dysmicoccus* spp., *Ferrisia virgata, P. pacificus* (India)	Fruits and leaves	Several countries/regions
Scale insects	Several genera and species	Leavesand stems	Several countries/regions
Spider mites	Several genera and species	Leaves and flowers	Several countries/regions
Minor insect pests			
Leaf hopper	*Empoasca fabae, Membracis foliata, Aethalion* spp.	Leaves and stems	Brazil, Colombia, Venezuela, American tropics
Thecla moths	*Oenomaus ortygnus*	Flowers and fruits	American tropics, Brazil
Aphids	*Aphis gossypii* and *Toxoptera aurantii*	Leaves and shoots	USA, Colombia, Peru, Brazil and Venezuela
Hemipterous insects	*Leptoglossus zonatus* and *Antiteuchus tripterus*		
Fruit spotting bug	*Amblypelta nitida*	Young fruits	Australia
Leaf larvae	Several genera and species	Leaves and stems	American tropics, Brazil
Leaf miners	*Leucoptera* spp. and	Leaves	Cuba and Ecuador

Common Name	Specific Name	Affected Plant Parts	Country/Region
	Phyllocnistis spp.		
Root grubs	*Anomala*	Roots	Philippines
Ants ("saúvas")	*Atta* spp. and *Acromyrmex* spp.	Leaves and petioles	Universal

There are three important groups of borer insects attacking annona species: the trunk borer, the fruit borer and the seed borer. Trunk borers are coleopterons, generally weevils, and three species are the most common: *Cratosomus bombina bombina* (Plate 6), *Euripages pennatus* and *Heillipus catagraphus* (Oliveira *et al.*, 1992). These insects are 2-4 cm long and they perforate the trunk, causing plant decline and finally death. The external symptom of the attack is a black oxidized sap exudation from the small holes where the insects entered the trunk. Injection of liquid pesticides, such as D-aletrina and D-tetrametrina into the trunk holes is an effective method of control (Oliveira *et al.*, 2001). In the Brazilian Cerrados brushing of the tree trunk with a 1% solution of a pesticide, commercially named Creolina, together with lime at 10%, has prevented fruit borer attack on soursop.

The annona moth (*Cerconota annonella*), commonly known as the 'fruit borer', is the most important of the insect pests attacking *Annona* species (Plate 5). Although it is known as the soursop moth in many areas, it has been recorded attacking and damaging fruits of several other annonas as well, including sugar apple and custard apple (Coronel, 1994; Oliveira *et al.*, 1992; Torres and Sánchez, 1992), but has not been reported on cherimoya fruits (Bustillo and Peña, 1992). The soursop fruit borer moth has a life cycle from egg to adult emergence averaging 36 days. The adult moth is attracted to black-light traps, which is an important method for monitoring this insect pest (Bustillo and Peña, 1992). The removal of rotted and damaged fruits from the ground is also an important cultural control method. Bagging the fruits with chemically treated bags (a common type is the chlorpyriphos bag) can keep 92% of the fruits totally undamaged before harvesting (Bustillo and Peña, 1992). Biological control using two braconids, which parasitize larvae of *C. annonella,* has been successful in Colombia and Ecuador (Bustillo and Peña, 1992). In the Cerrado ecosystem of central Brazil, the soursop ecotype Morada is less susceptible to the attack of the soursop moth than any other ecotypes (Junqueira *et al.*, 1996; Pinto and Silva, 1996), suggesting that appropriate cultivar selection can help to minimize the problem. Chemical control with triclorphon or fenthion at 0.1%, every 15 days can help to control this pest. Spraying should be directed at the fruits and started when they are still small (Torres and Sánchez, 1992)

The moth *Anonaepestis bengalella* is cited as the most destructive pest of sugar apple fruit in the Philippines (George and Nissen, 1992; Coronel, 1994). Another moth *Oemanus ortygnus*, which is widespread throughout the Caribbean region and the American tropics is considered a minor pest (Nakasone and Paull, 1998) and attacks the flowers instead of the fruits. In addition to the natural control methods described above for the annona moth, the removal of damaged and attacked fruits from the ground or even from the plant, followed by burial in holes at least 50 cm deep, would be a very effective cultural practice. The same chemical control can also be used for both species.

The soursop wasp (*Bephratelloides maculicollis* or *B. cubensis*, Hymenoptera), also called the annona seed borer (plate 5), is the second most important insect pest. Similarly *Talponia batesi* (Lepidoptera) also attacks cherimoya seed in Mexico (Nava-Díaz *et al.*, 2000). All other cultural practices for control of *Cerconota anonella* can be used for *Bephratelloides* spp. and *Talponia batesi*, except for the use of black-light traps, which are ineffective with these species. Chemical control with decamethrin 0.05% every 15 days when the fruits are still small (Torres and Sánchez, 1992; Junqueira *et al.*, 1996) can reduce infestation.

Several genera of fruit fly, *Anastrepha*, *Ceratitis* and *Bactrocera* are frequently mentioned (George *et al.*, 1987; Peña and Bennet, 1995; Rebollar-Alviter *et al.*, 1997; Alvarez *et al.*, 1999; Farré *et al.*, 1999) as important insect pests attacking annona fruits in many countries and regions (Table 10-13), especially on cherimoya fruits. The infestation occurs with the deposition of the eggs by the adult on the fruit skin or through the stem cavity (George *et al.*, 1987). By making galleries in the pulp, the larvae completely destroy the fruit. The larva starts its pupation phase outside the dropped fruit, underground (about 10 cm deep in the soil), from where the adults emerge and start a new cycle. The cycle of the fruit fly from egg to adult is completed in about 30 days (Nascimento *et al.*, 2000).

According to Farré *et al.* (1999), an incidence of fruit fly attack is generally due to favourable climatic conditions, high reproductive potential, alimentary adaptability and in some circumstances absence of natural enemies, which makes them a difficult pest to control. The size of the area under cultivation and economic importance of the crop can also add to the impact of an attack and the importance of the pest. In Spain, which is one of the most important cherimoya producers, the Mediterranean fruit fly (*Ceratitis capitata*) has a major economic impact, attacking up to 50% of cherimoya fruits (Farré *et al.*, 1999), while in Ecuador the incidence of cherimoya fruit fly (*Anastrepha* spp.) is greater than 94% (Alvarez *et al.*, 1999). However, in Brazil, a typically tropical country with very small areas producing cherimoya, the incidence of fruit flies on this species, or even on its hybrid atemoya, is not mentioned in the literature (Kavati *et al.*, 1997; Bonaventure, 1999). Also, the incidence of fruit flies on soursop, sugar apple and custard apple fruits is negligible or without economic importance, since there is no citation in the literature reviewed (Torres and Sánchez, 1992; Junqueira *et al.*, 1996; Pinto and Silva, 1994; Kavati and Piza Jr., 1997). The only exception occurs in Mexico, where the attack of *Anastrepha ludens* on soursop is cited by Rebollar-Alviter (1987), describing the work of Ponce and Vidal (1981). It is not clear why fruit flies are only minor annona pests in this area, because the flies attack other fruit species in the same areas where annonas are grown.

The mining character of fruit fly larvae, together with their underground pupation, has led practically all control methods to be directed at the adults, by using insecticides (Farré *et al.*, 1999). The spraying of insecticide on entire plants is still the most common practice. Distribution of a toxic bait, consisting of 4% hydrolyzed protein and 0.15% dimethoate, on the entire tree or over the top third only, has also been used (Fuentes *et al.*, 1999) to control Mediterranean fly (*Ceratitis capitata*) on cherimoya fruits. However, besides having questionable effectiveness, this method is also questioned by an increasingly environmentally sensitive society.

An integrated control system involving chemical, biological and cultural methods should be implemented for management and control of the fruit fly. For instance, in Spain, Farré *et al.* (1999), describing work of Hermoso *et al.* (1994) in the Experimental Station of La Mayora, affirmed that phosphate baits or pheromone traps, combined with field hygiene (removal of fruits on the ground), can reduce fruit fly attacks to 4 - 7% without any insecticide treatment. This percentage of fruit fly attack can be further reduced (to 0.5 - 2.0%) with immersion of cherimoya fruits in hot water (between 45 and 47°C) for 60 minutes. Similarly, Rebollar-Alviter *et al.* (1997) suggest that control involving only the removal of dropped over-ripened fruit on the ground can reduce fruit fly populations by up to 80%. Fruit bagging also provides an adequate protection against attack (Nakasone and Paull, 1998). After the removal of the fruit, a cultural practice commonly used in mango orchards in north-eastern Brazil, harrowing beneath the canopy, i.e. turning over the first soil layer, impedes pupation of fruit flies and interrupts their life cycle. Given the importance of these pests in many areas, it is curious that more complete integrated pest management systems have not been reported.

In Mexico, the insects *Biosteres longicaudatus* and *Aceratoneuromyia indica* have been used for biological control of *Annona* fruit flies (Rebollar-Alviter *et al.*, 1997). The use of chemical compounds from seeds or leaves of *Annona* trees, such as wild soursop and sugar apple, have also been tested with some success against fruit flies. Extracts from an infusion of 5% (dry weight) in water of sugar apple leaves can kill up to 70% of adult fruit flies when ingested in the laboratory (Catarino and Ezequiel, 1999) - see Chapter 6 on the chemical properties of *Annona* species.

Mealy bugs, various species of scales or cochineals and spider mites attack the stems, leaves, flowers and fruits of *Annona* species in numerous countries and regions (Table 10-13). They are all considered to be sucking insect pests and may be considered as economically important, due to their impact when they suck the sap of the young vegetative parts and fruits of annona trees. An orchard monitoring system is necessary to detect the phenological phase in which the attack is occurring at an economic level, so as to make control more effective. Mealy bugs are reported to be a major pest on marketable fruits in some areas of Australia and red spider mites can become a serious problem when attacking growing annona trees in dry areas (Nakasone and Paull, 1998). In Colombian and Brazilian soursop orchards, these insect pests have been controlled with mineral oil and systemic insecticides (dimethoate) (Torres and Sánchez, 1992; Junqueira *et al.*, 1996). It is recommended that mites be controlled by spraying specific insecticides (propargite) which can kill the eggs and the adult insects. The insecticide and water mixture needs to be used with an adherent. The mealy bug *Planococcus citri* is biologically controlled by its predator *Cryptolaemus montrouzieri*, however, the predator's action is hindered when there is a large population of the Argentinean ant, *Iridomyrmex humilis* (Farré *et al.*, 1999). Control of mealy bug should focus on biological control where possible, or the use of mineral oil.

Some minor insect pests also have significant economic importance in some regions. Aphids can transmit serious viral diseases to annona trees, while attacks of aphids and hemipterous bugs on fruits can promote irreversible damage to their quality for market. These insect pests are controlled by spraying with the pesticides malathion or parathion (Torres and Sánchez, 1992; Junqueira *et al.*, 1996). Aphids and bugs attacking soursop trees have been controlled efficiently in the Brazilian Cerrados by spraying a 20% solution of macerated leaves of the Neem (*Azadirachta indica*) tree. The fruit-spotting bug (*Amblyphelta nitida*) is considered a serious annona pest in Australia and its damage resembles the symptoms of black canker or diplodia rot (Nakasone and Paull, 1998). Where possible, if damage is limited, chemical use should be avoided.

10.3.7.2 Diseases

Major and minor diseases of annona trees have frequently been described (Table 10-14) (George *et al.*, 1987; Junqueira *et al.*, 1996; Pinto and Silva, 1996; Kavati *et al.*, 1997; Rebollar-Alviter *et al.*, 1997; Nakasone and Paull, 1998; SPT-TCA, 1999; Nava and Díaz, 2000). The intensity of the damage and the control methods differ in a number of ways, according to country and region where the attack occurred.

The most important root diseases caused by fungi are damping-off (*Rhizoctonia solani* and *Fusarium* spp.) and black root rot (*Phytophthora* spp., *Cylindrocladium clavatum* and *Sclerotium rolfsii*), whose attacks occur mainly on nursery seedlings, but also occasionally on adult plants (Melo *et al.*, 1983; Junqueira *et al.*, 1996). Although these diseases are caused by different species, heavy clay soils and high relative humidity (RH) are the main contributing factors for attacks. In addition, the symptoms and damage (wilting and death of seedlings and adult plants) are similar (Torres and Sánchez, 1992; Agustín and Alviter, 1996; Junqueira *et al.*, 1996). To control these diseases, the soil can be treated with a solarization system (see topic 10-1.1 and Plate 2). The use of resistant rootstocks, such as custard apple, appears to be an adequate form of management to avoid attack of these fungi (Kavati *et al.*, 1997), but is not yet widely used.

The base of seedlings or adult plants can be sprayed with a fungicide solution of benomyl 0.1% (Junqueira *et al.*, 1996) if necessary. Seedlings can also be drenched with 0.1% Bavistin at 10-12 day intervals (Singh, 1992).

Table 10-14. Major and selected minor diseases of *Annona* species

Common Name	Specific Name	Affected Plant Parts	Country/Region
Major Diseases			
Damping-off, Black rot	*Rhizoctonia solani (Thanatephorus cucumeris), Phytophthora* spp., *Cylindrocladium clavatum, Sclerotium rolfsii (Athelia rolfsii)*	Root and base of trunk	Universal
Seedling blight	*Pithyium* spp.	Seedlings	Universal
Bacterial wilt	*Ralstonia solanacearum*	Roots and canopy	Australia and Brazil
Anthracnose	*Colletotrichum gloeosporioides (Glomerella cingulata)*	Leaves, young stems and fruits	Universal
Black canker and Diplodia rot	*Phomopsis* spp., *P. anonacearum, Botryodiplodia theobromae*	Leaf scorch, twigs and fruits, fruits in storage	Universal
Purple blotch	*Phytophthora palmivora*	Fruits	Seveal countries
Brown rot and fruit rots	*Rhizopus stolonifer, Gliocladium roseum, Phytophthora* spp.	Peduncles and fruit	Brazil, India and American countries, Universal
Minor diseases			
Burn of string	*Corticium koleroga*	Leaves and twigs	Amazon region

Common Name	**Specific Name**	**Affected Plant Parts**	**Country/Region**
Zoned spot	*Sclerotium coffeicolum*	Leaves	Amazon region
Blight	*Phoma* spp.	Leaves, stems and twigs	Mexico
Black scab	*Fusarium* spp.	Trunk, branches and twigs	Mexico
Fumagina	*Stigmella* spp.	Leaves, stems and twigs	Universal
Rust fungus	*Phakopsora cherimoliae*	Leaves	USA (Florida)
Rubelose	*Corticum salmonicolor*	Branches and twigs	Brazil
Leaf spot	Cercospora anonae	Leaves	Brazil
Armillaria root rot	*Armillaria luteobubalina*	Roots, base of tree, decline	Ausralia
Nematodes	*Helicotylenchus* spp. and *Meloidogyne* spp.	Roots	Universal

Bacterial wilt is an important root disease, which was responsible for 70% of the deaths of atemoya trees established on sugar apple rootstocks in Australia (Nakasone and Paull, 1998). This disease is caused by the bacterium *Ralstonia solanacearum* and is manifested by rapid wilting and the death of young trees. Collar rots, dark internal discolouration of the root wood tissue, tree decline and eventual death are the symptoms on adult trees (George *et al.*, 1987). Some cherimoya cultivars are recommended as resistant rootstocks, such as 'White' in California and 'Negrito' and 'Cristalino' in Spain (George *et al.*, 1987). There is no chemical control for this disease.

There are several diseases attacking the fruits of *Annona* species during the preharvest and post-harvest phases: anthracnose, black canker, diplodia rot, purple blotch and brown rot (Rao *et al.*, 1962; Junqueira *et al.*, 1996; Pinto and Silva, 1996; Rebollar-Alviter *et al.*, 1997; Nakasone and Paull, 1998). Fruit rot caused by *Phytophthora* is prevalent on cherimoya, as well as soursop, custard apple, sugar apple and on related species, e.g., *A. diversifolia* (Weber, 1973).

Anthracnose (*Colletotrichum gloeosporioides*) is a cosmopolitan disease attacking all annonas. This disease is responsible for 90% of the preharvest loss of soursop fruits in Bahia, Brazil (Nieto-Angel, 1999). In Bahia, predisposing climatic conditions for anthracnose attacks are highly favourable, due to high rainfall and atmospheric humidity, and during wet seasons in dry areas (Dhingra *et al.*, 1980). In Mexico, the incidence of anthracnose in cherimoya varies from 50 to 70%, although mainly in orchards without adequate control (Rebollar-Alviter *et al.*, 1997). This disease causes twig dieback, defoliation and dropping of flowers and fruit, while in mature fruit its infection causes black lesions (Nakasone and Paull, 1998). Management and control of anthracnose involves a thorough cleanup at the end of the dry season, including the pruning of infected twigs, removal of rotting fruits on the ground, and then burning of all waste. Spraying with the fungicide benomyl 0.06%, intercalated with copper oxychloride 0.15%, every week during the rainy season and every three weeks during the dry season, gives adequate control (Junqueira *et al.*, 1996). In India, Singh (1992) recommended spraying with 0.05% benomyl or 0.2% mancozeb M43 at 15-20 day intervals.

Black canker (*Phomopsis* spp.), diplodia rot (*Botryodiplodia theobromae*) and purple blotch (*Phytophthora palmivora*) are fungal diseases attacking the fruits (George and Nissen, 1980; Agustín and Alviter, 1996; Nakasone and Paull, 1998). Black canker and diplodia rot occur mainly in neglected orchards; they show similar symptoms of purplish to black spots or blotches confined to the surface of the fruit. Diplodia rot is distinguished by its darker internal discolouration and the extensive corky rotting it produces. Diplodia rot has also been described by Junqueira *et al.* (1996) as attacking the junctions between rootstocks and scions of soursop, ultimately killing the plant. Purple blotch is distinguished by small spots on immature fruits that expand until most of the fruit surface is affected (George and Nissen, 1980). There are several management systems to control these diseases, most of which should be applied preventively: a) pruning the low branches to avoid high humidity under the canopy and brushing with 1% paste of copper oxychloride; b) keeping the plants in a good nutritional state; c) avoiding physical damage to the fruits, as well as keeping adequate control of fruit and seed borers; d) brushing the graft junction with 4% copper oxychloride paste; e) spraying with benomyl 0.2%, every 15-20 days during the rainy season (Junqueira *et al.*, 1996; Kavati *et al.*, 1997; SPT-TCA, 1999).

Brown rot (*Rhizopus stolonifer*) is another serious disease which attacks the fruits, generally at harvest and during post-harvest periods (Pinto and Silva, 1996; Rebollar-Alviter *et al.*, 1997) - (Plate 7). The main contributing factors for a higher incidence of brown rot are high RH in the orchard and some kind of physical damage to the fruit (Torres and Sánchez, 1992). Perforations by wasps (soursop seed borers) on the fruit peduncles are probably one of the entry points for fungal establishment, the attack of which promotes a brown rot and later mummification of the pulp (Torres and Sánchez, 1992; SPT-TCA, 1999). A preventive control measure is the elimination of seed borer attacks or other physical damage of fruits, as well as removal of damaged fruits on the ground (Torres and Sánchez, 1992).

Like many other tropical fruits, post-harvest rotting is largely responsible for the short shelf life of annona fruits and experimental studies have evaluated possible solutions to this problem. George *et al.* (1987) recommended dipping annona fruits in either a heated benomyl suspension with 0.5 g a.i./l (or the same concentration guazatine solution) at 50° to 52°C for 5 minutes for post-harvest control of rots. Dipping the annona fruits in unheated prochloraz (0.125 g a.i. per litre) for 1 minute at 25°C also provided a good control of post-harvest rotting. However, some treatments, particularly prochloraz, can induce skin injury at high concentrations, and should be avoided.

Minor diseases can also be important in some countries or regions (Table 10.14). Some fungi causing minor diseases develop and attack more severely under high relative humidity and hot temperatures. Two soursop diseases commonly called 'burning string' (*Corticium koleroga*) and 'zoned spot' (*Sclerotium coffeicolum*) are examples of these kinds of fungi. In Mexico, blight and black scab are also important diseases and the former can even show incidences of up to 80% on cherimoya leaves in the high humidity period of the year (Nava-Díaz *et al.*, 2000). Fumagina (*Stigmella* spp.) is a cosmopolitan fungus whose attack is aided by certain species of ants, although this disease is described as having one of the lowest incidences (28.5%) in Mexico (Nava-Díaz *et al.*, 2000). Rubelose (*Corticum salmonicolor*) and cercosporiose (*Cercospora annonae*) are common diseases on twigs and leaves of soursop, although predisposing environmental conditions and symptoms are different. Symptoms of rubelose are yellowish pink mycelium on the trunk followed by exudation of latex, whereas cercosporiose symptoms are distinguished by development of black circular lesions on the leaves. The former disease occurs under the high humidity and hot temperatures occurring in the Amazon region and in some north-eastern states of Brazil, while cercosporiose attacks under the lower temperatures and dry conditions of Brazil's central region. Spraying with copper oxychloride gives adequate control of these diseases (Junqueira *et al.*, 1996).

Nematodes of different species, such as *Helicotylenchus* spp., *Meloidogyne incognita*, *Macroposthonia* spp., *Tylenchorhynchus phaseoli* and *Xiphinema* spp. have been described as attacking cherimoya, soursop and sugar apple (Sharma, 1973; Sharma, 1977; Monteiro *et al.*, 1978; Ferraz *et al.*, 1989). In Brazil, the disease called soursop decline has been associated with the attack of nematodes of the *Gracilacus* species in Ceará State, north-eastern region, and in Brasilia (Sharma *et al.*, 1985; Freire and Cardoso, 1997).

10.3.8 Physiological disorders

Annona fruits occasionally present abnormalities that are not due to diseases or insect pests, but are due to physiological disorders. George *et al.* (1987) described some of them as follows:

Fruit splitting - probably caused by sudden changes in fruit moisture content or temperature, and some species and varieties appear to be less susceptible than others.

Russeting - superficial russeting of the fruit skin. The combination of low night temperatures (lower than 13°C) accompanied by low humidity is the probable main cause. Nearly mature fruits are more susceptible, and cherimoya is less susceptible than sugar apple and their hybrid atemoya.

Crocodile skin - Fruits show wavy and pointed carpels. Extremely vigorous plants show more severe symptoms. No hypotheses of cause have been advanced.

Hard seed casing and brown lumps - There is a suspicion that boron deficiency or sudden changes in fruit water content may be the main causes of this physiological disorder. In north-eastern Brazil, pulp of sugar apple fruit commonly shows hard seed casing disorder when trees are cultivated in dry areas without irrigation.

Chapter 11. Harvest, Postharvest and Processing

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11.1 Introduction

Cherimoya has been described as the most delicious of the annonas, and as the finest dessert fruit in the world, because of its unique flavour (George *et al.*, 1987). Soursop produces the largest fruit among the annonas, and presents the highest potential for processing (Nakasone and Paull, 1998). The pulp flavour of custard apple fruit is inferior to that of cherimoya and soursop, and, although some trees produce excellent fruits, they are generally not suitable for commercial cultivation (Salunkhe and Desai, 1984; Bora *et al.*, 1987; Nakasone and Paull, 1998). Sugar apple is the most widely distributed of the *Annona* species, and is sweeter than soursop, with a high soluble solid content (24° Brix) and a low acidity (0.58%) (Rego *et al.*, 1979), although the acidity recorded by Singh (1992) is lower still (0.19 - 0.24% depending on cultivar). It is common to find sugar apple in local markets, although due to the small size of fruit, large number of seeds and poor shelf life, they are seldom cultivated in large commercial orchards (Coronel, 1994; Nakasone and Paull, 1998). Wild soursop does not have commercial value at this time, but could be transformed by careful strategic planning, resources and especially germplasm selection.

In spite of the potential, the annonas have some limitations, principally regarding their resistance to transport to distant markets, because they ripen rapidly after harvest and this limits their shelf life. Attempts to enhance the post-harvest life of these fruits must take into account ripening physiology, physical-chemical aspects of fruit quality, and harvest and post-harvest handling (Alves *et al.*, 1997).

11.2 Harvest

Venkataratnam (1959) reported that *Annona* species usually start flowering 4 to 5 years after planting, but there is considerable variation; in Latin America, soursop usually bears fruit in the third year and cherimoya in the third to fourth year. There can be two distinct vegetative flushes, according to the season. Therefore, harvest time, also called harvest point, based on anthesis is impracticable, because flowering can occur during many months. On the other hand, some cultural practices, such as pruning or timing of hand pollination, can alter the time of harvesting, as can the use of appropriate cultivars.

Table 11-1. Harvesting season of the four major *Annona* species in different countries and regions

Countries	Cherimoya	Custard Apple	Soursop	Sugar Apple	Source
Argentina	Feb-Jul	-	-	-	Nakasone and Paull, 1998
Brazil	-	-	Jan-Mar	-	Lucas, 1994
Amazonas	-	-	-	-	Accorsi and Manica, 1994
Rio de Janeiro	-	-	-	Dec-May	Carvalho *et al.*, 2000
São Paulo	-	-	-	Feb-Jun	TCA, undated
Pernambuco	-	-	Jul-Sep	Jan-Aug	-
Pará	-	-	-	-	-
Caribbean	-	Feb-Apr	Year-round	Jun-Sep	Nakasone and Paull, 1998
Chile	Aug-Dec	-	-	-	Nakasone and Paull, 1998
China-Taiwan	-	-	-	Sep-Oct	Tsay and Wu, 1990
	-	-	-	Jul-Sep	Nakasone and Paull, 1998
	-	-	-	Oct-Mar	-
Colombia					
Andes Valley	-	-	Mar-Jun	-	Torres and Sánchez, 1992
Altantic Coast	-	-	Oct-Dec	-	Torres and Sánchez, 1992
Costa Rica	-	-	Year-round	-	-
Dominican Republic	-	-	Feb-Mar, Jul-Aug	-	FDA, undated
India					
Sangareddy	Nov-Jan	Mar-May	Apr-Jun	Oct-Dec	Venkataratnam, 1959
Poona	Nov-Feb	-	-	Aug-Nov	Nakasone and Paull, 1998
Indonesia	-	-	Year-round	-	Nakasone and Paull, 1998
Mexico	-	-	Jun-Sep	-	Nakasone and Paull, 1998
Peru	-	-	Dec-Mar	Nov-Aug	Alvarez *et al.*, 1999
Philippines	-	-	Jun-Aug	Jul-Sep	Nakasone and Paull, 1998; Coronel, 1994
Portugal	-	-	-	-	Nunes, 1997
Madeira	Nov-Feb	-	-	Oct-Jul	Nakasone and Paull,

Countries	Cherimoya	Custard Apple	Soursop	Sugar Apple	Source
					1998
South Africa					
(Natal)	-	-	-	-	FAO, 1988
Spain	-	-	-	Nov-Feb	Accorsi and Manica, 1994
Tanzania					
(West)	-	-	-	-	FAO, 1988
(East)	-	-	-	-	
USA					
California	Mar-Apr	-	-	-	Nakasone and Paull, 1998
Florida	Jul-Oct	Feb-Apr	Jun-Nov	Jul-Sep	
Puerto Rico	-	-	Mar-Sep	-	
Hawaii	-	-	Jan-Oct	-	
Zambia	-	-	-	-	FAO, 1988
Zimbabwe	-	-	-	-	FAO, 1988

In Taiwan, pruning of sugar apple in January and February leads to harvest from July to September, while pruning between June and October leads to harvest from October to March (Table 11-1) (Nakasone and Paull, 1998). Cherimoya fruit quality attributes, such as total soluble solids (TSS) and sugar content, change depending on the pollination time (Nomura *et al.*, 1997). Temperature has a primary effect on the ripening of annona fruit, with low temperature delaying fruit maturation, and high temperatures providing premature ripening on the tree, causing fruit fermentation and fruit fall (George, 1984; George *et al.*, 1987; Nakasone and Paull, 1998). The harvest season of the commercial *Annona* species differs among countries and regions (Table 11-1).

In Colombia, the soursop harvest occurs in two seasons, according to region (Torres and Sánchez, 1992). In the Andean valleys and the lower coffee region (altitude 500 to 1250 m), the major production zones; harvesting occurs between March and June and from October to December, with both seasons producing high quality fruits. Along the Atlantic coast, below 500 m, harvesting occurs between August and October, and the fruits have a very low quality because of the poor genetic resources and the high temperatures of the region (Torres and Sánchez, 1992). In Hawaii, soursop production occurs during most of the year, with two peaks from January to April and from May to August (Nakasone and Paull, 1998). In Brazil, production occurs year round, but in some regions, depending on the temperature and precipitation, the production shows harvesting peaks.

All annonas are characterized as climacteric ripening fruits, so fruits are harvested when they reach physiological maturity and are still firm, full ripening occurs after the climacteric peak. Fruits harvested prematurely will soften but have poor quality (Accorsi and Manica, 1994; Coronel, 1994; Nakasone and Paull, 1998). The time of harvesting is determined by the fruit skin colour, which changes with the proximity of physiological maturity. At harvesting time, soursop fruit skin changes from dark green to slightly yellowish-green, while the cherimoya and sugar apple fruits change from greyish green to yellowish-green, but in all cases their pulp should be firm (Nakasone and Paull, 1998).

A skin colour index to guide the harvest depends on the location of the market. For local markets, fruits must be harvested when mature, with 20 to 40% yellowish-green skin, and they will ripen in 4 to 6 days; for export markets, 10 to 20% yellowish-green skin is satisfactory, as this will provide slightly more time before ripening without the loss of quality. When the fruits are harvested with more than 75% yellowish-green skin, they will ripen in 1 to 3 days, while fruits harvested at less than 5% do not ripen completely at all (George *et al.*, 1987).

Fruit maturation within a plant or orchard is not synchronized, so the harvest season can last for 3 to 6 months. Hence, each tree must be inspected regularly to collect the fruits at the appropriate harvest point. The most suitable time of day to harvest is in the morning just after the evaporation of the dew, when the fruits are dry and fungal rot contamination is less likely (Accorsi and Manica, 1994).

Cherimoya fruits are generally harvested when the skin colour changes from greyish green to yellow-green, although some cultivars will change to almost brown (Accorsi and Manica, 1994). However, sometimes the change of skin colour is not very pronounced. Consequently, colour change, pollination time and fruit size are not reliable harvest indices. Therefore, the harvest index needs to be improved for cherimoya to ensure better fruit consistency, flavour and quality (Palma *et al.*, 1993; Alves *et al.*, 1997; Nomura *et al.*, 1997; Nakasone and Paull, 1998).

Soursop fruits ripen very quickly on the tree. As a consequence, they require frequent visits to the orchard during the harvest season. Maturation is identified when there is a loss in shine and the skin colour changes from dark green to light green (Salunkhe and Desai, 1984; Torres and Sánchez, 1992; Accorsi and Manica, 1994). The carpel units spread apart when the fruits are mature. In Colombia, growers and wholesalers press the fruit with their thumbs to check the fruit maturity (Torres and Sánchez, 1992). It is not recommended to leave soursop fruits ripening on the tree, because they fall and lose market quality. However, if they are harvested before physiological maturity, the fruits do not ripen well and the pulp may become bitter (Torres and Sánchez, 1992).

Sugar apple fruits are considered to be mature and reach their harvesting point when the skin changes colour and when the segments spread far apart, exposing a creamy yellow skin (Salunkhe and Desai, 1984). At this point they have reached their 'consumption point' (Plate 8). They mature at irregular intervals over a period of 3 months, so that picking every other day or so is obligatory. Premature harvesting can promote poor fruit quality and fruits left to ripen on the tree are often eaten by birds and bats, and when over-mature they have a tendency to break and decay (Salunkhe and Desai, 1984; Coronel, 1994; Lucas, 1994; Mosca *et al.*, 1997a).

Annona fruits must be hand-harvested and put into cushioned boxes or baskets to avoid mechanical damage or bruising (Nakasone and Paull, 1998). The boxes must remain in the shade and be protected from rain, wind and dust (Accorsi and Manica, 1994). The fruits may be cut from the branch with pruning scissors, leaving 0.5 to 1 cm of the peduncle to avoid loss in weight and fungal diseases (Accorsi and Manica, 1994; Alves *et al.*, 1997). If the fruits are pulled from the branch, the floral cushion can be damaged, reducing the next harvest. The wounds can also become entry points for rotting pathogens (Calzavara and Müller, 1987; Torres and Sánchez, 1992; Mosca *et al.*, 1997 b).

Depending on tree size, some species, such as sugar apple or soursop, are harvested by climbing using a ladder, or with a pole with a hook and a basket at its end (Torres and Sánchez, 1992; Coronel, 1994). Soursop harvest is more difficult and time-consuming than other annonas because the trees are usually taller and the fruits are larger (Nakasone and Paull, 1998). Nakasone and Paull (1998) suggested mechanical harvesting in larger soursop orchards. Cherimoya fruits are hand harvested by cutting the peduncle and by using net bags to hold or catch the fruit (Accorsi and Manica, 1994; Agustín and Angel, 1997).

11.3 Postharvest handling

11.3.1 Physiological changes

Annona fruits have a respiration peak and an increase in ethylene concentration after fruit harvest; this is typical of climacteric species. Cherimoya, soursop and sugar apple fruits present two successive rises in respiration rate, whereas the custard apple presents only one (Brown *et al.*, 1988). The ripening process occurs during climacteric respiration, with some modifications in the chemical composition leading to remarkable changes in flavour and a decrease in pulp firmness (Mosca *et al.*, 1997 a). Knowledge about this process is very important for post-harvest handling, because ripening occurs very quickly after harvest (Torres and Sánchez, 1992).

Cherimoya presents a climacteric peak 5 days after the harvest point and a second one after 10 days, when the fruits soften, and the flavour and aroma development are completed (Kosiyachinda and Young, 1975). In the cultivar 'Fino de Jete', Martinez *et al.* (1993) demonstrated a temporal coincidence between ethylene production and physical-chemical alterations. During the ripening process at 20°C, the pH dropped to 4.8, total titratable acids increased to 0.36 g citric acid/100 g fresh weight, starch content declined to 20.7 g/100 g fresh weight and Brix increased to 18.7°.

In soursop fruits, the climacteric peak corresponds to an increase in soluble solids content, the pH value decreases and titratable acids rise about 10 fold, due to increases in malic and citric acid concentrations (Paull *et al.*, 1983). Maximum production of volatile compounds and ethylene diffusion occurs 5 days after the harvest point. At this time, the highest concentrations of sugars and acids are attained; this is the moment of best quality for consumption. Fructose and glucose reach their peaks 5 days after the harvest point, while sucrose content rises to a maximum concentration 3 days after harvest point and then declines. Fructose exceeds sucrose concentration and contributes to the sweetness of the fruit (Paull *et al.*, 1983). Starch breakdown by amylases, polygalacturonase and cellulase activities increase during ripening 2 days after the harvest point (Paull *et al.*, 1983). These changes are ethylene independent and probably started at fruit detachment (Bruinsma and Paull, 1984; Paull, 1990). After the climacteric peak, volatile compounds are released, sugar and organic acid concentrations decrease, and there is a loss of fruit quality. The degree of skin darkening is a useful marker for these stages (Paull *et al.*, 1983). The best time for soursop consumption is 6 to 7 days after harvesting (Paull, 1982).

Sugar apple fruits soften during their second ethylene peak. The physical-chemical properties of sugar apple change very quickly after this peak, and abscissic acid increases dramatically and may have a role in fruit ripening (Tsay and Wu, 1990). Sugar apple fruits reach physiological maturity 15 to 17 weeks after pollination, when soluble solids and titratable acids increase (Pal and Kumar, 1995; Mosca *et al.*, 1997 a). Mature sugar apple fruits, at ambient temperature (28 ± 3°C), ripen 2 to 5 days after the harvest point. Ripening is completed and fruits should be consumed when softening is apparent, and also when the soluble solids content reaches 28º Brix and titratable acids fall to 0.3% (Pal and Kumar, 1995; Mosca *et al.*, 1997 a).

11.3.2 Handling

Annona fruits usually ripen 3 to 7 days after harvesting, thus becoming soft and easily injured. Careful, appropriate handling and transportation of fruit is necessary to avoid skin bruising. The fruits are very delicate, so one layer of fruits per box is recommended for storage and for shipment. If 2 or 3 fruit layers are used, fruits must be protected with soft cushioning between them (Calzavara and Müller, 1987; FDA, undated). A single layer in trays containing 6 to 8 kg of fruits is best (George *et al.*, 1987; Accorsi and Manica, 1994). As long as the fruits stay firm it is possible to transport them to distant markets, but they should be wrapped individually with soft materials, such as paper bags or polystyrene gloves (Salunkhe and Desai, 1984; Coronel, 1994; Lucas, 1994). A pre-cooling treatment prior to shipment improves the post-harvest life (George, 1984), except for sugar apple (Singh, 1992).

Aseptic treatment of tools and containers helps to prevent post-harvest infections from pests and diseases. These routines include the immersion of pruning scissors in fungicide solution (benomyl 1 g a.i./l) after every fruit harvested, to avoid transmission of fungal diseases, mainly *Lasiodiplodia theobromae* (Alves *et al.*, 1997; Mororó *et al.*, 1997).

To control fungal rots, George *et al.* (1987) suggested dipping the fruits in benomyl suspension (0.5 g a.i./L) or guazatine solution (0.5 g a.i./L) at 50 to 52°C for 5 minutes. Prochloraz solution (0.125 g a.i./L) for 1 minute at 25°C also gives good control. Immersion treatments longer than 5 minutes induce skin injury, due to the chemical concentrations and interactions. Seemingly, anthracnose (*Colletotrichum gloesosporoides* var. *minor*), *Phomopsis annonacearum* and *Rhizopus stolonifer* are also avoided with fungicidal treatment, but more studies with these diseases are necessary (George *et al.*, 1987). A specific treatment for sugar apple consists of rinsing in chlorinated water (100 ppm) at 10 to 12°C for 20 minutes, followed by 10 minutes in less chlorinated water (20 ppm). To remove chlorine residues, the rinse is followed by immersion or aspersion with water containing 2 ppm of chlorine and a fungicide (Alves *et al.*, 1997). For transport to distant markets, Babu *et al.* (1990) suggested the immersion of sugar apple fruits in 500 ppm of bevestin and placing them in polyethylene bags containing potassium permanganate. However, it must be pointed out that no chemical treatment can be a general recommendation, as each country has its own regulations about the chemicals allowed for each fruit species. Therefore the country's agricultural legislation must be clearly understood before the use of any product reported in the literature.

In case of doubt and considering the softness and sensitivity of annona fruits to mechanical damage, very careful handling in non-contaminated environments can avoid the use of chemical treatments. Gentle cleaning with compressed air and wrapping the fruit in paper or plastic film impregnated with potassium permanganate are good recommendations for carefully handled fruits (Alves *et al.*, 2001).

11.4 Storage

Annona fruits are very perishable and have a short post-harvest life; therefore they require efficient storage techniques (Coronel, 1994). Optimal storage conditions are 15 to 16°C with high relative humidity (RH) and even then storage should not exceed about 2 weeks (George *et al.*, 1987).

Some cherimoya cultivars can be held for 7 to 10 days at 17°C, however, normal ripening usually occurs between 15 to 30°C. Fuster and Prestamo (1980) suggested 10°C and 85% RH as the best storage conditions for the cultivars 'Campas' and 'Fino de Jete', and the optimal storage time ranges from 15 to 21 days. Cherimoya fruits stored at 20°C presented a rapid decrease in fruit firmness (Fuster and Prestamo, 1980; Lahoz *et al.*, 1993). Plaza *et al.* (1993) suggested storage of the 'Fino de Jete' cultivar in polyethylene bags at 8.5°C and 98% RH with 3.5 g KMnO4/kg of fruits. Due to the difference in temperature sensitivity among cultivars, a general recommendation for the storage of cherimoya without risk of chilling damage would be 10°C. The use of plastic bags or plastic wrapping film reduces water loss due to low relative humidity, and the use of potassium permanganate impregnated in the plastic or in sachet inside the pack delays softening.

Mature soursop stored at 22°C and 40-50% RH reaches a climacteric peak in 4 to 6 days, and is ready to consume 2 days later (Paull *et al.*, 1983; Mosca *et al.*, 1997 b). However, under low temperatures the fruits do not ripen properly (Livera and Guerra, 1994). Fresh soursop fruits harvested and stored at room temperature for 4 to 7 days, will reach optimum quality for processing 5 to 6 days after softening begins. Fruits must be stored on racks in the shade and inspected daily, by testing the softness with thumb pressure (Nakasone and Paull, 1998). Based on current knowledge, the best recommendation for the storage of soursop is 15°C and 90% RH.

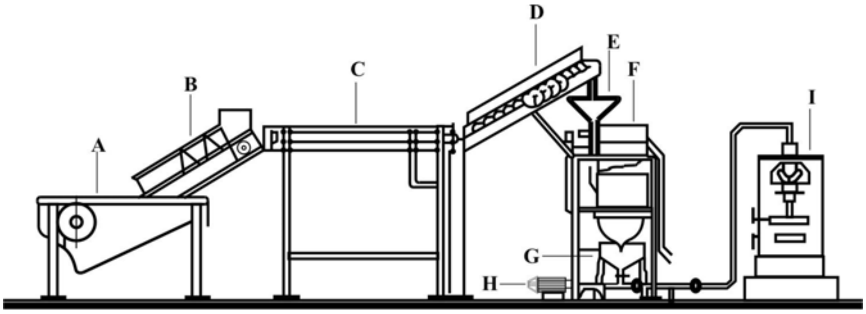
Physiologically mature sugar apples stored at 13°C for 12 days, and then transferred to room temperature (27.5°C) ripen within 4 days, while at 20°C they ripen and soften completely within 6 days; at room temperature ripening takes 2 to 4 days (Tsay and Wu, 1989; Coronel, 1994). The ripe fruits may be stored for 5 days at 5°C; if they are held 5 to 6 weeks at 4.4°C, the pulp remains in good condition, but the skin becomes brown and unattractive (Accorsi and Manica, 1994). Ripe fruits can be kept at room temperature for one day only (Salunkhe and Desai, 1984; Coronel, 1994), while immature fruits stored below 15°C develop chilling injury, resulting in an unpleasant appearance (Salunkhe and Desai, 1984; Tsay and Wu, 1989). Broughton and Tan (1979) reported that high temperatures (above 20°C) and a dry atmosphere accelerated the ripening process, and suggested that the optimal conditions to extend sugar apple storage life are temperatures of 15 to 20°C and RH of 85 to 90% (Broughton and Tan, 1979; Tsay and Wu, 1990; Nakasone and Paull, 1998). Alternatively they can be stored at 15 to 20°C with low oxygen and ethylene tensions, combined with 10% CO_2 and 85 to 90% RH (Broughton and Tan, 1979). Due to the sugar apple's chilling sensitivity, the safest recommended storage temperature is 15°C, with relative humidity around 90%.

Sugar apple, as well as cherimoya will benefit from the use of plastic packing film and potassium permanganate, since it acts only on the external ethylene gas expelled by the fruit during the ripening process by inhibiting this gas and prolonging post-harvest life of climacteric fruit (Pinto, 1978). Another advantage of potassium permanganate is the possibility of decreasing fruit injury by maintaining firmness, as well as being safer for consumption compared with other post-harvest preservation products, which may cause consumer concerns about allergic problems.

11.5 Processing

Annona fruits are mainly consumed as fresh fruit, however, some of them, such as soursop, sugar apple and atemoya, can be processed and used in the preparation of nectars, drinks, sherbets, ice cream, syrup and cakes. Soursop is the most suitable for processing, not only because of its high sugar content and delicate, aromatic flavour, but also because its pulp does not oxidize like that of sugar apple and cherimoya (George, 1984; Villachica *et al.*, 1996; Mororó *et al.*, 1997).

Figure 11-1. Sketch of a mechanized system to process fruit pulp: A) rinse/immersion; B) rinse/aspersion; C) selection; D) endless spiral system; E) storage tank; F) pulp extractor; G) pulp storage tank; H) pump; I) seal bag



Adapted from Mororó *et al.*, 1997.

Before processing, mature soursop fruits should be stored on racks in the shade and inspected daily. As the fruits ripen, they should be removed and processed for pulp extraction. For hand pulp extraction to produce soursop concentrate, Torres and Sánchez (1992) suggested the following steps: 1) fruit selection; 2) fresh water rinse; 3) hand peeling; 4) seed removal; 5) pulp scalding (1 minute); 6) cooling; 7) soluble solids determination; 8) 0.1% sodium benzoate addition; 9) blending (10 minutes); 10) sieving; 11) sugar addition; 12) air elimination and pulp concentration (60°C); 13) deposition of pulp into a container; 14) covering; 15) cooling; 16) labelling; 17) storage. The fruits are hand peeled by making 3 to 4 shallow cuts in the skin and pulling the skin sections from the apical extremity, being careful to eliminate all the skin to avoid depreciation of pulp quality.

Since soursop hand-peeling is a very difficult process to use commercially, Mororó *et al.* (1997) recommended a more practical processor (Fig. 11-1) for pulp extraction. After primary selection of the fruits, they are rinsed by immersion in 10 to 15 ppm chlorinated water (Fig. 11-1A), followed by rinsing with water (Fig. 11-1B). The aim is to remove the residues on the fruit surface, such as dust, soil and pesticides. Following further inspection (Fig. 11-1C) any damaged or unripe fruits that could remain from the first selection are discarded. After peeling, the fruits are transported by an endless spiral system (Fig. 11-1D) to a 'lung container' (Fig. 11-1E). The function of the lung container is to equilibrate pulp flux between extraction and automatic packing, using a dosimeter pump (Fig. 11-1H). The extraction is made by continuously sieving the fruit to separate the pulp from the seeds and other residues. Fine extractions can be made by using a small-hole sieve to separate the fibres, although the fibres are considered as an important dietary component for human health. The pulp is automatically packed into polythene bags and sealed (Fig. 11-1G).

The percentage of pulp recovery ranges from 62 to 85.5%. The variation is due to the type of equipment, extraction method, cultivar, cultural practices and number of seeds per fruit (Nakasone and Paull, 1998). Soursop pulp is viscous, and its dilution produces flat and weak nectar. In addition, the lack of uniformity in acidity and soluble solids concentration generally requires homogenization (Torres and Sánchez, 1992). In order to obtain a good nectar, the pH should be adjusted to 3.7 by the addition of citric acid, and the Brix to 15° by addition of sugar, thus creating an appropriate balance of acidity, sweetness and flavour (Torres and Sánchez, 1992; Nakasone and Paull, 1998). High starch, polyphenoxidase and peroxidase contents decrease the stability of the product's colour and taste (Torres and Sánchez, 1992). To produce a high quality product, soursop pulp should be processed below 93°C and frozen into polythene bags (Pinto, 1991; Torres and Sánchez, 1992).

After processing, the enriched pulp, sweetened or not, can be further processed into various products and puree can be used to prepare ice creams, drinks, sherbets and gelatine (Nakasone and Paull, 1998). The optimum pasteurisation conditions for soursop natural puree are 69 seconds at 78.8°C and pH 3.7 (Umme *et al.*, 1997). It has also been suggested that pulp treated at 70°C for 20 minutes, with addition of 0.5% ascorbic acid to avoid oxidation, and packed into polythene bags, can be stored for one month at 5°C. To obtain nectar for juices, marmalade and jams, 17.8% of pulp, 10.7% of added sugar, 0.02% of sodium benzoate, 0.02% of sodium metabisulfide and water are treated at 100°C for 15 minutes (Villachica *et al.*, 1996).

The pH of marmalade ranges from 3.1 to 3.3, and contains 60% concentrated pulp and 31% added sugar (Villachica *et al.*, 1996). The following steps to prepare marmalade are suggested: 1) scalding or boiling the pulp; 2) homogenization; 3) water addition; 4) sugar addition; 5) cooking for 30 minutes; 6) sugar addition; 7) cooking for 45 minutes; 8) fruit piece addition; 9) final cooking for 10 minutes; 10) placement into a container while warm; 11) labelling (Torres and Sánchez, 1992).

Sugar apple pulp mixed with milk results in a delicious drink and can also be frozen into ice cream, which is the main type of processing for this fruit.

Chapter 12. Economic Information

A. C. de Q. Pinto, D. I. Kinpara, S. R. M. de Andrade

In agro-economic terms, annona species fall into two groups. In the first are custard apple and wild soursop, as well as other species grown by subsistence farmers under smallholder conditions on a casual basis. Establishment of these small holdings is via cultivation of seedlings, even when in small orchards, and attention to market demand is a minor concern as long as fruits can be sold. In the second are cherimoya, soursop and sugar apple, which are often grown on commercial farms, with better technology, numerous inputs, such as irrigation and fertilization, have proper commercial organization and processing infrastructure, and heed market signals constantly. In many regions, however, the species of the second group, e.g., sugar apple and soursop, are still cultivated in conditions reminiscent of the species in the first group or may even have escaped from cultivation and are treated as an extractivist product (as occurs with sugar apple in some parts of India). Two factors will be important for expanding production in both groups: first, the wider application of existing technologies; and second, intensifying commercial production and practices, while heeding market signals.

It is very difficult to compile reliable statistical data on costs in the annona production-to-consumption system, even for cherimoya, which is the most important commercial annona fruit. Most of the scattered, available information suggests that cherimoya, as well as soursop and sugar apple, are highly remunerative crops for both small and medium scale farmers in many countries, although the price of annona fruits received by growers has decreased in the last ten years, reducing farm incomes. The annona fruit market might be strengthened by adopting policies to provide adequate institutional support, financial credit (especially lower interest rates), better infra-structure (e.g., road and ports), research to breed new cultivars, guarantee longer shelf life and develop processed products. Improved access to market information may be just as important as other policies, so that growers can enter their fruits into new and more demanding markets, especially out of season, to obtain better prices.

12.1 Economics of production

12.1.1 Production cost, price and income

The cultivation of cherimoya in Latin America is reputed to have a comparative advantage over other locations, especially considering the cost of production (Van Damme and Scheldeman, 1999). However, these authors do not list the costs for one hectare of cherimoya cultivation using standard production factors, such as labour, mechanization, fertilizers, transport etc. On the other hand, prices of cherimoya have been listed by various authors, which allows the estimation of supposed income for cherimoya growers.

In Spain, cherimoya production has an average yield of 11.8 t/ha during the normal harvest period (September to November). According to Requena (1998), the mean price of cherimoya in 1996 was about 200 pesetas/kg of fruit (at that time US$ 1.00 = pesetas 131.21; hence, the fruit was worth US$ 1.52/kg). From this we can conclude that a cherimoya grower in Spain could expect a gross farm gate income of US$ 17,900 per hectare in 1996. However, 15% of this would be subtracted due to fruit perishability between harvest and market, leaving a gross income of US$ 15,200.

The current cost of establishing one hectare of cherimoya in Spain, with a density of 357 trees/ha, is US$ 8,000-8,300 (Hermoso González, J.M., La Mayora Experimental Station, Spain, personal communication , 2004). This price does not include the price of land, which is frequently very expensive in the traditional growing areas of southern Spain. At present, land prices vary from US$ 185,000 to 190,000/ha and the costs of producing 12-14 t/ha are currently about US$ 5,600-6,000/ha.

Logically, the price of cherimoya depends on a lot of factors, such as size and quality of the fruit, place of sale and harvest date. The price of a good cherimoya fruit in Spain, for instance, has ranged between US$ 0.20 and 1.20/kg in the last few years, depending on the fruit size and harvest date. During the 2003 Christmas season, a good quality fruit was sold for US$ 1.50-1.70/kg (Dr. J.M. Hermoso González, personal communication , 2004). In Belgium, cherimoya fruits imported from Spain are sold for around US$ 5.00/kg in supermarkets, while in Ecuador they are sold for less than a US$ 1.00/kg (Scheldeman, X., personal communication , 2004). In Peru, the price of cherimoya fruit varied from US$ 1.00-2.00/kg in 1991 (Tijero, 1992) and from US$ 3.00 to 5.00/kg FOB for export in 1996 (INIA, 1997).

In Spain, a cherimoya grower, who owns the land under the orchard, can expect an average yield of 13 t/ha and an average price of US$ 0.70/kg of fruit, which gives a gross income of US$ 9,100 in 2003. Comparing the gross income obtained in 1996 with the income of 2003 there is a decrease of 49%. However, using a simple analysis, subtracting the cost of production (US$ 5,800/ha) from the gross income, there is still a profit of US$ 3,300 per hectare, which is an acceptable income per hectare for any fruit grower.

In Brazil, cherimoya is harvested from February to the end of October, and production in 1999 was estimated at 50,000 boxes of 4 to 5 kg, representing a total of 200-250 t of fruit. For a seven year-old cherimoya orchard of the 'Fino de Jete' cultivar, with 417 trees/ha and an average yield of 33 kg/tree (Richardson and Anderson, 1993; Bonaventure, 1999), a Brazilian grower could obtain a gross income of US$ 24,800, when the mean price of fresh fruit was US$ 1.80/kg (Bonaventure, 1999). Although there is no up-to-date information on cherimoya prices in Brazil, the increase in cultivated area surely increases fruit supply and reduces the fruit price in the Brazilian market, which is similar to the situation in Spain.

Today, agricultural production is not discussed in terms of "absolute advantage" or "comparative advantage", but "competitive advantage". Competitive advantage comes mainly from the creativity of adding "value" to the product, for instance, by harvesting fruit out of season when prices are higher in the market. Since cherimoya production occurs mainly between September and November, Spanish growers should use chemical pruning (see Chapter 10) to promote late harvesting (January to February), and get better prices for their fruits. Growers can also add value to their products by processing. By selling their fruits as frozen pulps, jellies and sweets, the 15% due to losses from fruit perishability described by Requena (1998) are eliminated. Both of these ideas might help to slow erosion of fruit prices in producing countries.

The available data on production of soursop and sugar apple in the Cauca Valley, Colombia, and in the central and north-eastern regions of Brazil (Torres and Sánchez, 1992; Pinto and Silva, 1994; Kavati and Piza Jr., 1997) suggest that the most important cost in the first year is the purchase of the irrigation system (18%). Other inputs, such as the cost of producing or buying grafted plants and purchasing fertilizers, are also important during this year, which corresponds to the period of orchard establishment (Pinto and Silva, 1994). Therefore, soursop growers should expect to have no positive net income during the first two years of cultivation; by the third year, the income starts to cover the cost of establishment and maintenance, and provides an economic return (Table 12-1).

The cost for establishment and maintenance of one hectare of soursop can be calculated from a matrix, the units and quantities for each factor of production should be multiplied by local prices for each unit (Torres and Sánchez, 1992; Pinto and Silva, 1994). Aguiar and Junqueira (2001), in their study on costs of establishment and economic returns for soursop, stated that the total cost of production varies from US$ 2,485 per hectare in the first year to US$ 1,183 in the sixth year (Table 12-1).

Intercropping with an annual crop (e.g., beans) or another fruit crop, such as papaya (Plate 3), could provide additional income and decrease the costs of orchard establishment and maintenance during the first unproductive years. Generally, the soursop ecotype Morada attains its mature yield of 50-60 kg of fruits/plant in the seventh year, when the mean productivity is around 10 t/ha and a net annual income of US$ 6,600 is expected. From the second to the seventh year, an accumulated net income of approximately US$ 17,000 is attained (after subtracting the US$ 4,328 costs of the two first years; Table 12-1). Of the US$ 2,486 for orchard establishment and maintenance in the first year, about 70% is maintenance. These numbers must be used cautiously, since mean productivity of soursop in Brazil is only about 4 t/ha and local cultivars of the north-eastern region must also be considered. Soursop, however, can be sold as a fresh fruit or for processing, the latter option adding value to the raw produce, which is a great advantage compared with cherimoya and sugar apple, which are sold almost exclusively as fresh fruit.

Table 12-1. Mean costs to establish and maintain one hectare of soursop cv *Morada*, based on 204 plants per hectare, and estimated gross and net incomes

Year	Establishment/Maintenance (US$)	Av. Yield (ton of fruitha)	Gross Income (US$)[1]	Net Income (US$)
1st	2,486	-	0	0
2nd	716	2	1,360	644
3rd	675	4	2,720	2,045
4th	923	5	3,400	2,477
5th	996	7	4,760	3,764
6th	1,184	9	6,120	4,936
7th	1,212	10	6,800	5,588

Data from central Brazil (Pinto and Silva, 1994; Aguiar and Junqueira, 2001)
[1] Price of fresh fruit was US$ 0.68/kg, at an exchange rate of US$ 1.0 = R$ 2.924 (January 2004).

In south-eastern Brazil, an orchard (417 trees/ha) of 6-year-old sugar apple trees can produce 60 fruits per plant (Lucas, 1994). This suggests that it is possible for sugar apple growers to obtain yields of 25,000 fruits/ha (12.5 t/ha). In July 1996, the price of sugar apple was US$ 0.40 per unit of fresh fruit (Kavati, 1997), resulting in a gross income of US$ 10,000/ha. However, the price of fruit has decreased since then due to a greater supply. In May

2003, the price of fresh sugar apple fruit (500 g weight) in Brasilia, Brazil's capital, was US$ 0.37 per fruit, therefore with the same yield as in 1996, the gross income would be US$ 9,250 in 2003. Even with the costs of production at about 30% of the income per hectare for productive plants, this profit is very good for Brazilian sugar apple growers.

In the semi-arid tropical São Francisco Valley, at Petrolina, Pernambuco, Brazil, sugar apple trees under irrigation can produce two harvests: a main harvest during the rainy season with a high yield (80 fruits/plant), and a second harvest during the dry season with a lower yield (20 fruits/plant), totalling approximately 21 t/ha per year. The semi-arid climatic conditions help to guarantee better fruit quality, translating into a better price and allowing a gross income at the fresh fruit market in Petrolina, of US$ 7,770, even allowing for the lower prices of 2003 (US$ 0.28 per 500 g fruit). However, if these semi-arid growers focus on the major Brazilian market in São Paulo, via the Central Food Clearing House of São Paulo State (CEAGESP), and considering an estimated cost-of-production of 22% of the gross income, their profitability will be much lower than that of São Paulo growers producing in the same period, due to the cost of transportation, since the São Francisco Valley is about 1,200 km from São Paulo.

12.1.2 Production, productivity and value

The estimated production area of cherimoya in the world in 1994 was 13,500 hectares and, considering an average yield of 6 t/ha, the total production was estimated at 81,000 t (PROCIANDINO, 1997). Spain, with more than 3,000 ha, is the most important cherimoya producer in the world, and Peru and Chile are the most important producers in South America, with areas larger than 1000 ha (Requena, 1998). These three cherimoya producing countries account for 46% of this total area. Chile had an average yield in 1998 of 25 t/ha, which is 4 times higher than the world average and 2.1 times higher than Spain (Table 12.2). Chile produced, for the internal market, more than 8,000 t in 1995 and currently has exported only 3% of its total production (Table 12.2), principally to the USA (70%), Japan (12%), Argentina (10%) and Brazil (5%) (Irazabal, 1997).

Mexico produced more soursop than Brazil in the late 1990s, due both to its larger area and to its better productivity. Assuming that the Philippines has the same area of sugar apple in the year 2000 as it did in 1978 (2059 ha), Brazil had comparatively higher production due to its higher productivity (Table 12-2).

Due to the niche markets of Asians and Latin Americans in the USA market, Thailand, the Dominican Republic and Costa Rica are becoming important cherimoya exporters to the USA (Crane and Campbell, 1990). Mexico with its numerous appropriate microclimate conditions, has a great potential to export cherimoya to USA and some growers have already thought of replacing their avocado orchards with cherimoya orchards (Agustin and Alviter, 1996), suggesting that the USA is still an important "open window" for cherimoya exporters.

Table 12-2. Total area, production, productivity and value of three important *Annona* species in some of the major producing countries

Species	Country	Year	Area (ha)	Production (x 1000-t)	Productivity (t/ha)	Value (x 1000-US$)
Cherimoya [1]	Chile	1998	1,152	28.8	25	34,560
	Peru	2000	1,975	14.6	7.4	17,527
	Spain	1998	3,090	36.5	11.8	43,800
Soursop [2]	Brazil	1997	2000	8	4	5,440
	Mexico	1996	5,915	349	5.9	23,732
	Venezuela	1987	3,496	10.1	2.9	6,868
Sugar apple [3]	Brazil	2000	1,294	11.3	8.7	6,328
	Philippines	1978	2,059	6.2	3.0	3,472

[1] Considering a price of US$ 1.20/kg for fresh cherimoya fruit in Spain in January 2004. [2] Considering a price of US$ 0.68/kg for fresh soursop fruit in Brazil in January 2004. [3] Considering a price of US$ 0.56/kg for fresh sugar apple fruit in Brazil in January 2004.

There is little available production data on soursop except in Mexico, Brazil and Venezuela. Due to an increasing demand for soursop, both fresh and processed, Mexico increased its soursop production area by 88% between 1990 and 1996. In Central Brazil, most soursop growers sell their fruits to small agroindustries, with prices varying from US$ 0.51-0.56/kg of pulp. The price of frozen soursop pulp was the highest (US$ 0.29/100 g in 2001) among the many fruit pulps sold in important Brazilian markets, such as São Paulo, Belo Horizonte, Brasilia and Rio de Janeiro.

Sugar apple is the most important annona fruit in Alagoas State, north-eastern Brazil, with production of 7,720 t, which makes Alagoas the most important producer in Brazil (Albuquerque, 1997). This production comes mainly from the Regional Cooperative of Palmeira dos Indios (CARPIL), in Palmeiras dos Indios County, where growers have an average of 1.17 ha of sugar apple each. Large sugar apple fresh fruits, produced in north-eastern and south-eastern Brazil were sold in May 2001, in Brasilia for US$ 0.56/ kg of fruit. In Petrolina, Pernambuco, Brazil, some growers obtained a better prices in the supermarket for purple sugar apple fruits (Plate 1) by selling them as exotic fruits only, since its fruit colour, which somewhat looks like a rotten fruit, is an impediment for better acceptance in the consumer market.

The price of all annona fruits in the national and international markets depends upon the seasonality of production, which interferes in the production value at that moment. Therefore, development of more technically oriented production systems in both the southern and northern hemispheres could expand the availability of fruit and reduce price fluctuations.

12.1.3 Social improvement

The production, processing, sale and use of annona products can improve social conditions in many areas where annonas are grown and processed, through the creation of new employment and the encouragement of small entrepreneurs. However, most annona growers in Latin America have limited knowledge about appropriate technology, so reap few of the possible benefits. In addition, few farmers own the appropriate farm implements, and most of them are still hand-operated and generally inefficient (Van Damme and Scheldeman, 1999). These limitations lessen their chances of competing in urban markets.

Rural people of north-eastern Brazil sell soursop and sugar apple fruits along the federal and state highways, contributing to family income. Some agroindustries contract small-scale soursop farmers to produce specifically for them through a dedicated contract system, which is an especially efficient way of increasing rural family incomes. Although the price offered by agroindustries is lower than that of urban retailers, the avoidance of transportation costs and market competition influences the small growers to deliver their fruits at the farm gate or along the roads. If these small farmers had proper processing infrastructure, they could add value to their raw produce themselves. However, limited or complete absence of access to capital keeps farmers at the subsistence level, preventing them from making decisions for profit maximization (Van Damme and Scheldeman, 1999). Organization into associations or cooperatives is a possibility for increasing access to capital, as well as producing a significant quantity of fruit that could attract larger buyers.

12.2 Marketing and commercialization

Marketing involves the policies that provide strategic support to get a product or service into the consumer market, helping to guarantee the commercial success of the initiative. It also involves the actions taken by individual entrepreneurs to sell their products. Marketing is often the weakest part of the production-to-commercialisation system in which annona growers must participate to sell their products.

Cherimoya has well established international marketing activities, with Spain and Chile as the main producers and marketers. The other annona fruits, however, are traded mostly in national markets of the countries where they are produced. According to Bandeira and Braga Sobrinho (1997), Bonaventure (1999) and Van Damme and Scheldeman (1999), the national and international markets for annonas are limited for the following reasons:

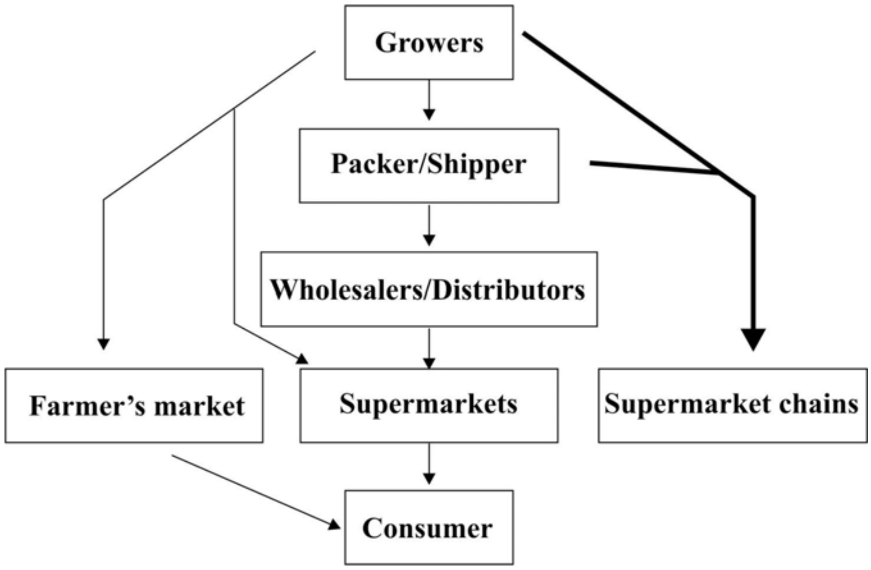
1. *Annona* species have not received adequate institutional support to be able to obtain financial credit with lower interest rates, good paved roads to avoid fruit damage, extension services to transfer technology and see good planting material is available, or for research to develop new cultivars.

2. Due to short shelf life and poor postharvest technologies, significant losses of fruits in transport impedes their export success.

3. Processed pulp is sometimes of low quality and does not meet the standards of the international markets, principally because adequate processing technologies are not readily available to most producers, especially small growers and wholesalers.

4. Lack of international market information, mainly for tropical *Annona* species, restricts crop and product diversification where it might otherwise be successful. Success in fruit commercialisation is entirely due to marketing policies. These depend on several factors, such as markets with established production-to-commercialisation systems, farmers' organisations, transport and roads, and institutional support, which include access to financial services, research and extension. Many of these factors depend upon state and national governmental policies and political will.

Figure 12-1. Commercialization channels for distribution of cherimoya in California, USA



Where there is a market, there is a production-to-commercialisation system, varying from a simple system to a more complex one (Fig. 12-1). In a simple system, annona growers can sell their fruits in farmers' markets directly to the consumer; these are generally small fairs in small cities or villages. A complex system leads into larger markets and is constructed around a system starting with producers selling to packers and shippers, then a number of wholesale companies that send annona fruits to supermarkets, and finally cherimoya, soursop or sugar apples are sold to consumers as specialties (Grossberger, 1999).

Prices of annona fruits vary according to their supply and demand. However, in general, well packed and shipped fruits are more expensive than fruits from a simple marketing system, due to their higher quality (less damage and disease, better shape and weight classification, and uniformity of external colour). Bonaventure (1999) commented that in São Paulo, Brazil, a carton with four high quality cherimoya fruits attained a price of R$ 35.00 (US$ 14.46/carton at US $1.00 = R $2.42) in 1998. According to this author, 500 g is the ideal weight for a cherimoya fruit in the Brazilian markets.

Fruit packing has a pattern of classification, which influences prices significantly. Grossberger (1999) commented that packing of cherimoya fruit for the USA market is generally in boxes of 4.5 kg, with plastic insertions that hold 6 to 16 fruits in appropriate positions. Lower quality fruit is generally sold in a loose pack, which is commonly packed in 18 kg boxes, as is seen in California. Fruits sold to supermarkets are considered specialties and only small amounts are displayed at any one time.

Soursop growers pack their fruits in single layer trays with 9 or 12 fruits per tray to be sold at supermarkets or they sell individual fruits in the local fresh fruit markets. Because soursop is a large fruit, especially that of the ecotype Morada, it is difficult to sell to an individual consumer. Some retailers in Brasilia, the capital of Brazil, slice the ripe soursop fruits and pack the slices (around 1 kg per slice) in trays with thin plastic covers, displaying them in freezers of large supermarkets in order to meet their consumers' requirements and facilitate commercialisation.

In Australia, sugar apple is commonly packed in single layer trays of 6 to 8 kg (George *et al.*, 1987). In Brazil, sugar apples are often packed in wooden boxes with weight varying according to the state or local market; smaller fruits are often sold in packages with 12 to 24 fruits (Lucas, 1994). Yokota (1986) commented that the types of classifications for sugar apple in São Paulo, Brazil, are mainly based on length, diameter and weight of the fruits. The fruit arrangement in the box varies according to the fruit size and number of fruits per box; a type 9 carton has fruits with average weights of 500 g, which is the best commercial weight, and the package has 9 fruits (Table 12-3).

Table 12-3. Carton types for classification and packing of sugar apple fruit in the São Paulo market, Brazil

Carton	Fruit Characteristics			Fruit Arrangement in the Package	
	Length (cm)	Diameter (cm)	Weight (g)	Columns	Rows
8	>10.5	10.5-11.5	600-620	2	4
9	9.5-10.5	10.0-10.5	480-520	3	3
12	8.5-9.5	9.0-10.0	360-390	3	4
15	8.0-8.5	8.5-9.0	280-320	3	5
18	7.5-8.0	7.5-8.5	210-215	3	6

Source: Yokota (1986).

Packing represents 8-10% of the gross value reflected in the market price and poor packing can decrease the fruit price by up to 30% (Kavati, 1997). Sugar apple packing carton type 9 is the most commonly commercialised in south-eastern Brazil. However, in Brasilia, a smaller and cheaper wooden box with six fruits is the most common type of packaging, with a retail price of R$ 4.00 per box (US$ 1.65/box) in May 2001, while the supermarket price was generally twice as high.

To provide the consumer with a good quality product on a timely basis with affordable prices, a well-constructed farmers' organization is necessary.

Close linkages between growers and retailers can be established through producer cooperatives. The development of this type of organization is extremely important for the success of most modern agricultural initiatives, but is beyond the scope of this book.

Looking at the participants of the market chain of annona fruits, growers are the ones who have the highest risk and the lowest profit, whereas consumers, at the end of the chain, pay for all the growers', wholesaler's and retailers' profits. The best example of this common economic equation is given by Alvarez *et al.* (1999) in Ecuador. Cherimoya prices in Ecuador in 1999 ranged from US$ 0.01 to 0.05 per fruit of 600-800 g at the farm gate. Wholesale buyers sold cherimoya to the supermarkets at the price of US$ 0.075 per fruit and supermarkets sold the fruit to the final consumer for US$ 0.25, which is an increase of 80 to 96% over the price received by the growers compared with the price received by the supermarket owners. However, it is necessary to remember that most of this price composition is aggregated by services needed to get the final product into market due to its perishability.

Chapter 13. Conclusions and Research Needs

A. C. de Q. Pinto

Several of the *Annona* species discussed here, especially cherimoya, soursop and sugar apple, have a great potential for an expanded world-wide market for fresh fruit consumption and industrially processed products. The lesser known species, such as custard apple, wild soursop, and other species not discussed, have limited importance for consumption as fresh fruit, although the uses of custard apple as a rootstock and of wild soursop for insecticidal formulations have demonstrated their relevance in many countries. Selection and agronomic development could change this in the mid-term future.

Important agronomic advances have occurred with *Annona* species. New cherimoya, soursop and sugar apple varieties offer better fruit quality for consumer markets. Even the purple sugar apple, which is offered in the market as a rarity or curiosity, has obtained double the price of a normal fruit. The hybrid atemoya produces better in inhospitable environments, and offers better fruit resistance to transport and post-harvest management, compared with either of its parents.

Relevant field technologies, such as the use of artificial pollination to increase fruit set and the development of new pruning and training techniques to improve plant architecture have both had positive effects on yield and fruit quality. Also, intercropping techniques now allow the growers to obtain additional income during the first 2-3 years in the field. Post-harvest technologies for the soft and difficult to handle fruits have been improved and new methods of fruit packing, with their systems of classification, have significantly influenced fruit quality and prices. Packaging of frozen soursop pulp in an appropriate size and format is a recent marketing strategy.

A major breakthrough in recent years has been the better identification and isolation of important industrial and medicinal compounds in *Annona* species. Almost without exception, *Annona* species have bioactive compounds in their roots, leaves, bark, fruits and seeds that have great potential for use in industry and medicine.

However, the expansion of the cultivated areas of annonas is still limited, except for cherimoya in China, Taiwan, Spain and Chile, soursop in Brazil and Mexico, and sugar apple in India. This is due partially to ecological, but principally to political and social factors. Field labour qualified to use new technologies, reduction of input costs and better fruit prices are the most important factors limiting cultivation and marketing today. Lack of government support for financial credit, research and extension services, roads and tax structures are policies that negatively influence the expansion of cultivation.

This review has highlighted intensive research on cherimoya in Spain. This has been wide-ranging and has covered studies on germplasm, agronomy and processing. Other research has focused on soursop in Mexico, Brazil and Colombia, which has had positive impacts on increasing commercialisation and demand. The research on soursop has been more fragmented than that on cherimoya, and there has been less successful dissemination and adoption of research findings. The application of new technologies by growers in Latin America is still limited, due mainly to poor education levels and low technical qualification. Additionally, few farmers have the appropriate implements and orchard management is still manual, with consequent impacts on fruit quality limiting commercialisation.

There has been other significant research, summarized in the body of the text. The basic research in India on sugar apple has been noteworthy, and basic and applied research in Australia, the Philippines, China and Taiwan on several species likewise.

Two important conclusions emerge from this review. First, all too often the adoption of modern agronomic practices is slow. This is a complex issue and requires targeted down-streaming of technologies and support from extension services. Second, too little attention has been given to the better exploitation of the *Annona* gene pool; current use of germplasm collections is woefully inadequate in all countries holding them. This means that selection of new cultivars has been almost a random process, when there is the urgent need to have a range of cultivars readily available for the agro-ecological niches where growers live and produce.

There are also socio-economic factors relevant to the production of annonas. For instance, most Latin American banks charge high interest rates for the financial credit they offer to small growers - a strong barrier against introduction and use of new technologies. Also, governments have given poor support to the construction and maintenance of paved roads, resulting in fruits of poor quality and lower prices in the market, a disincentive to both growers and consumers. Prices of annona fruits vary according to supply and demand, and small farmers sell their fruits mostly into simplified market channels in which low quality and price are demanded, resulting in low profits. In Brazil, fruit growers must pay high export taxes, representing up to

25% of the product's free on board (FOB) price, which negatively influences competitiveness in world markets.

Consumption habits are important social factors restricting expansion of annonas in various parts of the world. Cherimoya is not known by people living in many tropical regions of the world, although it can be found on supermarket shelves of big cities. Soursop and sugar apple are similarly poorly or unknown in temperate countries. Although wild soursop adapts very well to different altitudes and climate conditions, its presence is essentially restricted to Africa and its potential for expanded use beyond that continent is currently unknown.

The following section highlights those aspects which require development to allow utilisation of *Annona* species to their fullest potential for improvement of grower livelihoods, both at small and large scale. Adequate training in the growing, processing and marketing of *Annona* species is urgently needed.

13.1 Research requirements and technology transfer

The most important research requirements are listed below, although priorities will surely vary among institutions and countries that study and cultivate annonas.

13.1.1 Genetic resources and genetic improvement

a) Conservation of *Annona* germplasm is important to avoid excessive genetic erosion. Loss of diversity among traditional farmers is likely because the economic environment of the farm household strongly influences the extent of the diversity maintained on farm. Conservation of genetic resources should be carried out both *in situ* and *ex situ*. Developing a conservation strategy for the various *Annona* genepools also requires enhanced basic research on the species relationships and the patterns of variation within the genepools (the use of DNA markers is a particularly useful tool for this).

b) Better methods and enhanced attention to methods of characterizing germplasm are needed. This also depends on implementing the basic research in the above point.

c) Accessions in germplasm collections are by no means representative of the patterns of variation in wild and cultivated species. The current collections need urgent assessment and they should be nationalized and enriched. The collections are limited to a few *Annona* species (especially cherimoya and soursop) and to a few countries.

d) Variability in seedling rootstock performance, due to genetic diversity, is a major cause of low scion yield and poor fruit quality. Therefore, research on selection of vigorous and genetically stable rootstocks is very important.

e) Development of new scion cultivars, and crosses with cultivars with superior agronomic and yield traits is essential to provide high quality fruits (among other selected traits, cultivars should have high natural fruit set, out of season harvest, fruits with symmetrical form, excellent taste and a hard, resistant rind to improve pest and disease resistance, as well as to prolong post-harvest life).

f) During selection and breeding there are opportunities to find fruits with odd characteristics that might attract consumers and better prices. Skin colour is the obvious trait of interest, but others may exist.

g) For specific pharmacological purposes, evaluation and selection of wild and cultivated species with important medicinal and insecticidal uses should be pursued, and supported by field surveys and laboratory analysis (Abubakar and Abdurahman, 1998; Farrera Villanueva *et al.*, 1999).

h) Biotechnology needs to be much more widely applied. Studies, such as those of Encina *et al.* (1999) on genetic transformation to improve the control of the ripening, to change the post-harvest characteristics of fruits, and to provide pest and disease resistance should continue.

13.1.2 Propagation studies

a) Vegetative propagation by budding or grafting is slow, often costly and in some cases, inefficient. Tissue culture research should be accelerated to provide reliable micro-propagation of desirable planting materials.

13.1.3 Studies on crop management

a) Pruning for increased yield should be better developed for each species in a range of environmental conditions. These studies would look for better fruit distribution and supply, and help to stabilize prices in the markets and profitability for growers.

b) Water management and modern irrigation techniques have not been fully investigated or developed and need more attention. Intercropping and cover-cropping systems should be better studied, both to support water management and to improve fruit production.

c) A full range of organic production techniques and practices should be examined and adapted to production of the major export annonas, especially cherimoya. Locally, both sugar apple and soursop might benefit in specific markets.

13.1.4 Postharvest and processing

a) *Annona* fruits do not ripen adequately when harvested at the immature stage, hence identification of the best stage for picking is essential. On the other hand, ripe fruits are particularly vulnerable to rot and decay, thus quickly losing their shelf life and quality. This raises the need for adequate on and off-farm facilities and technology to store and/or process these fruits.

b) Appropriate packaging techniques for long-distance transport are necessary, especially for markets that demand better flavour and appearance, due to the fact that fruits are nearer maturity when picked.

c) Currently, adding value through product diversification is a priority area for research attention, although this should be done by the private sector. However, in most less developed countries, the public sector must get involved, preferably in partnership with the private sector.

13.1.5 Industrialisation and marketing

a) Better technology for pre-prepared juices is an urgent requirement, since many annona flavour components are extremely volatile and are lost with current preparation technologies. Capture and return of these volatile components may be the key to preparing bottled and tetra-packed juices for many markets, including export.

b) *Annona* species are already used for the preparation of medicinal products with high values. Soursop acetogenins have potential anticancer uses, but no information is available about which is the best plant part for extraction of these secondary metabolites. Rain Tree, USA, is the only enterprise so far that has shown an interest in the industrialization of secondary metabolites. Interest by the public sector should be mobilized to accelerate development of these opportunities, always in accordance with the Convention on Biological Diversity.

c) Extract of wild soursop is prepared domestically and used with success as an insecticide in Africa. Studies on methods for more efficient small-scale industrialization of the extract should be pursued.

d) Traditional marketing systems are still used by the majority of growers and, consequently, prices received by them are still low, especially for small growers. It is extremely important that government agencies and institutions carry out policy research and stimulate organization of small growers into associations or co-operatives, so that they can better compete in national markets and reach international markets.

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Appendix A. Common chemical compounds found in annonas

Table A-1. Some of the Most Common Chemical Compounds Found in Different Parts of Cherimoya (*Annona cherimolia*), Custard apple (*A. reticulata*), Soursop (*A. muricata*), Wild soursop (*A. senegalensis*) and Sugar Apple (*A. squamosa*)*.

Compounds	References	A.c.	A.r.	A.m.	A.se.	A.sq.
Acetogenins						
4 deoxyannoreticuin	Hopp *et al.*, 1998					b
Alumunequin	Cortés *et al.*, 1993b; Duret *et al.*, 1994	r,s				
Annocherin	Woo *et al.*, 2000	S				
Annogalene	Sahpaz *et al.*, 1996	S				
Annoncherimolin	Kim *et al.*, 2001	S				
Annomolin	Kim *et al.*, 2001	S				
Annomonicin	Chang *et al.*, 1993		l			
Annomuracins A, B	Wu *et al.*, 1995 a c			l		
Annomuracin E	Kim *et al.*, 1998			l		
Annonacin 10 one	Wu *et al.*, 1995 a c; Rieser, 1996			l,s		
Annonacin A	Wu *et al.*, 1995 a c			s		
Annomuricatin B cyclopeptide	Vhao-Ming *et al.*, 1998			s		
Annonastatin	Nonfon *et al.*, 1990					s
Annopentocin A, B, C	Zeng *et al.*, 1996			l		
Annoreticuin	Chang *et al.*, 1993; Chang *et al.*, 1998		l,s			
Annoreticuin 9	Hopp *et al.*, 1997					b
Annoreticuin 9 one	Change *et al.*, 1993; Change *et al.*, 1998		l, s			
Annosenegalin	Sahpaz *et al.*, 1996				s	
Annosquamosins A, B cyclopeptides	Chao-Ming *et al.*, 1997					b
Anonacins	Nonfon *et al.*, 1990					s
Anonins	Nonfon *et al.*, 1990; Pinto & Silva, 1994		s	l,s		s
Arianacin	Reiser, 1996			s		
Aromin A	Chen *et al.*, 1999	st,l,s				
Asimicin	Nonfon *et al.*, 1990					s

Compounds	**References**	**A.c.**	**A.r.**	**A.m.**	**A.se.**	**A.sq.**
Bullatacin	Li *et al.*, 1990; Hernández & Angel, 1997; hang *et al.*, 1999		s			b,s
Bullatacinone	Li *et al.*, 1990; Duret *et al.*, 1994; Hernández & Angel, 1997	r				b,s
Chermolin 1	Cortés *et al.*, 1993 b	s				
Cherimolin 2	Cortés *et al.*, 1993 b	s				
Cis 4 deoxyannoreticuin	Hopp *et al.*, 1998					B
Cis annonacin	Reiser, 1996; Woo *et al.*, 1999 a			s		
Cis annonarin-10-one	Reiser, 1996			s		
Cis and trans annomuricin C,D,E	Kim *et al.*, 1998 a			l		
Cis goniothalamicin	Wu *et al.*, 1995 c; Rieser, 1996			l,s		
Cis trans bullatacinone	Chang *et al.*, 1998		s			
Cis trans isomurisolenin	Chang *et al.*, 1998		s			
Cis trans murisolinone	Chag e*et al.*, 1998		s			
Cyclopeptide muricatonins A,B	Wu *et al.*, 1995 c			s		
Donhexocin	Yu *et al.*, 1998			s		
Epomuricenins A,B	Roblot *et al.*, 1993			s		
Gigantetrocin A	Wu *et al.*, 1995 c			l,s		
Isoannoreticuin	Chang *et al.*, 1993		l			
Isocherimolin 1	Duret *et al.*, 1994	r				
Isomolvizarin 1	Duret *et al.*, 1994	r				
Isomolvizarin 2	Duret *et al.*, 1994	r				
Javoricin	Reiser, 1996			s		
Liriodenine	Philipov *et al.*, 1994			s		
Laherradurin	Cortés *et al.*, 1993 b	s				
Molvizarin	Hisham *et al.*, 1994		stb			
Muricapentocin	Kim *et al.*, 1998 a			l		
Muricatocins A,B,C	Wu *et al.*, 1995 c			l		
Muricin	Pinto & Silva, 1994			st,l,s		
Muricinin	Pinto & Silva, 1994			s		
Muricatetrocins A,B	Wu *et al.*, 1995 b			l,s		
Muricoreacin	Kim *et al.*, 1998 b			l		
Murihexocin C	Kim *et al.*, 1998 b			l		
Murihexol	Yu *et al.*, 1998			s		

Compounds	**References**	**A.c.**	**A.r.**	**A.m.**	**A.se.**	**A.sq.**
Otivarin	Cortés *et al.*, 1993 a	S				
Panatellin	Gleye *et al.*, 1998			r		
Reticulatacin	Gleye *et al.*, 1998			r		
Reticulatacin-10-one	Gleye *et al.* 1998			r		
Reticulacinone	Hisham *et al.*, 1994		stb			
Rolliniastatin	Chang *et al.*, 1993		l			
Rolliniastatin 2	Hisham *et al.*, 1994		stb			
Sabedelin	Gleye *et al.*, 1999			r		
Solamin	Myint *et al.*, 1991; Chang *et al.*, 1993; Gleye *et al.*, 1998		l,s	r,s		
Squamocin	Duret *et al.*, 1994; Hernández & Angel, 1997	r	s			s
Squamone	Li *et al.*, 1990; Chang *et al.*, 1993		l			b
Squamotacin	Hopp *et al.*, 1996					b
Uvariamicin I	Gleye *et al.*, 1998			r		
Uvariamicin IV	Gleye *et al.*, 1998			r		
2,4 cis and trans annocherinone	Woo *et al.*, 2000	s				
2,4 cis and trans isoannonacin	Wu *et al.*, 1995 b; Woo *et al.*, 1999 a	s		l		
2,4 cis and trans squamoxinone	Hopp *et al.*, 1998					b
2,4 cis and trans mosinone A	Hopp *et al.*, 1997					b
Alkaloids						
(-)Roemerine	Bhakuni *et al.*, 1972; Oliver-Bever, 1986; Cassady, 1990; You *et al.*, 1995; Chuliá *et al.*, 1995; Fatope *et al.*, 1996	r	l,s		l	l
Anonaine	Yang & Chen, 1970; Bhakuni *et al.*, 1972; Fresno & Cañavate, 1983; Bridg, 1984; Philipov *et al.*, 1995	r,stb, l,p,b, s	r,b	l	r,l,b	r,l,b
Aporphine	Cassady, 1990; Salluja *et al.*, 1990; Maeda *et al.*, 1993; Chuliá *et al.*, 1995; You *et al.*, 1995; Fatope *et al.*, 1996	r	s		l	l
Benzyllioquinoline	Maeda *et al.*, 1993		s			

Compounds	**References**	**A.c.**	**A.r.**	**A.m.**	**A.se.**	**A.sq.**
Caffeine	Lizana & Reginato, 1990	s				
Corydine	Oliver-Bever, 1986		l,s			b,r,st,s
Dehydroroemerine	Chuliá *et al.*, 1995	r				
α-Glaucine	Oliver-Bever, 1986					b,r,st,s
Isoboldine	Philipov *et al.*, 1995				r,l,b	
Isocorydine	Oliver-Bever, 1986					b,r,st,s
Isoquinoline	Leboeuf *et al.*, 1981; Maeda *et al.*, 1993		s	l,s,r,b		
Lanuginosine	Fresno & Cañavate, 1983	stb,l,p,b,s				
Liriodenin	Fresno & Cañavate, 1983; Morton, 1987; Philipov *et al.*, 1995	stb,l,p,b,s	r,b	s	r,l,b	
Norcorydine	Oliver-Bever, 1986					b,r,st,s
Norisocoryline	Bhakuni *et al.*, 1972					l
Pyrimidine β carboline	Maeda *et al.*, 1993		s			
Other Compounds						
β farnesene essential oil	Leal, 1990					s
α pirene essential oil	Leal, 1990					s
β pirene essential oil	Leal, 1990					s
Aliphatic ketone	You *et al.*, 1995				l	
Alkanes	You *et al.*, 1995				l	
Alkanols	You *et al.*, 1995				l	
Aminoacids	You *et al.*, 1995				b	
Amyl caproic acid	Pinto & Silva, 1994			p		
Amyloids	Kooiman, 1967			s		
Annosquamosins A,B diterpenoids	Wu *et al.*, 1996		s			f,b
Cherimoline	Chen *et al.*, 1998	st,l				
Cherinonaine	Chen *et al.*, 1998	st,l				
Coclamine	Khan *et al.*, 1997			p		
Couximine	Khan *et al.*, 1997			p		
Cohibins A,B	Gleye *et al.*, 1997			r		
Dihydroferuloyltyramine	Chen *et al.*, 1998	st,l				
Diterpenes	Mukhophadhyay *et al.*, 1993					r,stb
Ent-kaurenoids	Fatope *et al.*, 1996				rb,st,s,tb	
Essential oils (others)	Bridg, 1964; MacLeod & Pieris,	l,s	l,r	f	f	S,l

Compounds	References	A.c.	A.r.	A.m.	A.se.	A.sq.
	1981; Jivoretz *et al.*, 1998					
Esthers	Idstein *et al.*, 1984; You *et al.*, 1995	p				
Flavonoids	Cassady, 1990; Langanson *et al.*, 1994				l	
Geranyl caproic acid	Pinto & Silva, 1994				l	
Kaurane diterpenoids	Adeogan & Durodola, 1976; Maeda *et al.*, 1993; Wu *et al.*, 1996	st,l	s		b	f,r
Lactam amide	Chen *et al.*, 1998	st,l				
Limorene essential oil	Leal, 1990					s
Monoterpenoids	You *et al.*, 1995				l	
Murisolin	Khan *et al.*, 1997			p		
n-trans caffeoyltyramine	Chen *et al.*, 1998	st,l				
n-cis caffeoyltyramine	Chen *et al.*, 1998	st,l				
n-cis feruloymethoxytyramine	Chen *et al.*, 1998	st,l				
n-cysferuloyltyramin	Chen *et al.*, 1998	st,l				
n-fatty acyl tryptamine	Maeda *et al.*, 1993		s			
n-p-coumaroyltyramine	Chen *et al.*, 1998	st				
n-trans feruloylmethoxytyramine	Chen *et al.*, 1998	st,l				
n-trans feruloyltyramine	Chen *et al.*, 1998	st,l				
Purine	Cehn *et al.*, 1998	st				
Reticulin	Khan *et al.*, 1997			p		
Rhamnoside	Salluja *et al.*, 1990					l,s
Saponins	Salluja *et al.*, 1990; Langanson *et al.*, 1994				l	s
Sesquiterpenoids	You *et al.*, 1995				l	
Stepharine	Khan *et al.*, 1997			p		
Steroids	Chen *et al.*, 1998	st				
Sterols	You *et al.*, 1995				l	
Tannins	Burkill, 1966; Langanson *et al.*, 1994	l	l	p	l	
Trans orimene essential oils	Leal, 1990					s
Volatiles (terpenes hydrocarbons, esters, carbonyls)	Idstein *et al.*, 1984	p				

Key: r-root; rb-root bark; st-stem; stb-stem bark; l-leaf; f-fruit; p-pulp; b-bark; s-seed.

* This is not a comprehensive list of compounds.

Appendix B. Uses of Annona species in medicine

Table B-1. Some Uses of Annona Species in Medicine, Cherimoya (*Annona cherimolia*), Custard apple (*A. reticulata*), Soursop (*A. muricata*), Wild soursop (*A. senegalensis*) and Sugar Apple (*A. squamosa*)

Human Bioactive Effects	Compound	Reference	A.c.	A.r.	A.m.	A.se.	A.sq.
Abortion	Unkown	Salluja & Santini, 1990; Asolkar *et al.*, 1992				s	s
Anal prolapse	Unknown	Chao-Ming *et al.*, 1997			l		l
Antibacterial	Murisolin, couxine, couclamine, stepharine, reticulin	Asolkar *et al.*, 1992; Khan *et al.*, 1997			l		+
Anti-HIV principle	16β17 dihydroxy kauran19oic acid	Wu *et al.*, 1996					f
Antineuralgic properties	Essential oils	Calzavara *et al.*, 1987; Moura, 1988			l		
Antiparasitic and protozoa activity	Probably acetogenins and essential oils	Calzavara *et al.*, 1987; Bories *et al.*, 1991; Philipov *et al.*, 1994	s		s,l		
Antispasmodic	Probably flavonoids alkaloids tannins saponins	Moura, 1988; Philipov *et al.*, 1994; Chuliá *et al.*, 1995	r		l,s		
Antiulcer	Flavonoids	Langanson *et al.*, 1994				l	
Astringent	Unknown	Calzavara *et al.*, 1987; Asolkar *et al.*, 1992; Khan *et al.*, 1997;	f	b	l,f		
Atonic dyspepsia	Unknown	Calzavara *et al.*, 1987; Khan *et al.*, 1997			f		

Human Bioactive Effects	Compound	Reference	A.c.	A.r.	A.m.	A.se.	A.sq.
Bed bugs/lice	Acetogenins, alkaloids flavonoids tannins saponins	Rupprecht *et al.*, 1990; Bories *et al.*, 1991; Asolkar *et al.*, 1992; Langanson *et al.*, 1994;Hernández & Angel, 1997; Abubaka & Abdurham, 1998	s	l,s,p	s	l,s,dried f	s
Burning of the throat	Resin	Lizana & Reginato, 1990	s		l		
Cancer treatment	Kaurene, diterpenoids, acetogenins	Cassady, 1990; Asolkar *et al.*, 1992; Chang *et al.*, 1993; Hopp *et al.*, 1994; Wu *et al.*, 1995; You *et al.*, 1995; Fatope *et al.*, 1996; Hopp *et al.*, 1996; Reiser *et al.*, 1996; Sahpaz *et al.*, 1996; Zeng *et al.*, 1996; Hopp *et al.*, 1997; Kim *et al.*, 1998 a	s	s,l,b		s,r,stb,l,b	b
Cathartic	Unknown	Lizana & Reginato, 1990; Asolkar *et al.*, 1992	s				
Cemopreventative agents	Flavonoids	Cassady, 1990	l,b,f,r,s	l,b,f,r,s	l,b,f,r,s	l,b,f,r,s	l,b,f,r,s
Chest pain	-	You *et al.*, 1995				r,l	
Colic	Murisolin, couxine, couclamine, stepharine, reticulin	Khan *et al.*, 1997			f		
Convulsions	Unknown	You *et al.*, 1995				r,l	
Depression (sedative, anxyolitic)	Alkaloids, others	Bories *et al.*, 1991; Chao-Ming *et al.*, 1997	l		l		r
Diabetes	Unknown	Calzavara *et al.*, 1987			l		

Human Bioactive Effects	**Compound**	**Reference**	**A.c.**	**A.r.**	**A.m.**	**A.se.**	**A.sq.**
Diarrhoea, dystentery	Alkaloids, murisolin, couxine, couclamine, stepharine, reticulin	Calzavara *et al*., 1987; Leal, 1990; Asolkar *et al*., 1992; Philipov *et al*., 1995; You *et al*., 1995; Khan *et al*., 1997		b	l,f,r	r,b,l	+
Diuretic	Unknown	Calzavara *et al*., 1987; Khan *et al*., 1997			f		
Dryness of the mouth	Lizana & Reginato, 1990						
Emetic	Resin	Calzavara *et al*., 1987; Lizana & Reginato, 1990; Asolkar *et al*., 1992	s		s	+	
Eye inflammation	Alkaloids, flavonoids tannins saponins	Calzavara *et al*., 1987; Philipov *et al*., 1995			fw	l	
Febrifuge	Murisolin, couxine, couclamine, stepharine, reticulin	Calzavara *et al*., 1987; Asolkar *et al*., 1992; You *et al*., 1995; Fatope *et al*., 1996; Khan *et al*., 1997			l,f	r	
Filariosis	Unknown	You *et al*., 1995; Fatope *et al*., 1996				r,l	
Gastric & digestive processes, intestine diseases in general, as a tonic or laxative	Alkaloids, flavonoids tannins saponins	Leal, 1990; Langason *et al.* 1994; Philipov *et al*., 1995; Voigt *et al*., 1995; You *et al*., 1995; Khan *et al*., 1997	l		l	r,b,l	l,r
Haemolysis of red blood cells	Saponins	Salluja & Santani, 1990					s
Immunosupressant	Acetogenins	Rupprecht *et al*., 1990	r,s	s	r,l,s	l,s	s
Intense photophobia	Resin	Lizana & Reginato, 1990	s				
Liver disease, jaundice	Acids	Calzavara *et al*., 1987			p		

Human Bioactive Effects	**Compound**	**Reference**	**A.c.**	**A.r.**	**A.m.**	**A.se.**	**A.sq.**
Malaria	Murisolin, couxine, couclamine, stepharine, reticulin	Khan *et al.*, 1997			f		
Male impotency	Alkaloids	You *et al.*, 1995				r,l	
Nausea & vomiting	Resin	Calzavara *et al.*, 1987; Lizana & Reginato, 1990; Khan *et al.*, 1997	s		f,s		
Oedema	Murisolin, couxine, couclamine, stepharine, reticulin	Khan *et al.*, 1997			f		
Parasites of the feet	Acids	Calzavara *et al.*, 1987; Asolkar *et al.*, 1992; Philipov *et al.*, 1994	s		p		
Peptic ulcers	Murisolin, couxine, couclamine, stepharine, reticulin	Khan *et al.*, 1997			f		
Pneumonia	Unknown	Williamson, 1974; Vogt, 1995				b,l	+
Pupil dilation	Resin	Lizana & Reginato, 1990	s				
Purgative	Alkaloids	Leal, 1990					r
Rash, skin diseases, sores	Murisolin, couxine, couclamine, stepharine, reticulin	Asolkar *et al.*, 1992; Vogt, 1995; Khan *et al.*, 1997; Chen *et al.*, 1998	s,t		f	r,l,b	l
Rheumatological problems	Essential oils	Calzavara *et al.*, 1987; Moura, 1988			l		
Scorbutic	Probably vitamin C	Calzavara *et al.*, 1987, Khan *et al.*, 1997			f		
Snake bite	Alkaloids	Philipov *et al.*, 1995; Vogt, 1995; You *et al.*, 1995				b,l	

Human Bioactive Effects	**Compound**	**Reference**	**A.c.**	**A.r.**	**A.m.**	**A.se.**	**A.sq.**
Spinal marrow disease	Alkaloids	Chao-Ming *et al.*, 1997					r
Swelling	Unknown	Chao-Ming *et al.*, 1997					l
Trypanosomiasis	Alkaloids, flavonoids others	You *et al.*, 1995; Fatope *et al.*, 1996				l	
Venereal disease	Alkaloids	Asolkar *et al.*, 1992; Philipov *et al.*, 1995; Vogt, 1995, You *et al.*, 1995				r,l	+
Worm infestations	Essential oils alkaloids flavonoids acetogenins	Nonfon *et al.*, 1990; Bories *et al.*, 1991;Asolkar *et al.*, 1992; Cortés *et al.*, 1993; Philipov *et al.*, 1994; Vogt, 1995; You *et al.*, 1995	s	s	l,s	r,b	

Key: r-root; rb-root bark; st-stem; stb-stem bark; l-leaf; f-fruit; fw-flower; p-pulp; b-bark; s-seed; +-whole plant.

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International Centre for Under-utilised Crops,
University of Southampton
Southampton, SO17 1BJ
United Kingdom

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Department of Agricultural and
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Newcastle-on-Tyne, NE1 7RU
United Kingdom

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Homestead, FL 33031

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6301 Worth Way
93012, Camarillo
USA

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Horticulture Department,
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USA

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Horticultural Science Department,
University of Florida
P.O. Box 110690
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Honolulu, Him
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California 92521
USA

Paull R. E.
University of Hawaii at Manoa
Honolulu, HI
USA

Pena J. E.
Tropical Research and Education Center,
University of Florida
18905 S.W. 280th Street

Ronning C. M.
National Clonal Germplasm Repository,
U.S. Dept. of Agriculture
13601 Old Cutler Road

Homestead, FL 33031
USA

Miami
USA

Subtropical Horticultural Research Unit, USDA
13601 Old Cutler Road
Miami FL 33158
USA

VENEZUELA

Avilan Rovira L.
FONAIAP - Centro Nacional de Investigaciones Agropecuarias
Aptdo. 4653, Maracay 2101
Venezuela

León de Sierralta S.
Departamento de Química,
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La Universidad de Zulia
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4005, Maracaibo
Venezuela

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4005, Maracaibo
Venezuela

Ramírez M.
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Facultad de Agronomia,
La Universidad de Zulia
Apartado 15205
4005, Macaraibo
Venezuela

Appendix D. Countries and Institutions with Collections of Germplasm

<u>Legend Headings</u>: For the germplasm descriptions, the following legend was used:
<u>Taxon sample</u> : taxon specific name
<u>Sample Type</u>: AC – advanced cultivar; BL – breeding and inbred lines; CU – cultivated; GS – genetic stocks; IF – introgressed forms; LR – landrace or traditional cultivar; MT – mutants; WS – Wild/Weedy species; UN – unknown; no description
<u>Geogr. Origin</u>: UN – Unknown; ISO code for the country where the sample was originally collected or bred; No description.
<u>N°</u>: Number of accessions per taxon.
<u>Updated</u>: date when record was last updated.

AUSTRALIA

1. Tropical Fruit Research Station, Department of Agriculture
P.O. Box 72, Alstonville, New South Wales 2477

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	Aus	2	31-12-1991
A. Irbid (atemoya)	AC	Aus	2	31-12-1991
A. diversifolia	No description	UN	1	31-12-1991
A. reticulata	No description	UN	1	31-12-1991
A. squamosa	No description	UN	1	31-12-1991

2. Northern Territory Department of Primary Production
P.O. Box 5160, Darwin, Northern Territory, 5794 Australia

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	BL	UN	4	31-12-1991
A. reticulata	AC	AUS	2	31-12-1991

3. Maroochy Horticulture Research Station
Queensland Department of Primary Industries
P.O. Box 5083 SCMC, Nambour, Queensland, 4560 Australia

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	AC	AUS, ISR, USA	8	31-12-1991
A. Irbid (atemoya)	AC	AUS., ISR, USA	20	31-12-1991

BRAZIL

1. Departamento de Genética da Universidade de Brasilia
Caixa Postal 04477, 70919-000 Brasilia-DF

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. coriacea	No description	BRA	1	07-05-1999
A. crassiflora	No description	BRA	1	07-05-1999

2. Laboratórios de Recursos Genéticos (CCTA)
Universidade Estadual do Norte Fluminense
Av. Alberto Lamego 2000, Bairro Horto
28015-620 Campos dos Goytacazes-RJ

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	LR	BRA	28	14-05-1999
A. reticulata	LR	BRA	6	14-05-1999
A. squamosa	LR	BRA	8	14-05-1999

3. Estação Experimental de Fruticultura Tropical (EBDA)
Via Conceição do Almeida-São Felipe, km 4
Conceição do Almeida, Bahia State

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. glabra	WS	BRA	1	30-04-1999
A. muricata	AC	BRA (8), MEX (1), VEN (3)	12	30-04-1999
A. squamosa	WS	BRA	4	30-04-1999

4. Estação Experimental de Itajaí
Empresa de Pesquisa Agropecuária de Santa Catarina - EPAGRI
Via Antonio Heil, km 6 s/n; Caixa Postal 277, 88301-970 Santa Catarina State, e-mail: eeitajai@melim.com.br

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona cacaus	WS	BRA	1	13-05-1999

5. Dept. de Horticultura, FCAVJ/UNESP
Rodovia Carlos Tonanni, km 5
Caixa Postal 145, 14870-000 Jaboticabal, São Paulo State

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cacaus	WS	UN	1	07-05-1999
A. cherimola	No description	UN	2	07-05-1999
A. cherxasquam	No description	UN	5	07-05-1999
A. coriacea	WS	UN	1	07-05-1999
A. glabra	WS	UN	2	07-05-1999
A. muricata	LR	UN	5	07-05-1999
A. pupurea	WS	UN	1	07-05-1999
A. reticulata	No description	UN	3	07-05-1999
A. squamosa	No description	UN	2	07-05-1999

6. Instituto nacional de Pesquisa da Amazonia – INPA
Ministério de Ciência e Tecnologia, Alameda Cosme Ferreira 1756,
Caixa Postal 478, Manaus, Amazonas State

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. montana	LR	BRA	1	28-04-1999

7. Empresa Pernambucana de Pesquisa Agropecuária – IPA
Av. General San Martin 1371, Bonji
50761-000 Recife, Pernambuco State

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	LR	BRA	18	06-10-1999
A. squamosa	LR/WS	BRA	85	06-10-1999

CAMEROON

Center de Recherches Agronomiques de Njombe (IRA/CRA)
P.O. Box 13, Nkongsamba

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	LR	UN	4	18-03-1991
A. reticulata	LR	UN	4	18-03-1991
A. squamosa	LR	UN	1	18-03-1991

COSTA RICA

1. Estación Experimental "Fabio Baudrit Moreno"
Universidad de Costa Rica (UCR), Apartado 183-4050,
4050 Alajuela, Costa Rica, e-mail: eefbm@cariari.ucr.ac.cr

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	UN	15	19-04-1999
A. muricata	No description	UN	10	19-04-1999

2. Escuela de Ciencias Agrarias, Universidad Nacional
Apartado 86, 3000 Heredia, Costa Rica

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	UN	8	19-04-1999

3. Corporación Bananera Nacional S.A. (CORBANA)
Apartado postal 390-7210, La Rita, Pococi, Limón, Costa Rica

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	LR, AC, GS	No description	6	15-09-1993

4. Asociation ANAI
Apartado 170, 2070 Sabanilla, Montes de Oca, Costa Rica

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	No description	1	17-09-1993
A. diversifolia	No description	No description	1	17-09-1993
A. montana	No description	No description	1	17-09-1993
A. muricata	No description	No description	1	17-09-1993
A. purpurea	No description	No description	1	17-09-1993
A. reticulata	No description	No description	1	17-09-1993
A. spp.	No description	No description	2	17-09-1993
A. squamosa	No description	No description	1	17-09-1993
A. hybrid (atemoya)	No description	No description	2	17-09-1993

5. Centro Agronomico Tropical de Investigación y Ensenanza (CATIE)
Apartado 7170, e-mail: name@catie.ac.cr
7170 Turrialba, Cartago, Costa Rica.

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. glabra	No description	BRA	2	15-04-1999
A. muricata	No description	AC, COL, CRI, ECU, HND, SLV, MEX, PAN, PRI	50	15-04-1999
A. pittieri	No description	CRI	1	15-04-1999
A. purpurea	No description	PAN, CRI, SLV, GTM, MEX	4	15-04-1999
A. reticulata	No description	CRI, SLV, GTM, HND, MEX, PAN PER, USA	3	15-04-1999
A. spp.	No description	CRI, HND	2	15-04-1999

CUBA

1. Instituto de Investigaciones Fundamentales en Agricultura Tropical (INIFAT), Calle 1, esq. 2, Stgo. de las Vegas; e-mail: inifat@cenial.inf.cu, 17200 Boyeros, Ciudad de la Habana

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	AC	No description	1	30-07-1999
A. cherimola x *A. purpurea*	AC	No description	1	30-07-1999
A. cinerea	No description	No description	2	30-07-1999
A. glabra	No description	No description	1	30-07-1999

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. montana	No description	No description	1	30-07-1999
A. muricata	No description	No description	6	30-07-1999
A. purpurea	No description	No description	1	30-07-1999
A. reticulata	No description	No description	2	30-07-1999
A. salzmannii	No description	No description	1	30-07-1999
A. squamosa	No description	No description	3	30-07-1999

2. Dirección de Investigaciones de Citros y Otros Frutales
Calles 7ª y 42 Miramar
La Habana, Cuba

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	BL	No description	1	31-12-1991
A. muricata	BL	No description	3	31-12-1991
A. reticulata	BL	No description	4	31-12-1991
A. squamosa	BL	No description	2	31-12-1991

CYPRUS

Plant Genetic Research and Herbarium Agricultural Research Institute
P.O. Box 2016, e-mail: ari@athena.cc.ucy.ac.cy
Nicosia, Cyprus

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	AC	USA	4	11-01-1999

ECUADOR

1. Centro Andino de Tecnologia Rural (CATER)
Universidad Nacional de Loja
Casilla 399, Loja, Ecuador

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	WS	ECU	150	19-04-1999

2. Estación experimental Napo Payamino (INIAP)
km 5 via Coca-Lago Agrio, El Coca Napo, Ecuador

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona glabra	LR	ECU	20	14-04-1999

3. Estación Experimental Portoviejo (INIAP)
km 12 Carretera Santa Ana, Apartado 13-01-100
e-mail: iniapo@po.iniap-ecuador.gov.ec
Portoviejo, Manabi

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	LR	ECU	1	10-06-1999
A. muricata	LR	ECU	1	10-06-1999
A. reticulata	LR	ECU	1	10-06-1999

4. Estacion Experimental Tropical Pichilingue (INIAP)
km 5 via Quevedo-El Empalme, C.P. 24;
Quevedo, Los Rios

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	LR	ECU	1	19-04-1999
A. muricata	LR	ECU	4	19-04-1999
A. squamosa	LR	ECU	3	21-04-1999

5. Granja Experimental de Tumbaco (INIAP)
Casilla 2600, Tumbaco, Pichincha

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	LR	ECU, ESP, USA, PER, CRI, AUS	66	14-04-1999

EL SALVADOR

Centro Nacional de Tecnología Agropecuaria y Forestal (CENTA)
Km 33,5 Carretera Santa Ana a Cantón; C.P. 885;
e-mail: cdtzal@es.com.sv
Arce, San Andrés, Dept. La Libertad

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. diversifolia	WS	SLV	23	10-06-1999
A. glabra	WS	HND	2	10-06-1999
A. muricata	WS	SLV	30	10-06-1999
A. purpurea	WS	SLV	2	10-06-1999
A. reticulata	WS	SLV	4	10-06-1999

FRANCE

CIRAD-FLHOR Station de la Guadeloupe
Neufchateau-Sainte Marie
97130 Capesterre Belle-Eau

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	CRI, ESP, AUS	4	03-01-1992
A. hybrid (atemoya)	No description	USA, AUS	2	03-01-1992
A. muricata	No description	CRI, BRA, AUS	13	03-01-1992
A. reticulata	No description	GLP, GTM	2	03-01-1992
A. squamosa	No description	USA, AUS, THA, NCL	4	03-01-1992

GERMANY

Greenhouse for Tropical Crops
Inst. Prod./Nutr. World Crops, Un. Kassel
Steinstrasse 19, 37213 Witzenhausen

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	ESP	1	17-08-1994
A. muricata	No description	IDN	1	17-08-1994
A. squamosa	No description	TWN	1	17-08-1994

GHANA

Crop Research Institute Plant Genetic Resources Unit
P.O. Box 7, Bunso

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. hybrid (atemoya)	AC	No description	1	11-07-1994
A. muricata	AC	No description	1	11-07-1994
A. reticulata	AC	No description	1	11-07-1994
A. squamosa	AC	No description	1	11-07-1994

GRENADA

Caribbean Agricultural Research & Development Institute (CARDI)
Westerhall, St. David´s, P.O. Box 270
e-mail: cardignd@caribsurf.com
St. George´s

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. hybrid (atemoya)	AC	USA	2	12-04-1999
A. squamosa	AC, LR	GRD, CUB	2	12-04-1999

GUATEMALA

Centro Universitario de Sur Occidente (CUNSUROC)
Universidad de San Carlos
Apartado Postal 606, Mazatenango, Suchitepequez

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. diversifolia	WS	GTM	3	14-05-1999
A. glabra	WS	GTM	8	14-05-1999
A. muricata	WS	GTM	4	14-05-1999
A. primigenia	WS	GTM	1	14-05-1999
A. purpurea	WS	GTM	5	14-05-1999
A. reticulata	WS	GTM	6	14-05-1999
A. scleroderma	WS	GTM	2	14-05-1999

HONDURAS

1. Centro Universitario Regional del Litoral Atlantico (CURLA)
   Km 8, Carretera La Ceiba-Tela, Apartado 89
   La Ceiba, Dept. de Atlantida

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. scleroderma	No description	No description	1	24-05-1999

2. Jardin Botanico Wilson Popenoe de Lancetilla
Apartado Postal 49, Tela, Atlantida

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. diversifolia	No description	No description	1	13-07-1999
A. glabra	No description	No description	1	13-07-1999
A. muricata	No description	No description	1	13-07-1999
A. purpurea	No description	No description	1	13-07-1999
Annona spp.	No description	No description	1	13-07-1999

INDIA

Indian Institute of Horticultural Research
Hessaraghatta Lake Post, 560089 Bangalore, Karnataka

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona spp.	No description	No description	10	31-12-1991

ISRAEL

Horticultural Institute Volcani Center
P.O. Box 6
e-mail: vhwisma@volcani.bitnet
50250 Bet Dagan

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona spp.	No description	No description	20	21-03-1995

JAMAICA

1. Research Development Division Ministry of Agriculture & Mining
Hope Gardens, P.O. Box 480.
Kingston

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona spp.	AC	No description	9	31-12-1991

2. College of Agriculture, Science and Education
Passley Gardens, Portland, Post Box 170.
Port Antonio, Portland

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	WS	JAM	1	09-04-1999
A. squamosa	WS	JAM	1	24-01-2000

MALAWI

Bvumbwe Agricultural Research Station
P.O. Box 5748, Limbe

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona spp.	AC	BRU, MOZ	3	31-12-1991

MEXICO

Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias
(INIFAP), Serapio Rendon 83, 06470 Col. San Rafael, México-D.F.

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	No description	1	19-04-1999
A. cherimola	AC	No description	2	19-04-1999
A. squamosa	No description	No description	1	10-04-1999

PANAMÁ

1. División de Mejoramiento Genético (INDIAP)
Apartado 6-4391. El Dorado
Panamá

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	No description	No description	10	14-06-1999

2. Facultad de Ciencias Agropecuarias, Universidad de Panamá
Apartado Estafeta Universitad, Panamá City

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cinerea	No description	No description	1	14-06-1999
A. muricata	No description	No description	3	17-06-1999

PAPUA NEW GUINEA

Lowlands Agriculture Experimental Station (LAES)
P.O. Box 204, Kokopo, East New Britain Province

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona spp.	AC	No description	4	02-01-1992

PERU

1. Universidad Nacional Hermilio Valdizan (UNHEVAL)
Giron 2 de Mayo 680; Apartado 278
Huánuco

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	LR	PER	11	19-05-1999

2. Instituto de Desarrollo del Medio Ambiente
Jr. Junin 459
e-mail: ldmahua@net.cosapidata.com.pe
Huánuco

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	LR	PER	2	21-05-1999

3. Universidad Agraria La Molina
Av. La Universidad, Apartado 456
La Molina, Lima

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	AC	PER	4	02-01-1992
A. cherimola	LR	PER	45	02-01-1992
A. muricata	WS	PER	6	02-01-1992

4. Estacion Experimental Pucallpa – Ucayali (INIA)
Av. Centenario km 4, Apartado 203
Pucallpa, Coronel Portillo

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	LR	PER	2	21-05-1999

PHILIPPINES

1. Institute of Plant Breeding, College of Agriculture (UPLB)
e-mail: opd@ipb.uplb.edu.ph
4031 College, Laguna

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. hybrid (atemoya)	AC	No description	8	02-01-1992
A. muricata	WS	No description	7	02-01-1992
A. reticulata	WS	No description	11	02-01-1992
Annona spp.	WS	No description	5	02-01-1992
A. squamosa	WS	No description	43	02-01-1992

2. National Plant Genetic Resources Laboratory (IPB/UPLB)
College, 4031 Laguna

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona spp.	No description	No description	9	14-09-1994

PORTUGAL

Departamento de Fitotecnia Estação Agronomica Nacional
2780 Oeiras

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona cherimola	AC	No description	7	13-02-1995

PUERTO RICO

Agricultural Experiment Station, University of Puerto Rico
HC-01, P.O. Box 1165; e-mail: eealajas@caribe.net
00667 Lajas

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	WS	PRI	7	19-05-1999

SAINT LUCIA

Caribbean Agricultural Research & Development Institute (CARDI)
La Ressource, Dennery, Post Box 971
e-mail: cardi@candw.lc
Castries

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	AC	No description	2	08-04-1999

SEYCHELLES

Grand Anse Experimental Centre Ministry of Agric. & Fisheries
P.O. Box 166
Mahe

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	AC	No description	5	31-08-1994

SOUTH AFRICA

Institute for Tropical and Subtropical Crops
Private Bag X11208, 1200 Nelspruit, Transvaal

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	AC	CHL	4	11-11-1991
A. cherimola	WS	USA	7	11-11-1991

SUDAN

Horticultural Research Section, Agricultural Research Corporation
P.O. Box 126, Wad Medani

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. squamosa	AC	SDN	7	02-01-1992

SURINAME

1. Agricultural Experimental Station, Ministry of Agriculture
L. Vriesdelaan 10, Post Box 160, Paramaribo

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	AC	No description	2	08-04-1999

2. STIPRIS (Foundation for Experimental Gardens), Tijgerkreek-West and Boma, L. Vriesdelaan 9, Post Box 160.
Paramaribo

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	AC	No description	1	09-04-1999
Annona spp.	AC	No description	3	09-04-1999

TAIWAN

Chiayi Agricultural Experiment Station (TARI)
2, Min-cheng Road
60014 Chia-yi

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	No description	7	10-10-1991
A. montana	No description	No description	1	10-10-1991
A. muricata	No description	No description	1	10-10-1991
A. reticulata	No description	No description	1	10-10-1991
A. squamosa	No description	No description	1	10-10-1991
A. hybrid (atemoya)	No description	No description	3	10-10-1991

TANZANIA

Tropical Pesticides Research Institute
POB 3024, Arusha

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. cherimola	No description	No description	2	28-01-1992
A. muricata	No description	No description	2	28-01-1992

UNITED STATES OF AMERICA (USA)

1. Agricultural Experiment Station
University of the Virgin Islands
R.R. # 02 Box 10000, Kingshill, St. Croix, USVI 00850

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona spp.	AC	USA	9	07-04-1999

2. Tropical Agricultural Research Station
Clonal Repository USDA-ARS, P.O. Box 70, 00709-0070 Mayaguez

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
Annona spp.	No description	No description	8	28-08-1990

3. Department of Horticulture, College of Agriculture Science
University of Puerto Rico, Mayaguez, Puerto Rico

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	WS	No description	250	02-01-1992

4. Subtropical Horticultural Research Unit (USDA)
13601 Old Cutler Road, Miami-FL 33158
http://www.ars-grin.gov/ars/SoAtlantic/Miami/homes

Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. bullata	No description	No description	2	12-08-1988
A. diversifolia	No description	No description	3	12-08-1988
A. glabra	No description	No description	2	12-08-1988
A. hybrids	No description	No description	21	12-08-1988
A. montana	No description	No description	5	12-08-1988
A. muricata	No description	No description	13	12-08-1988
A. reticulata	No description	No description	17	12-08-1988
Annona spp.	No description	No description	14	12-08-1988
A. squamosa	No description	No description	13	12-08-1988

VENEZUELA

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Details of Holdings

Taxon Sample	Sample Type	Geogr. Origin	N°	Updated
A. muricata	BL	VEN	7	14-04-1998

Source: IPGRI, 2001.

Glossary

A

abcission

The normal shedding of leaves, flowers or fruits from a plant at a special separation layer.

abiotic

not living, as opposed to biological.

acute

terminating with a sharp or well defined angle.

actinomorphic

having radially symmetric shape, usually refers to the petals of a flower.

acuminate

the shape of a tip or base of a leaf or perianth segment where the part tapers gradually and usually in a concave manner.

adnate

joined to or attached to.

adventitious

describes an organ growing where it is not normally expected.

albumen

Starchy and other nutritive material in a seed, stored as endosperm inside the embryo sac, or as perisperm in the surrounding nucellar cells; any deposit of nutritive material accompanying the embryo.

alternate

describes leaves that are not opposite to each other on the axis, but arranged singly and at different heights.

anatropous

bent over through 180 degrees to lie alongside the stalk.

androecium

all the male reproductive organs of a flower; the stamens. *cf. gynoecium.*

angiosperm

a plant producing seed enclosed in an ovary. A flowering plant.

annual

a plant that completes its life cycle from germination to death within one year.

anterior

front; on the front side; away from the axis.

anther

the pollen-bearing (terminal) part of the male organs (stamen), borne at the top of a stalk (filament).

anthesis

flower bud opening; strictly, the time of expansion of a flower when pollination takes place, but often used to designate the flowering period; the act of flower bud opening.

apex

the tip of an organ, the growing point.

apical

pertaining to the apex.

apiculate

having a short point at the tip.

arcuate

bow-shaped.

areole

a small pit or cavity marked out upon a surface.

asexual

lacking sexual characteristics, or when referring to reproduction, occurring without the fusion of egg and sperm.

autotrophy

refers to a process by which an organism that can process inorganic materials in to organic by using energy outside the organism such as sunshine on chlorophyll.

axil

the upper angle formed by the union of a leaf with the stem.

axillary

pertaining to the organs in the axil, e.g. buds flowers or inflorescence.

axis

the main or central stem of a herbaceous plant or of an inflorescence.

B

basal

borne on or near the base.

biotic

refers to any aspect of life, but especially to characteristics of entire populations or ecosystems.

bipinnate

(of leaves) a pinnate leaf with primary leaflets themselves divided in a pinnate manner; cf pinnate.

blade

the flattened part of a leaf; the lamina.

budding

method of propagating woody plants. A cutting of one variety, called the scion with buds attached, is joined onto another related species or variety called the rootstock. As the plant grows, the two parts graft together to form one plant.

C

caducous

falling off early, or prematurely, as the sepals in some plants.

calyx

the outer whorl of floral envelopes, composed of the sepals.

carpel

one of the flowers' female reproductive organs, comprising an ovary and a stigma, and containing one or more ovules.

chlorosis

a yellowing of the leaves, reflecting a deficiency of chlorophyll and caused by waterlogging or a lack of nutrients, often iron.

clone

a group of plants that have arisen by vegetative reproduction from a single parent, and which therefore all have identical genetic material.

cordate

heart-shaped, often restricted to the basal portion rather to the outline of the entire organ.

coriaceous

of leathery texture.

cotyledon

seed leaf; the primary leaf or leaves in the embryo.

crenate

shallowly round-toothed, scalloped.

crenulate

finely crenate.

cross pollination

the transfer of pollen from the anther of the flower of one plant to the flowers of a different plant.

cultivar

a race or variety of a plant that has been created or selected intentionally and maintained through cultivation.

cuneate

wedge-shaped; triangular with the narrow end at point of attachment, as in the bases of leaves or petals.

cuspidate

with an apex abruptly and sharply constricted into an elongated, sharp-pointed tip.

cyme

a broad, more or less flat-topped, determinate flower cluster, with central flowers opening first.

cymose

inflorescence showing the cyme arrangement.

D

deciduous

falling at the end of one season of growth or life, as the leaves of non-evergreen trees.

decoction

herbal preparation made by boiling a plant part in water.

deflexed

bent abruptly downward; deflected.

dehiscence

the method or process of opening a seed pod or anther.

dentate

with sharp, spreading, course indentations or teeth, perpendicular to the margin.

denticulate

minutely or finely dentate.

derived

originating from an earlier form or group.

dichogamy

the differing times of maturation of stamens and pistils in a flower.

dichotomous

forked, in 1 or 2 pairs.

dicotyledon

a flowering plant with two cotyledons.

diploid

having two sets of chromosomes.

dorsal

upon or relating to the back or outer surface of an organ.

downy

covered with short and weak soft hairs.

E

ecosystem

an interacting complex of a community, consisting of plants and/or animals and functioning as an ecological unit.

elliptic

oval in outline.

emarginate

having a shallow notch at the extremity.

endocarp

the inner layer of the pericarp or fruit wall.

endosperm

the starch and oil-containing tissue of many seeds.

entomophilous

insect pollinated.

epigynous

borne on or arising from the ovary; used of floral parts when the ovary is inferior and flower not perigynous.

explant

a plant part asceptically excised and prepared for culture in a culture medium.

exocarp

the outer layer of the pericarp or fruit wall.

F

flacate

scythe-shaped; curved and flat, tapering gradually.

fasicle

a condensed or close cluster.

faveolate

honey-combed.

ferruginous

pertaining to or coloured like iron rust.

filament

thread; particularly the stalk of the stamen, terminated by the anther.

filiform

thread-shaped, long, slender and terete.

flexuose

zig-zig; bending from side to side; wavy.

fulvous

dull, brownish-yellow.

fuscous

dusky, greyish-brown.

G

genotype

the genetic constitution of an organism, acquired from its parents and available for transmission to its offspring.

genus

a group of related species, the taxonomic category ranking above a species and below a family.

glabrous

not hairy.

glaucous

bluish white; covered or whitened with a very fine, powdery substance.

globose

globe-shaped.

glabrescent

becoming glabrous with age.

grafting

a method of propagation, by inserting a section of one plant, usually a shoot, into another, so that they cam grow together into a single plant.

gynoecium

all the female parts of a flower.

H

haploid

half the full set of genetic material found in a chromosome.

hermaphrodite

bisexual - with both male and female reproductive parts in the same flower.

homonym

a scientific name given two or more times to plants of the same taxonomic rank but which are quite distinct from each other.

hybrid

a cross-breed of two species, usually having some characteristics of both parents.

hypocotyl

the axis of an embryo below the cotyledons which on seed germination develops into the radicle.

I

indehiscent

not regularly opening , as a seed pod or anther.

indigenous

native and original to the region.

inflorescence

the flowering part of a plant and especially the mode of its arrangement.

integuments

an outer covering or coat.

K

karyotype

characterization of a chromosome set of an individual or group.

L

lamina

a blade, the leafy portion of a frond or leaf.

lanceolate

shaped like a lance head, several times longer than wide, broadest above the base and narrowed toward the apex.

lateral

side shoot, bud etc.

lamellae

a thin, flat plate or laterally flattened ridge.

lenticellate

having a body of cells as a pore, formed on the periderm of a stem, and appearing on the surface of the plant as a lens-shaped spot.

locular

having a cavity or chamber inside the ovary, anther or fruit.

M

membranous

thin in texture, soft and pliable.

mesocarp

the fleshy middle portion of the wall of a succulent fruit between the skin and the stony layer.

micro-propagation

propagation of plants thought tissue culture.

monophyletic

descended from a single ancestral line.

See Also: polyphyletic.

mucronate

terminated abruptly by a distinct and obvious spur or spiny tip.

N

naturalized

to cause a plant to become established and grow undisturbed as if native.

nectar

sweet secretion of glands in many kinds of flower.

nectrotic

Death of cells or tissues through injury or disease.

nectiferous

producing nectar.

O

oblique

slanting, unequal sided.

obovate

inverted ovate; egg-shaped, with the broadest part above.

obtuse

blunt or rounded at the end.

octaploid

having 8 times the basic number of chromosomes.

orbicular

circular.

ovary inferior

with the flower-parts growing from above the ovary.

ovary superior

with the flower-parts growing from below the ovary.

ovate

egg-shaped, with the broader end at the base.

ovule

the body which after fertilization becomes the seed.

P

parthenocarpic

refers to the fruiting of plants which have not been pollinated or otherwise fertilized.

pedicel

a tiny stalk; the support of a single flower.

pendulous

more or less hanging or declined.

peduncle

a primary flower stalk supporting either a cluster or a solitary flower.

perianth

the floral envelope consisting of the calyx and corolla.

pericycle

the tissue of the stele lying just inside the endodermis.

perigynous

adnate to the perianth, and therefore around the ovary and not at its base.

petal

a division of the corolla; one of a circle of modified leaves immediately outside the reproductive organs, usually brightly coloured.

petiole

the stalk of a leaf that attaches it to the stem.

phenology

the science of the relations between and periodic biological phenomena

phenotype

the morphological, physiological, behavioural, and other outwardly recognizable forms of an organism that develop through the interaction of genes and environment.

pilose

hairy, especially with soft hairs.

pilosulous

minutely pilose.

pinnate

a compound leaf consisting of several leaflets arranged on each side of a common petiole.

pistil

the seed-bearing organ of the flower, consisting of the ovary, stigma and style when present.

polygamous

bearing male and female flowers on the same plant.

polyphyletic

having members that originated, independently, from more than one evolutionary line.

polyploidy

having more than two sets of chromosomes.

polyporate

pollen grain with many apertures.

prolate

having flattened sides due to lengthwise elongation.

propagate

to produce new plants, either by vegetative means involving the rooting or grafting of pieces of a plant, or sexually by sowing seeds.

protandrous

refers to a flower, when the shedding of the pollen occurs before the stigma is receptive.

protogynous

referring to a flower where the shedding of the pollen occurs after the stigma has ceased to be receptive.

psilate

referring to a pollen grain having a smooth surface.

pubescent

covered with hairs, especially short, soft and down-like.

R

raceme

a simple inflorescence of pediceled flowers upon a common more or less elongated axis.

rachis

the main stalk of a flower cluster or the main leafstalk of a compound leaf.

radicle

the portion of the embryo below the cotyledons that will form the roots.

ramification

branching.

reticulate

in the form of a network, net-veined.

retuse

with a shallow notch at a rounded apex.

rootstock

the root system and lower portion of a woody plant to which a graft of a more desirable plant is attached.

rotundate

nearly circular; orbicular to oblong.

rugose

wrinkled.

rugulose

covered with minute wrinkles.

S

scandent

climbing but not self-supporting.

scarify

to scar or nick the seed coat to enhance germination.

scion

a cutting from the upper portion of a plant that is grafted onto the rootstock of another plant, usually a related species.

self pollination

the transfer of pollen from the anther of a flower to the stigma of the same flower, or different flowers on the same plant.

sepal

a division of a calyx; one of the outermost circle of modified leaves surrounding the reproductive organs of the flower.

serrate

having sharp teeth pointing forward.

serrulate

finely serrate.

sessile

without a stalk.

sheath

a tubular envelop.

spinescent

1. having spines
2. terminating in a spine
3. modified to form a spine.

stamen

one of the male pollen-bearing organs of the flower.

stigma

that part of a pistil through which fertilization by the pollen is effected.

stipule

an appendage at the base of a petiole, often appearing in pairs, one on each side, as in roses.

style

the usually attenuated portion of the pistil connecting the stigma and ovary.

subulate

awl-shaped.

sulcate

grooved or furrowed.

syncarp

an aggregate or multiple fruit produced from coherent or fused pistils, the small single fruits massing and growing together into a single fruit.

T

tetraploid

having 4 sets of chromosomes (twice the normal number of chromosomes).

testa

the outer seed coat.

tomentose

covered with a thick felt of radicles; densely pubescent with matted wool.

tomentulose

rather tomentose.

tomentum

closely matted, woolly hairs.

transverse

cross-wise in position.

triploid

having three sets of chromosomes.

tropism

the movement of an organism in response to an external source of stimulus, usually toward or away from it.

truncate

ending abruptly, as if cut off transversely.

tuberculate

bearing tubercles, covered with warty lumps.

U

unguiculate

narrowed, clawed.

V

valvate

open by valves.

Z

zygomorphic

capable of division by only one plane of symmetry.

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