Chapter 6
Genetic Diversity in Nutritious Leafy Green Vegetable—Chaya (*Cnidoscolus aconitifolius*)

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Abstract Chaya (*Cnidoscolus aconitifolius* ssp. *aconitifolius* Breckon) is a fast-growing, semi-perennial, and semi-woody Mesoamerican euphorbiaceous. It is used as a leafy green vegetable and prevailingly cropped in tropical savanna climate. However, cropping of chaya is possible in both dryer and more humid climates. Although the crop has its origin in the Maya region of Southeast Mexico, Guatemala, and Belize, chaya is popular throughout Mesoamerica. Due to its high nutritional value, cooked chaya leaves are an essential ingredient of the diet of Maya communities, especially in Southeast Mexico. Chaya is also used as an ornamental plant, for forage, and in traditional Maya medicine, where it is used to cure a wide range of diseases such as diabetes, kidney problems, arteriosclerosis, gallstones, and high cholesterol. Chaya can be called a semi-domesticated plant: Apart from wild chaya, there are four chaya varieties, whose grade of domestication varies from cropped almost wild phenotypes to entirely domesticated: 'Chayamansa,' 'Redonda,' 'Estrella,' and 'Picuda.'

Keywords *Euphorbiaceae* · Spinach tree · Agroforestry · Maya cuisine · Traditional Mesoamerican agriculture · Family home gardens · Edible tropical plants

6.1 Introduction

Chaya (*Cnidoscolus aconitifolius* ssp. *aconitifolius* Breckon), also known as spinach tree, is an attractive shrub that slightly resembles a hibiscus or cassava plant. With a protein content of 57 g kg^{-1} fresh leaves (with outstandingly well-balanced amino

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acids), chaya is considered one of the most nutritious leafy green vegetables grown on land. Furthermore, the plant is rich in vitamin A, vitamin C, calcium, potassium, iron, and antioxidants.

Chaya production systems are noteworthy in that they require few external inputs as well as simple crop management. The shrub, which is usually reproduced by clones, can be grown on different soils. Given that no significant pests or diseases have been reported for the crop, and due to its modest crop management and high nutritional value, chaya has undoubtedly the potential to alleviate nutritional deficits in hot regions of developing countries all around the globe. Thanks to its high protein content, the crop can additionally serve as an attractive enrichment of vegetarian diets; no wonder that chaya is considered one of the most promising edible horticultural crops worldwide. Furthermore, a more widespread use of chaya as medicinal plant is highly conceivable—and its potential use as forage plant is still underexploited. With all this potential, chaya can be undoubtedly labeled one of the new potential 'super crops.'

6.2 Taxonomy

The chaya is a leafy and shrubby *Euphorbiacea* (Quezada Tristán et al. 2006). *Euphorbiaceae* comprehends over 8000 species structured in five subfamilies: *Phyllanthoideae*, *Oldfieldioideae*, *Acalyphoideae*, *Euphorbioideae*, and *Crotonoideae.* The latter includes *Cnidoscolus* spp., classified in the tribe *Manihoteae* (Webster 1994). All *Euphorbiaceae* are dicotyledons with unisexual and often small flowers. In Mexico, there are 43 genera and 782 species (as well as 32 intraspecific taxa) of *Euphorbiaceae*, which can be found from sea level to 3000 m altitude. The most diversified genera are *Euphorbia* spp. (241 spp., 31% of the species of *Euphorbiaceae* known of Mexico) and *Croton* spp. (124 spp., 16%). Fifty-seven percent of the Mexican species are endemic, which represents 9% of *Euphorbiaceae* worldwide. *Euphorbia pulcherrima* Willd. ex Klotzsch, the poinsettia, is probably the best known *Euphorbiaceae*. Of the introduced species, *Manihot esculenta* Crantz, cassava or manioc, and *Ricinus communis* L., the castor bean, are most frequently cropped in Mexico (Steinmann 2002).

Cnidoscolus spp. itself includes 67 species. The genus is endemic to the Americas and mainly distributed in Mexico and Brazil, but is also found in the Caribbean and in remaining South America (Fernández Casas 2008). In Mexico, 24 species of Cnidoscolus have been identified, 19 of them are endemic. Formerly, many species of *Cnidoscolus* spp. were grouped with the genera *Manihot* and *Jatropha* (Steinmann 2002). Due to their ardent trichomes, petiolar or foliar glands, and a characteristic single white floral envelope, *Cnidoscolus* spp. was considered an independent genus by McVaugh (1944). This classification was upheld by later anatomic and pollen morphological studies (Miller and Webster 1962).

C. aconitifolius is one of the most widespread species of this genus. The word *Cnidoscolus* is derived from two ancient Greek words that mean nettle and thorn,

while *aconitifolius* means leaves like aconitum (Fernández Casas 2007). Being commonly cultivated, it is assumed the species is not under threat (Ocampo and Balick 2010). *C. souzae* McVaugh is the morphologically closest species to cropped chaya. Chaya is correctly denominated as *C. aconitifolius* ssp. *aconitifolius* Breckon. Yet, there is serious taxonomic confusion regarding the plant: In the literature, the synonym *C. chayamansa* McVaugh is found frequently, even in recent publications, where it refers to the domesticated varieties of chaya (Ross-Ibarra 2003). Contrariwise, *C. aconitifolius* refers to wild phenotypes as well as to four cultivated varieties of chaya, including one called 'Chayamansa.' *C. multilobus* (Pax) I. M. Johnston, a different plant, is occasionally also called chaya (Fernández Casas 2008). There are acknowledged researchers, such as Breckon (1975), that do not consider chaya a domesticated plant. Still, for pioneers on chaya such as Jeffrey Ross-Ibarra (2003), chaya meets all the requirements of a domesticated crop.

The name chaya comes from the Yucatec Maya word *chay*, which refers to both cultivated and wild *C. aconitifolius.* Additionally, chaya has common names from diverse linguistic backgrounds for chaya (Fernández Casas 2007). Many of these names are Spanish and refer to the urticating hairs of the plant, e.g., *picar* (to sting). Other names denote the use of chaya as a leafy green vegetable, hence the English term 'tree spinach' (Ross-Ibarra and Molina-Cruz 2002; Table 6.1).

Table 6.1 Common names for chaya (Fernández Casas 2007; González Arce 2008; Mariaca-Méndez and de Tabasco 2012; Ocampo and Balick 2010; Ross-Ibarra 2003)

Region or country	Common names
Yucatan Peninsula	Chaya, s picar, chaya amarilla, chaya brava, chaya del monte, chaya pica, jom chaay, k'an chaay, keken-chay, ts'its'ik-chay, x'etel, xtsaj, chaay, chaay kool, k'eek en chaay, xe'tel, saj, tsaaj
Chiapas	Kulis ek, salik la, sla ek
Oaxaca	Mala mujer
Veracruz-Llave	Chaya
Remaining Mexico and Belize	Chaya, picar, mala mujer, tza, tsats, x'chay, ya'ax chay
Guatemala	Chaya, chay, chatate, chayo, copapayo
Honduras, Cuba	Chaya
Nicaragua	Quelite
Costa Rica	Chicazquil, chicsaquil
Cuba	Chaya
Virgin Islands	Tree spinach
USA	Chaya, tree spinach, spinach tree
Philippines	Chaya

6.3 Origin and Actual Distribution

Chaya is both wild and domesticated. Wild chaya has extensive distribution, growing from southern Texas south along the Gulf Coast, throughout Southeastern Mexico and the entire Central America down to Colombia, with a disjunct population in the Mexican state of Guerrero on the Pacific coast (Colunga-García Marín and Zizumbo-Villarreal 2004; Ross-Ibarra and Molina-Cruz 2002).

There is agreement that wild chaya is of Mesoamerican American origin (Quezada Tristán et al. 2006) and that it was domesticated in a region that includes Guatemala, Belize, South, and Southeast Mexico (Ross-Ibarra and Molina-Cruz 2002). Yet, there are contrary theories as to where chaya was first domesticated. Like many acknowledged researchers, Ross-Ibarra (2003) favors the Yucatan Peninsula and the Mexican state of Chiapas as the origin of domesticated chaya. Ross-Ibarra sustains this theory through ethnobotanical arguments: These are the areas with the most extensive and diversified medicinal and nutritional uses of chaya by the local population.

However, Breckon (1975) argues that at the very least the variety 'Chayamansa' comes from the Department of Petén in Guatemala, which is also the only region where all four varieties of chaya ('Chayamansa,' 'Estrella,' 'Picuda,' and 'Redonda'; the latter is almost exclusively found in Guatemala), are being cropped. Since there was continuous information and plant material exchange between Mayas in the lowlands of Petén and on the neighboring Yucatan Peninsula (Ford 2008), it is certainly plausible that 'Chayamansa' later moved to Yucatan. There it could have become quickly widespread due to the poor soil fertility and low soil depth on the peninsula, which favors the cropping of chaya over more demanding traditional Mesoamerican crops. What is for sure in this debate is that domesticated chaya has been cultivated since pre-Hispanic times in all regions inhabited by Maya population. Although cropped Chaya is still most common in Mesoamerica (Fernández Casas 2007), it can now be found all over the world, often in milder, more humid, and even under significantly dryer conditions than in Mesoamerica. There is evidence of chaya being cropped from 0 to 1000 m above sea level—which does not necessarily imply its altitude limit.

Cropped chaya is mostly distributed throughout the Yucatan Peninsula, which apart from the Mexican states of Campeche, Quintana Roo, and Yucatán, and also includes the Petén in Guatemala and the northern part of Belize (De Clerck and Negreros-Castillo 2000; Fedick et al. 2008; Flores-Delgadillo et al. 2011; Mariaca-Méndez and de Tabasco 2012; Ocampo and Balick 2010; Ross-Ibarra and Molina-Cruz 2002; Standley and Steyermark 1958). As for the rest of Mexico, there is evidence that chaya is currently cropped in Aguascalientes, Chiapas, Coahuila, Colima, Jalisco, Guerrero, Guanajuato, Hidalgo, Morelos, Oaxaca, Puebla, Querétaro, San Luis Potosí, Tabasco, Tamaulipas, and Veracruz-Llave. In Chiapas and Veracruz-Llave, chaya has been known for centuries; in most of the other states, chaya was introduced recently (Colunga-García Marín and Zizumbo-Villarreal 2004; Fernández Casas 2007; Quezada Tristán et al. 2006; Ross-Ibarra 2003).

Cropping of chaya is evidenced all over Central America. It has a strong presence in Belize (Berkelaar 2006; Fernández Casas 2007; Ross-Ibarra 2003), Guatemala, and Costa Rica, where it was brought to from Mexico in the 1980s (Ocampo and Balick 2010; Ross-Ibarra and Molina-Cruz 2002). Chaya is also cropped in Honduras, El Salvador, Nicaragua, and Panama (Fernández Casas 2007; Ross-Ibarra 2003). The shrub grows in South America (Poot-López et al. 2012) and has been documented in Bolivia, Brazil (Berkelaar 2006), and Colombia (Ross-Ibarra and Molina-Cruz 2002).

After Mesoamerica, the Caribbean is the region with the second highest distribution of chaya. Use and production of the crop are particularly popular in Cuba (Fernández Casas 2007; Ross-Ibarra and Molina-Cruz 2002; Stephens 1994). Additionally, the shrub can be found on the Virgin Islands (Fernández Casas 2007), in Puerto Rico (Newton 1984), the Bahamas, and the Dominican Republic (Berkelaar 2006). Chaya cuttings from Cuba were also introduced to southern Florida, where it is often found as a wild shrub, but rarely used as food (Stephens 1994). In suburban areas of the Southwestern United States, especially in south Texas, however, chaya has been introduced recently by its Hispanic population for its use as a vegetable and as medicinal plant (Kuti and Torres 1996).

Not only did chaya spread from the Caribbean to the USA, but also to Africa: In the second half of the twentieth century, it was introduced to Ghana from Puerto Rico. Subsequently, its cultivation spread into neighboring Nigeria (Newton 1984). Then, it became popular in most tropical Africa, especially in Eastern Africa. There, it can be found in Kenya, Zambia, and Tanzania (Berkelaar 2006). Shortly after being brought to Africa, chaya production also started in Asia, where it was first evidenced in Brunei (Peregrine 1983). The Philippines (Fernández Casas 2007) and Indonesia are further Asian countries for which chaya consumption and cropping are documented. Recently, chaya was introduced to the Marshall Islands, the Federated States of Micronesia, Fiji, and Vanuatu. Hawaii is the part of Oceania, where chaya has the longest history: In the mid-twentieth century, it was established by the US government as a new perennial vegetable. Despite little presence in Hawaiian cuisine, the shrub can still be observed growing wild (Berkelaar 2006).

6.4 Ethnobotany

Since the limestone bedrock of the Yucatan Peninsula is covered by a thin layer of soil, the region is often characterized as a challenging environment for agriculture. Yet the Maya inhabitants, both ancient and modern, have managed to successfully cultivate this landscape through a variety of innovative techniques and microscale adaptations (Fedick et al. 2008). In the Peninsula, the most relevant cropping system—which is found throughout Mesoamerica—is undoubtedly the *milpa* (Hernández 1995). In the *milpa*, at least two varieties of maize (*Zea mays* L.) are associated with diverse legumes, squash (*Cucurbita moschata* Duchesne) and a varying number of other crops (Toledo 2003). Before and long after the conquest, the *milpa* system has sus-

tained a large indigenous population on the Yucatan Peninsula in a relatively secure food situation.

The Yucatec Maya also integrated other production systems in their agroecological portfolio, such as the family home gardens (Fig. 6.1). These gardens are highly agrobiodiverse, providing the peasant family with esculents as well as medicinal and ornamental benefits. They also provide material for construction and secondary functions, such as generating shadow and delivering an optimum environment for small-scale backyard animal breeding. Home gardens are based on native and introduced shrub and tree species, among them wild and domesticated chaya (Mariaca-Méndez and de Tabasco 2012; Colunga-García Marín and Zizumbo-Villarreal 2004). The soil of most home gardens does not show major signs of physical and chemical degradation despite prolonged and intensive land use, a rare situation for agricultural soil in the tropics. The healthy state of these soils is contributed to the cultivating skills of Maya women, who are usually in charge of home gardens and the fact that plantings are situated within natural cavities that are common in the karstic Yucatec bedrock. These cavities are filled with both natural and household organic residues, providing an efficient substrate for cropping perennial plants. Home gardens are usually located on family-owned parcels or *solars* (Fedick et al. 2008). In contrast to *milpas* which are often walking or biking distance from the homes, *solars* are close to or in the family homes plots. Chaya has been an integral part of these gardens for generations.

Such a long-lasting relationship between Maya people and chaya is accompanied by cultural practices for the cultivation and care of the chaya shrub. A widespread belief in Mesoamerica, for example, is that one must ask a chaya plant for permission before harvesting to avoid being stung by its spines. Similarly, chaya is said to

Fig. 6.1 Chaya is commonly used as a hedge plant in traditional Yucatec Maya home gardens

require a special way of cutting to avoid harmful twitches and greetings such as 'Good morning Mrs. Chaya! Will you give me leaf?' are common. It is also believed that the plant, and thus its spines, wakes up with the arrival of the sun, and that to harvest leaves safely, they should be cut in the early morning or late evening (Mariaca-Méndez and de Tabasco 2012; Ross-Ibarra and Molina-Cruz 2002).

6.5 Morphology

Chaya is an evergreen or drought-deciduous, fast-growing, semi-perennial, and semi-woody tropical shrub (Berkelaar 2006; Ross-Ibarra and Molina-Cruz 2002; Standley and Steyermark 1958). Some authors, such as Ocampo and Balick (2010), report that chaya reaches a height maximum of three meters, but most have observed that it reaches a height between three and five meters (Breckon 1975; Ross-Ibarra and Molina-Cruz 2002; Standley and Steyermark 1958). This discrepancy is probably due to the observation of higher wild and cropped, respectively pruned, lower plants. Its width is approximately two meters (Berkelaar 2006).

Chaya leaves look like those of okra. They are dark green and commonly surfaced with some hairs. Each leaf is borne on a slender 10–30 cm long and succulent petiole. Young leaves are often lacking lobes, while mature chaya leaves are shallowly or deeply, palmately lobed with three to seven alternately arranged lobes per leaf. The blades of mature leaves are about 30 cm long and broad, and the leaves exhibit entire to slightly dentate margins and abundant latex. Where the stem connects to the leaf, the veins are fleshy and cuplike (Ocampo and Balick 2010; Ross-Ibarra and Molina-Cruz 2002; Standley and Steyermark 1958; Stephens 1994).

Like many *Euphorbiaceae*, *Cnidoscolus* spp. is characterized by irritating latex and highly stinging trichomes (Fig. 6.2) that contain toxic compounds like linamarin and glycoside flavonoids. For chaya, they are an effective defense mechanism, preventing leaf damage by herbivorous insects; also, human contact results in a very strong skin irritation (Rates 2001; Scheman and Conde 2001; Torres-González and García-Guzmán 2014; Tuberville et al. 1996). These stinging hairs are predominantly found on the young chaya stem (Stephens 1994). Noteworthy, more irritating leaf latex means less presence of urticant pubescences on stems, leaves, flowers, fruits, and vice versa (Miranda Velásquez et al. 2016; Parra-Tabla et al. 2004; Torres-González and García-Guzmán 2014).

There is a considerable inter- and intravarietal morphological diversity of chaya leaves. In a study of Quezada Tristán et al. (2006), chaya plants from 13 Mexican states were observed for differences on their leaves. The results showed that 91.9% of the monitored plants had three-lobed leaves, 7.9% five-lobed, and 0.2% four-lobed leaves. Furthermore, 80% of the leaves had sagittate shape, while 10% were decurrent and 10% showed chordate shape. Nineteen percent of observed leaves manifested pubescence and 96% glands.

Chaya is a self-compatible, monoecious species with separate male and female flowers located at the end of long flower stems. Each flower exhibits defunct reproduc-

Fig. 6.2 Urticant pubescences on stems and leaves of wild chaya

tive organs of its opposite sex (Parra-Tabla et al. 2004; Ross-Ibarra and Molina-Cruz 2002; Stephens 1994). Its flowers are white and tubular. They are usually arranged on cyme-branched and three-forked inflorescences, in which the pistillate flowers are located on the basal fork and the staminate flowers are expanded distally from the base of the lobes (Kuti and Torres 1996; Parra-Tabla et al. 2004). Both kinds of flowers are small and less than 10 mm long. The white male flowers are much more abundant (Stephens 1994). Chaya flowers bloom frequently (Ocampo and Balick 2010). They are considerably fragrant, making them attractive to pollinators, predominantly butterflies and several bee species, including *Apis mellifera* L. (CC Grow 2015; Parra-Tabla et al. 2004). The fruits of *C. aconitifolius* are schizocarpic, with rounded pods, approximately 2.5 cm wide, have three seeds, and are dehiscent by explosion (Ocampo and Balick 2010; Standley and Steyermark 1958).

Chaya has fibrous roots, which are a consequence of their asexual reproduction using stem cuttings (Aguilar et al. 2011). The wood of young stems is soft, easily broken, and susceptible to rot. When cut, the stem exudes a white latex (Stephens 1994).

6.6 Composition

Since chaya contains high amounts of crude protein, minerals, and vitamins, the plant can be considered among one of the most complete vegetables (Table 6.2).

The chaya leaf contains high levels of all amino acids, with the exception of arginine and glutamine (Kuti and Kuti 1999). Its well-balanced protein content over

Table 6.2 Content of water, nutritional composition, and nutritional value of 1 kg fresh leaves of chaya (*C. aconitifolius*), spinach (*Spinacia oleracea* L.), chard (*Beta vulgaris* L. subsp. *vulgaris* DC), lettuce (*Lactuca sativa* L.), and curly kale (*Brassica oleracea* convar. *acephala* Alef. var *sabellica* L.) (Aguilar et al. 2000; Kuti and Torres 1996; Vogel 1996)

Crop	Water	Protein	Fat	Crude fiber	Carbohydrates	Ash	Nutritional value
	%	g	g	g	g	g	kJ
Chaya	85.3	57	4	19	42	22	1140
Spinach	91.6	25	2	18	5	18	640
Chard	92.2	21	3	10	7	17	590
Lettuce	95	13	2	15	11	6	480
Kale	86.3	43	9	42	25	11	1550

Table 6.3 Mineral, metal, and vitamin content of 1 kg fresh leaves of chaya, spinach, chard, lettuce, and kale (Kuti and Torres 1996; Vogel 1996)

Crop	Ca	K	P	Fe	Provitamin A	Vitamin B	Vitamin C
	mg	mg	mg	mg	mg	mg	mg
Chaya	1994	2172	390	114	8	8	1650
Spinach	1250	6350	550	40	4	3	500
Chard	1050	3750	400	27	35	3	400
Lettuce	350	2250	350	11	8	2	130
Kale	2100	4900	850	19	41	3	1050

performs popular leafy greens such as spinach, chard, lettuce, and kale (Aguilar et al. 2000; Kuti and Torres 1996; Santacruz et al. 2013; Sarmiento-Franco et al. 2003a, b). In regard to mineral and metal content, chaya is also an outstanding vegetable: Compared to spinach, chaya offers almost three times more iron and twice the amount of calcium. The same applies for its contents of vitamin B and C, where chaya is superior to most leafy greens (Table 6.3).

6.7 Biodiversity

Compared to other crops, the domestication of chaya had a relatively short-term process of approximately 500 years (Ross-Ibarra and Molina-Cruz 2002). The principal selection criteria were leaf size and form, the reduction of trichomes, and a decrease of reproductive growth. Given the climatic and edaphic diversity of the regions where chaya is historically cropped, an adaptation to different environments certainly also played an important role in its diversification process (Ross-Ibarra 2003). Apart from wild phenotypes, four cropped varieties of chaya have been identified: 'Estrella,' 'Picuda,' 'Redonda,' and 'Chayamansa.' Since wild and cropped chaya is one and

the same plant, morphological and physiological differences between them are fluent. The four recognized varieties differ from wild chaya in their leaf morphology and leaf size (Stephens 1994). Chaya varieties also differ in the presence and density of stinging hairs and their cyanide content (Abdala-Roberts and Parra-Tabla 2005). A further distinction criterion is fertility (Table 6.4).

Wild chaya (Fig. 6.3), which is called 'Tzin-tzin chay' or 'X'etel' on the Yucatan Peninsula, has relatively heterogenic leaves and high fertility. It is rarely eaten (Ross-Ibarra 2003; Stephens 1994). This circumstance can undoubtedly be ascribed to its frequent, white, tall, stiff, and highly irritating stinging hairs; they are found on all leaf veins and margins. Compared to the domesticated varieties, wild chaya is characterized by notably big leaves. They can have five to nine lobes, of which the central one stands out for being the longest and widest. The apex of all lobes is acuminated. The petiole of wild chaya leaves is remarkably long and entirely covered by trichomes. The trunk of wild chaya is slightly lignified and has a round form. It does not break as easily as the stems of domesticated chayas and is entirely covered by trichomes. Wild chaya blooms all year and produces abundant fruits. In traditional Maya medicine, it is used to cure chronic wounds.

In contrast, 'Chayamansa' (Fig. 6.4), often simply referred to as 'chaya,' 'sweet chaya,' or 'plegada,' is clearly the most domesticated variety. The usual overlapping of the central three lobes cannot be found in wild chaya. Furthermore, leaves are not covered by stinging hairs (Ross-Ibarra and Molina-Cruz 2002). The petioles are short and smooth. Normally, 'Chayamansa' achieves a maximum height of 170 cm. The

Table 6.4 Morphological differences of four identified chaya varieties (Ross-Ibarra 2003; Ross-Ibarra and Molina-Cruz 2002; Stephens 1994)

Variety	Leaf morphology	Number of lobes	Stinging hairs	Fertility
'Chayamansa'	Three obovate central lobes overlap two adjacent ones	5	Degenerated hairs along the petiole and the bottom margin of the lamina	Low and never viable seed production; commonly empty anther sacks
'Redonda'	Juvenile leaves: often entire; mature leaves: entire to slightly dentate margins	3 (mostly)	Very scarce and atrophied	Mature plants flower and actively produce pollen
'Picuda'	Lobes are strongly dentate to pinnatifid	5–9	Trichomes are scarce but usually filled; they appear empty and flaccid	Produces abundant quantities of seeds, pollen, and mature fruit
'Estrella'	Spreading, non-overlapping dentate lobes	5	Similar to 'Picuda'	Scarce flowers; low fertility; no mature fruits

Fig. 6.3 Leaves of wild chaya show five to nine lobes and large trichomes

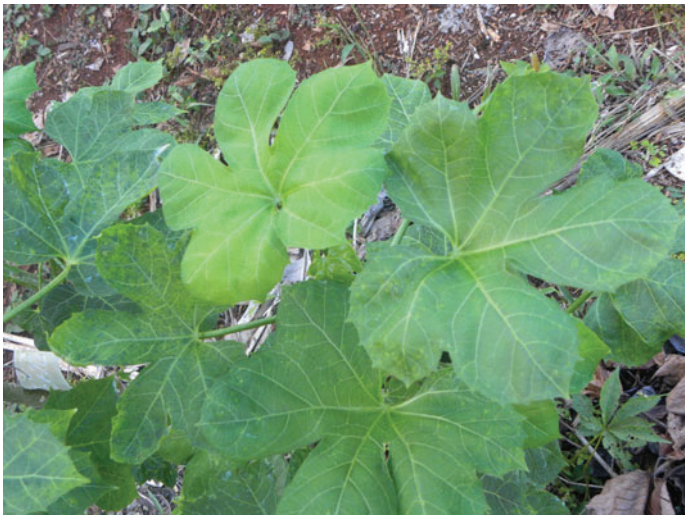

Fig. 6.4 'Chayamansa' is the most popular variety in the Yucatan Peninsula

stems are scarcely lignified, plain, succulent, and quadrangular. They break easily. ‘Chayamansa’ flowers intensely with up to fifty flowers per plant. Its anthers produce at best a few, usually deformed, pollen grains. On the Yucatan Peninsula, this variety is appreciated for its sweet taste and the softness of its leaves.

‘Redonda’ (Fig. 6.5), occasionally called ‘Mansa,’ ‘In Sul,’ or ‘Pig Chaya,’ represents the least known and unrecognized chaya variety. In Maya home gardens, ‘Redonda’ reaches heights between two to three meters. It has small leaves with a smooth lamina and (normally three) relatively broad, rounded lobes. ‘Redonda’ has a low density of atrophied trichomes on its leaves. Leaf petioles are long and plain. The variety is characterized by scarcely lignified, plain, and quadrangular stems, which tend to break easily. Tests showed that less than 1% of this pollen is viable and mature fruit and seed are extremely rare (Ross-Ibarra and Molina-Cruz 2002; Stephens 1994). Different from other varieties, ‘Redonda’ is prepared by frying instead of boiling. Its resin is occasionally used to cure insect bites.

Also, ‘Picuda’ (Fig. 6.6) rarely exhibits trichomes. On the Yucatan Peninsula, ‘Picuda’ is frequently labeled ‘Tzin-tzin chay,’ which refers to the resemblance of its leaf morphology with wild chaya. The plant usually has five to seven lobes, occasionally up to nine, which are strongly dentate to pinnatifid and the apex is acuminate or caudate. Scarce trichomes are observed on the veins and are considerably denser on

Fig. 6.5 Juvenile leaves of ‘Redonda’ are rarely lobed

Fig. 6.6 'Picuda' is a highly fertile chaya variety

the long leaf petioles. The stems of 'Picuda' are thin and round and are not covered by trichomes. 'Picuda' is considered a highly fertile variety of chaya. Nonetheless, samples in Maya home gardens have demonstrated that there are also completely unfertile individuals. Noteworthily, it is the only variety whose roots are used in traditional medicine, particularly to cure kidney infections.

'Estrella' (Fig. 6.7), also known as 'X'etel' on the Yucatan Peninsula, shows leaf similarities with wild chaya. It shares this characteristic with 'Picuda,' but differs from it in having less fine lobes (Ross-Ibarra 2003; Ross-Ibarra and Molina-Cruz 2002). The leaf lamina of 'Estrella' is smooth. The leaves usually have five lobes

Fig. 6.7 'Estrella' is characterized by spreading, non-overlapping dentate lobes

whose apex is acuminate and the leaf margins are scarcely toothed. Trichomes are dense and frequent on the large petioles of 'Estrella' leaves, yet sparsely located on the margins and central leaf vein. The lignified stems are covered by short, brown trichomes. The variety never produces mature fruit. Only young leaves are eaten; their taste is considered less sweet compared to 'Chayamansa.'

'Estrella' and 'Picuda' are usually not considered entirely domesticated and rather represent cropped wild plants versus varieties. Both varieties exhibit few morphological differences compared to wild chaya and can be reproduced sexually. Consequently, 'Estrella' also shows the highest genetic diversity of all varieties; it is followed by 'Picuda,' which is still more diverse than wild chaya. In comparison, 'Redonda' and 'Chayamansa' meet all of the requirements for a domesticated crop; they have lost their ability of sexual reproduction, which makes human intervention indispensable, and they demonstrate low genetic diversity and have morphological characteristics (especially on their leaves; Fig. 6.8) which are rarely found in wild chaya (Ocampo and Balick 2010; Ross-Ibarra 2003). The clonal structure is another meaningful indicator for the current state of domestication of a crop. Ross-Ibarra (2003) identified in his benchmark publication on the origin of chaya, that throughout Mexico and Guatemala, only one clone for 'Chayamansa,' and three clones of 'Redonda' existed, while 'Estrella' and 'Picuda' possessed significantly more clones.

On the Yucatan Peninsula, 'Chayamansa' is the most common variety, while 'Estrella' and 'Redonda' are rare, and 'Picuda' is almost unknown. On the contrary, in Central and South America (except Guatemala, where there is only ornamental use), 'Picuda' is the most popular variety, whereas 'Chayamansa' and 'Estrella' are less frequent. Finally, 'Redonda' is popular in Guatemala and the Mexican state of Chiapas (Ross-Ibarra 2003; Ross-Ibarra and Molina-Cruz 2002).

6.8 Uses

6.8.1 Nutritional Use and Dishes

Chaya is a highly nutritious food, whose leaves taste somewhat like spinach. For consumption, the leaves and shoots are cut into manageable pieces and can be fried, boiled, frozen, or canned for later use (CC Grow 2015; Loarca-Piña et al. 2010; Ross-Ibarra and Molina-Cruz 2002). An obstacle regarding the usability of chaya as food or fodder is the presence of cyanogenic glycosides in fresh leaves (García-Rodríguez et al. 2014; Miranda Velásquez et al. 2016; Stephens 1994). González-Laredo et al. (2003) demonstrated a hydrogen cyanide concentration of 23.7–42.5 mg kg^{-1} dry leaves. Fortunately, boiling eliminates this anti-nutritional compound (Castro-Juárez et al. 2014; Molina-Cruz et al. 1997). Up to 15 min is recommended for boiling (Molina-Cruz et al. 1997; Quezada Tristán et al. 2006; Stephens 1994). Although drying the chaya leaves also reduces their cyanogenic glycosides content,

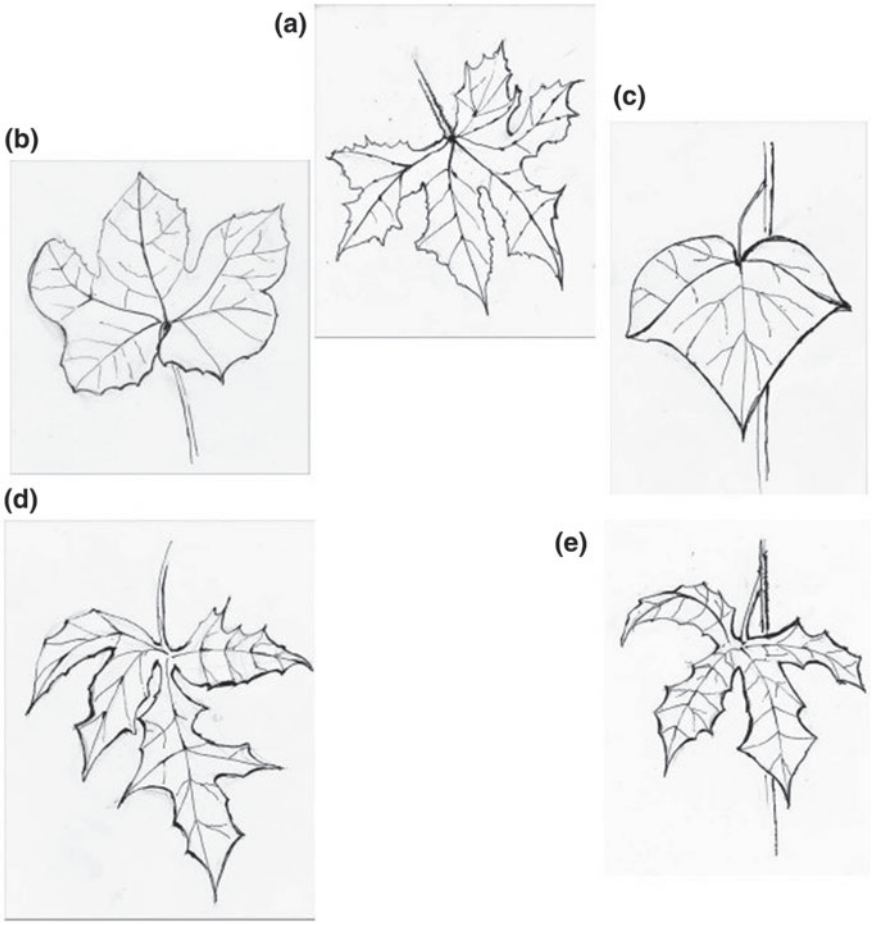

Fig. 6.8 Leaf morphology of wild chaya (**a**), variety 'Chayamansa' (**b**), juvenile leaves of variety 'Redonda' (**c**), variety 'Picuda' (**d**), and variety 'Estrella' (**e**). Drawing: Sylvia Ebel

complete elimination still requires subsequent cooking (Berkelaar 2006; González-Laredo et al. 2003).

Removing cyanides in fresh chaya through drying or cooking affects the nutritional content of the chaya leaves. Drying chaya leaves increases the ash, fiber, and protein content more than four times and the content of fats even more, but also significantly decreases the vitamin C content (Durán Mendoza et al. 2012; Molina-Cruz et al. 1999). Boiling the chaya leaves is more common. It causes a relative increase of carbohydrates, fat, calcium, phosphorous, and iron and decreases crude fiber, protein as well as potassium (Kuti and Torres 1996; Table 6.5). Vitamin C is transferred from the leaves to the water when boiling, while vitamin B is conserved through cooking (Molina-Cruz et al. 1997).

Table 6.5 Nutrient content of 1 kg fresh and cooked chaya leaves (Kuti and Torres 1996)

	Protein	Fat	Crude fiber	Carbohydrates	Ca	K	P	Fe
	g	g	g	g	g	g	g	g
Fresh leaves	57	4	19	42	1.99	2.17	0.39	0.11
Cooked leaves	41	5	14	77	2.15	1.4	0.45	0.2

Since pre-Columbian times chaya leaves and young shoots have been consumed on the Yucatan Peninsula (Martin et al. 1977), the region where most information about chaya as food is available. Two sixteenth-century Spanish chronicles mention a wide use of the plant on the Yucatan Peninsula at the time of the European conquest. Its continuity is evidenced up to the twenty-first century. Even now, chaya is consumed weekly in rural communities of the Peninsula, where it is sold in almost all markets and supermarkets (Ross-Ibarra 2003; Ross-Ibarra and Molina-Cruz 2002). Chaya is eaten all year long, although it is most abundant during the rainy season.

For the Yucatec Maya population, chaya is the essential vegetable protein source after legumes (Salazar et al. 2016). In times of food scarcity, both domesticated and wild chaya even serve as a replacement for meat, which is why chaya is occasionally associated as food for the poor (Fernández Casas 2007; Ross-Ibarra and Molina-Cruz 2002). Nevertheless, chaya continues to be an essential ingredient of plentiful regional dishes. Usually, the larger mature leaves are used as wraps and the young leaves and apical shoots are eaten (Loarca-Piña et al. 2010).

Modern usage of chaya on the Yucatan Peninsula is highly diverse, and at least 70 recipes are documented. Often leaves are simply eaten after boiling them in water with salt (Ross-Ibarra and Molina-Cruz 2002) or served with oil (Stephens 1994). Various traditional Maya dishes combine chaya with crops obtained from the *milpa*, such as maize, bean, squash, and chili pepper, and other products from the home garden. In a study done in a representative Maya community, 5% of regularly consumed dishes included chaya and 3% showed chaya as primary ingredient (Salazar et al. 2016).

Different variations of the following traditional recipes exist throughout the Yucatan Peninsula: A well-known chaya dish is *Dzotobichay*, also called *Brazo de la India*, a *tamal* filled with diced chaya leaves, covered with a sauce made of tomato or other vegetables, wrapped in banana or chaya leaves. *Tamal* is a dish, where nixtamalized[1] maize dough and lard are mixed, covered by a maize husk or diverse leaves and later steamed. Usually, they are filled with vegetables or meat. Also popular is *Pibxcatic*, stuffed peppers served over chaya leaves, which is often combined with *Cochinita Pibil*, slow-roasted shoat, intensively marinated with sour orange and annatto and wrapped in banana leaves. A traditional dish known as *Chay je'* in which previously boiled chaya leaves are mixed with eggs, onions, and occasionally tomatoes, is gaining popularity in the larger cities of the Yucatan Peninsula. *Chakbilchay* is a soup made of chaya and lime; *Caldillo je'* is chaya with eggs and

[1]Nixtamalization refers to soaking and cooking maize kernels in water with a lye of lime, chalk, or wood ash.

pasta, and *Chayiwaaj* is a *tamal* that only contains chaya and lard (Ross-Ibarra and Molina-Cruz 2002; Salazar et al. 2016).

Since chaya is so versatile and can be added to soups, pasta, sauces, salads, eggs, and breads (Ross-Ibarra 2003), it is being integrated into many common Yucatan and Mexican dishes. Some examples are *Chaya K'abax* (cooked beans with chaya), *Tzajbi chay* (fried chaya), *Jorochitos de Chaya* (maize dumplings with chaya), *Enchiladas de chaya* (fried chaya, wrapped in tortilla and covered by a sauce made of tomato or tomatillo), or *Escabeche de Chaya* (pickled chaya).

As for drinks, chaya infusions are consumed regularly in the Maya region of the Yucatan Peninsula—but with a predominantly medicinal purpose (Andrade-Cetto et al. 2006). In restaurants with non-indigenous clients, shakes made of blended fresh chaya leaves, fruits, and sugar are offered regularly.

6.8.2 Medicinal Use

Chaya is a versatile medicinal plant. A total of 15 constitutional effects are reported for the plant:

- Antidiabetic and hypoglycemic (Loarca-Piña et al. 2010; Palos Suárez et al. 2006; Valenzuela Soto et al. 2015);
- Anti-inflammatory;
- Antimicrobial (Obichi et al. 2015);
- Antimutagenic (González-Laredo et al. 2003);
- Antioxidant (González-Laredo et al. 2003; Gutiérrez Zavala et al. 2007; Kuti and Konuru 2003; Loarca-Piña et al. 2010);
- Bone and muscle-building (León de Gutiérrez and Díaz Bolio 1971);
- Cardioprotective and circulation restorative (Diaz-Bolio 1974);
- Cholesterol lowering (Diaz-Bolio 1974; Mariaca-Méndez and de Tabasco 2012);
- Diuretic (Andrade-Cetto et al. 2006; Diaz-Bolio 1974);
- Hepatic (Fernández Casas 2008);
- Lactation stimulant (Fernández Casas 2008);
- Laxative (Diaz-Bolio 1974)
- Memory restorative and brain stimulant (Donkoh et al. 1999);
- Nail strengthening (Diaz-Bolio 1974);
- Vision improving (Diaz-Bolio 1974; Donkoh et al. 1999).

On the Yucatan Peninsula, chaya is widely sold in local markets as a medicinal plant, although occasionally other plants are traded under the name chaya. The respective knowledge is passed from generation to generation. Although most of its medicinal properties have not been clinically tested (Ross-Ibarra and Molina-Cruz 2002), chaya is used to cure a large variety of ailments:

- Alcoholism (Donkoh et al. 1999);
- Anemia (Fernández Casas 2008; León de Gutiérrez and Díaz Bolio 1971);

- Atherosclerosis (Diaz-Bolio 1974);
- Constipation (León de Gutiérrez and Díaz Bolio 1971);
- Cough (León de Gutiérrez and Díaz Bolio 1971);
- Diabetes (Castro-Juárez et al. 2014; Kuti and Kuti 1999; Kuti and Torres 1996; León de Gutiérrez and Díaz Bolio 1971; Loarca-Piña et al. 2010; Valenzuela Soto et al. 2015);
- Elevated uric acid (León de Gutiérrez and Díaz Bolio 1971);
- Eye irritations (León de Gutiérrez and Díaz Bolio 1971);
- Fatigue (Ross-Ibarra and Molina-Cruz 2002);
- Gallstones (Diaz-Bolio 1974);
- Gastrointestinal disorders;
- Gout (Donkoh et al. 1999);
- Headache (Fernández Casas 2008);
- Hemorrhoids (León de Gutiérrez and Díaz Bolio 1971);
- Infections of teeth, tongue, and gum (León de Gutiérrez and Díaz Bolio 1971);
- Inflammation of veins (León de Gutiérrez and Díaz Bolio 1971);
- Insomnia (Donkoh et al. 1999);
- Menstruation pain and fatigue (León de Gutiérrez and Díaz Bolio 1971);
- Muscle disorders (Ross-Ibarra and Molina-Cruz 2002);
- Overweight (León de Gutiérrez and Díaz Bolio 1971).

Chaya is also increasingly popular in Western herbal and naturopathic medicine, for many reasons, including inefficiencies in conventional medicine or abusive or incorrect use of synthetic drugs resulting in severe side effects. Additionally, a large percentage of the world's population does not have access to conventional medicine and plants like chaya are an accessible and effective source for treating illnesses (Rates 2001). However, caution should be used with chaya. Although the plant is not lethal at a single dose, chaya does contain cyanide. Thus, the current research on chaya places emphasizes on the importance of the dose for receiving benefits from this plant (García-Rodríguez et al. 2014).

In traditional Mesoamerican medicine, chaya is most applied as a remedy for the treatment of diabetes mellitus (Castro-Juárez et al. 2014; García-Rodríguez et al. 2014), particularly in the treatment of noninsulin-dependent (type II) diabetes (Kuti and Kuti 1999; Loarca-Pina et al. 2010). This application is also popular among Hispanics in the USA (Kuti and Torres 1996). Chaya decreases the level of blood glucose, which is most likely related to the level of glycosides found in the plant. In medical animal experiments, chaya consumption was shown to reduce blood glucose levels of diabetic rats (Valenzuela Soto et al. 2015) and rabbits (Kuti and Torres 1996). Such studies, however, are not considered to be entirely conclusive. For example, Palos Suárez et al. (2006) reported that feeding chaya to diabetic rats did not affect their blood levels of glucose, but did decrease their triglyceride levels. It is also noteworthy that chaya may only be hypoglycemic for diabetic individuals: blood sugar levels increased for non-diabetic rabbits fed with chaya tea (Kuti and Torres 1996).

The cardioprotective activity of chaya is associated with its content of antioxidant glycosides (García-Rodríguez et al. 2014; Kuti and Konuru 2003). Yet, there is an academic dispute regarding the intensity of chaya's antioxidant potential: Gutiérrez Zavala et al. (2007) detected high antioxidant properties, while González-Laredo et al. (2003) and Loarca-Piña et al. (2010) attest chaya which has poor antioxidant capacity.

Chaya's content of glycosides has been clearly proven. As for phenolic glycosides, they involve protocatechuic acid (Loarca-Piña et al. 2010), related to the antimutagenic (González-Laredo et al. 2003) and anti-inflammatory effect of chaya. Most studies suggest that chaya is poor in phenols (García-Rodríguez et al. 2014; Santacruz et al. 2013). In contrast, a considerable part of the medicinal properties attributed to chaya is related to its high content of flavonoids: Chaya leaves contain the antioxidants catechin and kaempferol, as well as the main anti-inflammatory agents, rutin and quercetin (González-Laredo et al. 2003; Loarca-Piña et al. 2010; Molina-Cruz et al. 1997). Chaya also shows presence of saponins (Santacruz et al. 2013) and glycosides that protect against hypertension and have antibiotic and anti-inflammatory properties (Obichi et al. 2015). Cholesterol-lowering sterols as well as diuretic (but also moderately toxic) coumarins were identified in chaya leaves (García-Rodríguez et al. 2014). Chaya also presents low contents of alkaloids and tannins, particularly antioxidant, anti-inflammatory, and potentially antidiabetic gallic acid (Loarca-Piña et al. 2010; Miranda Velásquez et al. 2016; Molina-Cruz et al. 1997; Santacruz et al. 2013). In addition to traditionally used aqueous extraction, the active compounds of chaya have been detected using extractions with ethanol, methanol, and hexane (Table 6.6).

Chaya is exceptionally high in calcium and iron (Berkelaar 2006). Calcium supports bone and dental health and is alleged to mitigate weight; iron supports the

Table 6.6 Chemically identified pharmacologically functional groups and active substances of chaya and respective extraction methods (García-Rodríguez et al. 2014; González-Laredo et al. 2003; Kuti and Kuti 1999; Kuti and Torres 1996; Loarca-Piña et al. 2010; Miranda Velásquez et al. 2016; Molina-Cruz et al. 1997; Obichi et al. 2015; Santacruz et al. 2013; Sarmiento-Franco et al. 2003a, b; Valenzuela Soto et al. 2015)

Functional group	Active substances	Water	Ethanol	Methanol	Hexane
Flavonoid glycosides	Amentoflavone, astragalin, catechin, dihydromyricetin, kaempferol, quercetin, rutin		X	X	
Phenolic glycosides	Protocatechuic acid		X	X	
Saponin glycosides			X		
Steroidal glycosides					X
Alkaloids		X	X		
Tannins	Gallic acid	X	X		

X Extraction with the respective substance evidenced

hemoglobin synthesis (Lukaski 2004). Chaya also contains copper, manganese, zinc, and magnesium, essential cofactors for proper enzyme activity relevant to cardiovascular homeostasis (García-Rodríguez et al. 2014; Kuti and Kuti 1999). Furthermore, the plant contains proteolytic enzymes (Iturbe-Chiñas and Lopez-Munguia 1986), which have anti-inflammatory properties and support the immune system.

Finally, numerous health benefits of chaya are related to its vitamin content. Chaya is notably high in provitamin A (Sarmiento-Franco et al. 2003a, b) and vitamin B (Obichi et al. 2015) and shows an exceptionally high vitamin C content: Only 25 g cooked chaya leaves can provide the daily dosage recommended for adults of antioxidant vitamin C. Provitamin A, which is conserved through cooking, is linked to improvement of vision, has anti-inflammatory and antimutagenic properties, and possibly also has a positive effect on human skin (Molina-Cruz et al. 1997). Vitamin B is associated with lowering cholesterol and has hypoglycemic and cardioprotective effects (Lukaski 2004).

For medicinal purposes, chaya leaves are usually used orally (Castro-Juárez et al. 2014; Ross-Ibarra and Molina-Cruz 2002). The most common preparations are aqueous extracts, such as teas and infusions (Mellen 1974; Valenzuela Soto et al. 2015). The latter are characterized by higher herbal concentrations and by a longer steeping time than for making tea. Fresh chaya leaves are cooked in water (Valenzuela Soto et al. 2015) or occasionally infusions prepared with lukewarm water are also drunken (Castro-Juárez et al. 2014). A rather unusual technique is the use of dried chaya leaves for preparing aqueous extracts (Loarca-Piña et al. 2010). Apart from the medicinal use as tea or infusion, cooked chaya leaves can be eaten (Mellen 1974) and drunk for medicinal purposes (Ross-Ibarra and Molina-Cruz 2002; Valenzuela Soto et al. 2015).

Different parts of the plant are also used to treat body ailments directly. The sap of the plant is applied directly for treating skin disorders; chaya stems or leaves are rubbed on sore or injured muscles and joints; and the painful stinging caused by chaya's trichomes is alleged to cure muscle disorders, rheumatism and arthritis (Ross-Ibarra and Molina-Cruz 2002).

6.8.3 Use as Forage

Free range pigs and chickens are common in Maya home gardens, where they are fed with in situ forages such as the chaya (Acosta et al. 1998). Due to its high content of proteins, chaya can be used as fodder in diverse silvopastoral or agroforestal systems (Santacruz et al. 2013) but also for intense animal breeding, predominantly chicken production (Aguilar et al. 2000). Chaya even serves as a functional forage for fishes, particularly tilapia (Poot-López et al. 2012). The use as forage is undoubtedly one of the most promising areas regarding innovative applications of chaya. Further research in this regard should consider diverse processing techniques to enhance digestibility and resource-efficient use of chaya.

6.9 Cropping

Chaya is commonly cropped in soil but has also been grown in black polyethylene bags with a substrate mixture of sand and compost (Valenzuela Soto et al. 2015). Dry and hot conditions are ideal for transplanting chaya (Sarmiento-Franco et al. 2003a, b; Stephens 1994), and it performs best under full sun to partial shade. The plant grows slowly under full shade but tolerates it. Chaya demands well drained, even sandy soils (Kuti and Torres 1996; Ross-Ibarra and Molina-Cruz 2002). Good soil drainage is a requirement for a healthy development of chaya (Berkelaar 2006). Since soils of the Yucatan Peninsula are tendentially alkaline, chaya might have problems with highly acid conditions.

Despite chayas' multifunctional use, there is a lack of precise data regarding the cropping of chaya, which has changed little from pre-hispanic times (Cuanalo de la Cerda and Guerra Mukul 2008). This indicates the opportunity for further research in cropping and the potential to increase chaya yield and quality.

Chaya is frequently found in the biodiverse and agroforest like Maya home gardens, rather than grown in agricultural fields. There, it usually forms part of hedges (Ross-Ibarra and Molina-Cruz 2002), often with a fencing purpose. In these hedges, both wild and cropped chaya are found and often not directly associated with other plants (Mariaca-Méndez and de Tabasco 2012). In an experiment documented by Aguilar et al. (2011), chaya was successfully polycropped with Spanish cedar (*Cedrela odorata* L.) and Persian lime (*Citrus* × *latifolia* Tanaka ex Q. Jiménez). Principally, chaya can be associated with numerous other plants and even tolerates the invasion of weeds (Berkelaar 2006). Thus, polycropped plants need to be selected carefully: *Hibiscus sabdariffa* L., for example, does not result in an improvement of its annual yield (Ebel et al. 2016).

Cropped chaya is reproduced almost exclusively by cuttings (Mariaca-Méndez and de Tabasco 2012). Only the variety 'Picuda' is occasionally reproduced by seed (Ross-Ibarra and Molina-Cruz 2002). Thick and woody stem cuttings are normally selected for transplanting (Stephens 1994). It is recommended to let the cuttings dry for up to one month before using them because they require intense watering after transplanting and tend to rot easily (Ross-Ibarra and Molina-Cruz 2002). As for their preferable length, dimensions of 10–60 cm are reported (Aguilar et al. 2011; Sarmiento-Franco et al. 2003a, b). In the Maya region of Quintana Roo, cuttings of 40 cm (without leaves) are most common. They are planted upright in excavations of about 25 cm depth and only partially refilled with earth or substrates.

Since chaya is rarely produced commercially, little information is available regarding optimum planting densities. Circular arrangements (Aguilar et al. 2011) as well as linear ones (Ebel et al. 2016) are reported. As for the distance between plants in a linear arrangement, CC Grow (2015) recommends 20 to 30 cm, while Ebel et al. (2016) worked successfully with 50 cm and with 2 m between rows. Aguilar et al. (2011, 2012) report that in polycropping systems, a planting density of up to 3770 chaya plants ha^{-1} delivers the highest survival of cuttings and most cuttings with satisfactorily long roots; maximum 2650 plants ha^{-1} result in the highest develop-

ment of callus, while most roots per cutting are obtained with 3000 plants ha^{-1} and the best vegetative growth with up to 2890 plants ha^{-1}. In monocropping models, densities of 5000 plants ha^{-1} generate a positive vegetative development of chaya. Thus, 10,000 plants ha^{-1} deliver the highest yield. Polycropping favors yield in the dry season, although monocropping clearly produces the highest annual output (Ebel et al. 2016).

As cuttings, the initial aerial growth of the vegetative parts is fast, but the root growth is slow (Aguilar et al. 2011). Therefore, the leaves are not harvested until the second year (Sarmiento-Franco et al. 2003a, b). Leaf biomass is also directly related to leaf length (Parra-Tabla et al. 2004). Pruning chaya in its first year results in rapid vegetative growth (Stephens 1994), decreases generative growth but also stimulates its trichome density (Abdala-Roberts and Parra-Tabla 2005). It is recommended to break the stems rather than to cut them, as this seems to decrease the incidence of infection. Pruning also prevents branches from breaking easily by the wind (Ross-Ibarra and Molina-Cruz 2002).

Chaya is tolerant of heavy rain as well as moderate drought (Peregrine 1983). According to Stephens (1994), chaya requires 650–1500 mm of annual precipitation. Yet successful production in non-irrigated desert conditions (Ross-Ibarra and Molina-Cruz 2002) suggests that chaya can withstand dryer conditions. Drought does not affect plant quality since protein, ash, iron, and zinc content is not affected by changing soil moisture levels (Cifuentes and Bressnniz 2010). During the dry season on the Yucatan Peninsula, Maya peasants tend to irrigate chaya weekly with two liters per plant.

Apart from common synthetic fertilizers, chaya can be manured with organic inputs, such as compost and liquid manure (Berkelaar 2006). In regard to nutrients, the plant requires 370 kg ha^{-1} of nitrogen (Cifuentes and Molina 2000). Potassium plays a smaller role (Cifuentes and Bressnniz 2010), while the most limiting nutrient in the poor Yucatec soils is plant-available phosphorus (Fedick et al. 2008). There are also varietal differences regarding nutrient response: 'Estrella' converts up to 400 kg ha^{-1} a^{-1} nitrogen and 225 kg ha^{-1} a^{-1} phosphate in abundant biomass, while 'Chayamansa' does not respond that strongly to the application of N and P. For both varieties, the application of N has a positive effect of their protein content but reduces ash, Fe, and Zn in the leaves. The application P and K does not impact neither of these parameters (Cifuentes and Bressnniz 2010).

Chaya has very few problems with pests and diseases (Kuti and Torres 1996; Peregrine 1983). Although chaya is exposed to diverse herbivores on the Yucatan Peninsula (Arango et al. 2000), the plant shows a fast and flexible response to leaf damage (Parra-Tabla et al. 2004). The few herbivores mentioned in this context include the caterpillars of the white-striped long tail (*Chioides catillus* ssp. *albofasciatus* Hewitson) and the yellow angled-sulfur (*Anteos maerula* Fabricius) as well as grasshoppers (Parra-Tabla et al. 2004). In Quintana Roo, the red spider mite (*Tetranychus urticae* C. L. Koch) and unspecified species of leafcutter ants are occasionally observed. Outside of the Yucatan Peninsula, the tomato hornworm (*Manduca quinquemaculata* Haworth) is reported as a potential pest (CC Grow 2015).

Since there is a relatively low risk of entomopathogenic fungi in tropical ecosystems (Gilbert 2002), few fungal diseases are associated with chaya. The same applies for bacteria. However, according to Berkelaar (2006), if an older chaya is cut back too close to the ground the entire plant can be exposed to fungal or bacterial diseases. Virus represents a more serious threat to chaya, especially the cassava common mosaic virus. Fortunately, the effect of this pathogen on chaya is minimal (Elliott and Zettler 1987). It is presumably transmitted mechanically through infected knives during stem cutting (Lozano et al. 1981).

For harvesting, it is recommended to cut leaves on their petioles and to select soft and fresh material, starting on the bottom of the shrub (CC Grow 2015). The use of gloves is highly recommended to protect the hands from chaya's trichomes and spines (Stephens 1994). Harvesting can be started in the first ten weeks of the second year of establishment of chaya (Kuti and Torres 1996). It should then be repeated every two to three months (Ross-Ibarra and Molina-Cruz 2002), never exceeding the half of total foliage biomass (Sarmiento-Franco et al. 2003a, b). Berkelaar (2006) reports that under tropical winter, chaya shows an almost dormant appearance and does not produce harvestable material.

In the Yucatec home gardens, highest level yields are reported for between five and ten years, although yields have been reported for after ten years. An output of approximately 5.5 t ha^{-1} dry or 38 t ha^{-1} fresh leaves can be expected (Cifuentes and Molina 2000). Dense planting may improve this potential considerably (Ebel et al. 2016). Comparing the most frequent varieties, 'Estrella' produces more biomass than 'Chayamansa' and correspondingly higher yields, especially if the input of nitrogen and phosphorous is abundant (Cifuentes and Bressnniz 2010). Research on storing chaya is poor, although it is known that chaya can be stored for at least one week in a refrigerator (CC Grow 2015). Internationally, chaya is occasionally sold in pickled form (Kuti and Torres 1996).

6.10 Chaya and Maya Identity: What Does Chaya Taste Like?

The plant called chaya is an important ingredient in many different recipes of all kinds of Yucatecan cuisine. It is regarded as part of the culinary heritage of the Maya indigenous people and as the paradigm of the 'typical' food of the Yucatan Peninsula. However, the term 'typical food' is pejorative. Rather, the gastronomically correct meaning is that it seasons Maya food as an exquisite gourmet dish.

The concept 'typical food' is the result of centuries of colonialism and neocolonialism (Palacios 2014). It is derived from the premise of binary oppositions such as Maya versus *dzul* (roughly understood as 'white male') or Indian food versus rational people's food.

Explanations, interpretations, and analyses based on binary oppositions place indigenous people and non-indigenous people in different, exclusive, antagonistic,

and irreconcilable social structures. This is not to say that 'both' social groups live in perfect harmony with each other. In fact, conflict has been always present between them (Castillo Cocom 2005).

Bartra (2007) notes that the naturalist and explorer Alexander von Humboldt wrote that corn was a staple food of the Mexican people and animals. He adds:

> Corn is what Indians eat, what peasants eat, what the *peladaje* [low social class with little education] eats. And Creoles and their heirs, who despise the Indians, and also despise the grain that feeds them. Corn has been overshadowed by racist considerations. The racial contempt for indigenous peoples has been a constant of the Mexican right wing, both creole, and later the Frenchified and nowadays Americanized. (Bartra 2007)

However, Bartra has a somewhat romantic view of the Maya. They are not a homogeneous and compact group, neither a big fraternity governed by feelings of equality, fairness, and respect. They are just like any human being: not good or bad, just humans. Sometimes, the Indians also insult one another using the same words that some white people use to insult them: Indio! [Bow Bender!].

Chaya as food for Indians is an ethnic marker among Maya indigenous peoples themselves. In Xocenpich, Yucatán, Nardo, a Maya Indian, was watching Juan, another Maya, eat a toasted Chaya taco with its ubiquitous *chile maax* (*Capsicum annuum* L.) *tamulado* (roasted and wrung out *maax* chili pepper) and to which Juan added lemon juice, and Nardo asked his wife:

– What does chaya taste like?
– I have never tasted it!

His question and statement confer him to the status of people of reason.

Chaya is used by Maya indigenous people and by people of reason to express not only the socioeconomic and cultural group to which they belong, but social agents also associate the plant with humor through nicknames (affective, derogatory, racist, and euphemistic). Amaro Gamboa (1999) in its compendium of regionalisms *Vocabulario de el Uayeísmo en la Cultura de Yucatán* includes the word chaya as part of the Spanish language spoken in Yucatán.

Chaya f. Poor woman 'ill-mannered' and poor, badly dressed, low social class; word of the terminology of racial prejudice in Yucatan. Dim. *chayita* doubly pejorative. Nickname: so-and-so *chaya*. Plant Bot. *Jatropha Urens*, L. *Euforbiáceas* The equivalent for men is common to both terms: the *chaya* so-and-so or chayote, which also means freeloader; a person who hangs around and does not work (Amaro Gamboa 1999).

Chayote (V. *Chaya*) 'the *Chaya* Pepe Gómez'… (applied) to the individual man (or women) of the lower class… its synonym chayote it has also has other meanings: in: scrounger, freeloader, and sponger, parasite… (Amaro Gamboa 1999).

Chaya is much more than a simple ethnic marker or something that boosts our immune system or the paradigm of the food of Maya indigenous people. Chaya is a mirror of the consensual and not so consensual resonances that construct new reflexivities but also explore spaces of noise and racism, residues of colonization.

6.11 Outlook

The versatility and accessibility of chaya make it a plant that has incredible potential to alleviate hunger and nutritional challenges in many areas of the world and provide health and healing benefits for benign and life-threatening ailments and diseases, and nutritious forage for livestock. However, research is lacking in all of these areas to develop the plants full potential.

Since chaya grows well on the thin and low fertile soil of the Yucatan Peninsula, the shrub could be cropped in other areas with similar conditions (Ross-Ibarra and Molina-Cruz 2002). In this regard, its potential to provide food security and additional income for Latin American farmers is not exploited to its full potential. Furthermore, although the crop has achieved certain distribution in some tropical countries, chaya can be cultivated in hot (tropical but also dryer) regions of Africa, Asia, and Oceania. Chaya, with its high protein and mineral content, has serious potential to alleviate nutritional deficits around the world. Chaya also has the potential to make a significant nutritional contribution to the diet in the industrialized world, particularly because of its high and diverse protein content; chaya may be the new 'superfood' for vegans.

The processing of chaya is still an almost undiscovered area. It may be relevant for its use as food, forage, and as medicinal plant. In regard to medicinal purposes, only its antidiabetic properties have been demonstrated in scientific research. Chaya's cardioprotective and cholesterol-lowering potential, well known in traditional medicine, deserve deeper examination. Understanding the constitutional effects of chaya on the human body would also allow the development of efficient therapies. Similar to chaya as food, its use as medicine and forage can deliver substantial benefits for regions with difficult cropping conditions (as long as they are hot enough).

There are other potential applications of chaya. For instance, chaya's high content of nitrogen, calcium, potassium, phosphorous, and iron makes it an ideal resource to produce fermented bio-fertilizers for foliar application. Additionally, due to its glycoside content, thinking of chaya as organic pesticide has potential.

In short, although chaya is already sold on the international market, the development of chaya as a new horticultural crop would transcend its current ethnic popularity and create a worldwide market for the plant and its products (Kuti and Torres 1996; Ocampo and Balick 2010), whether as a leafy green vegetable, as a therapeutic herbal tea, as new chicken fodder, or as something totally different.

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