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RESEARCH ARTICLE

ORIGIN, DISTRIBUTION, TAXONOMY, GENETIC DIVERSITY AND BREEDING OF CHAYOTE {*Sechium edule* (Jacq.) Swartz.}

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ABSTRACT

Chayote belongs o the Family- Cucurbitácea, Subfamily- Sicyoideae, Genus- *Sechium* and species *edule*. Chayote has ten botanical varieties viz., 1) *Sechium edule* var. *albus minor,* 2) *Sechium edule* var. *albus dulcis*, 3) *Sechium edule* var. *albus levis*, 4) *Sechium edule* var. *nigrum minor*, 5) *Sechium edule* var. *nigrum conus*, 6) *Sechium edule* var. *nigrum levis*, 7) *Sechium edule* var. *nigrum xalapensis*, 8) *Sechium edule* var. *nigrum spinosum*, 9) *Sechium edule* var. *nigrum maxima*, and 10) *Sechium edule* var. *virens levis*. Chavote is known bv different name in Indian regional languages such as Seema vankava or Bengaluru vankaava (in Telugu). Chocho or Chow Chow or Bengaluru katharikkai (in Tamil), Seeme badane, chow-chow (in Kannada). Putative wild populations of *S. edule* and related wild species are found in Central America, and therefore this region is most likely the centre of origin of chayote. Chayote was already a common cultivated vegetable among the Aztecs in pre-Columbian times. Chayote (*Sechium edule*) is cultivated throughout tropical and subtropical regions of the world and utilized in pharmaceutical, cosmetic and food industries because it is an excellent source of minerals, dietary fibers, protein, vitamins, carotenoids, polysaccharides, phenolic and flavonoid compounds, and other nutrients. In this review article origin, distribution, taxonomy (classification, species, wild types, synonyms, botanical varieties), botanical description, flower biology and pollinators, growth and development, genetic diversity, genetic resources, breeding (inter-specific and infra-specific hybridization, commercial varieties), production and international trade, uses, nutritional value, halth benefits, and cultivation of chayote are discussed.

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INTRODUCTION

Chayote belongs o the Family- Cucurbitácea, Subfamily- Sicyoideae, Genus- *Sechium* and species *edule* (Ortega-Paczka *et al*. 1998). Chayote has ten botanical varieties viz., 1) *Sechium edule* var. *albus minor,* 2) *Sechium edule* var. *albus dulcis*, 3) *Sechium edule* var. *albus levis*, 4) *Sechium edule* var. *nigrum minor*, 5) *Sechium edule* var. *nigrum conus*, 6) *Sechium edule* var. *nigrum levis*, 7) *Sechium edule* var. *nigrum xalapensis*, 8) *Sechium edule* var. *nigrum spinosum*, 9) *Sechium edule* var. *nigrum maxima*, and 10) *Sechium edule* var. *virens levis* (Avendaño Arrazate *et al*., 2010). The word chayote is the Spanish name for the fruit and comes from Nahuatl, where it is called hitzayotli and means something like "prickly pumpkin". The plant and its fruit are known by different names depending on the country or even region: Güisquil, Huisquil (Guatemala) Christophine (Caribbean) Cho Cho (Jamaica) Chou-Choute (New Caledonia) Mirliton (Louisiana, Haiti) Talote, Tayote (Puerto Rico) Papa de aire / papa al aire ("air potato") u. a. in (Paraguay) Chuchu (Portugal) / Chu Chu, Xuxu (Brazil) Caiota (Azores) Chouchou (Reunion & Mauritius) Pimpinela (Madeira) Tayota (Dominican Republic) Chow Chow (Sri Lanka); Su su, trai su (Vietnam) Choko (Australia, New Zealand) Pasta (Honduras) Davadava (La Palma) Sayote (Philippines) Iskus (Nepal) Caihua, Caigua chilena (Peru) Labu Siam (Indonesia) (Wikipedia,2022a). Chayote is known by different name in Indian regional languages such as Seema vankaya or Bengaluru vankaaya (in Telugu), Chocho or Chow Chow or Bengaluru katharikkai (in Tamil), Seeme badane, chow-chow (in Kannada). Putative wild populations of *S. edule* and related wild species are found in Central America, and therefore this region is most likely the centre of origin of chayote. Chayote was already a common cultivated vegetable among the Aztecs in pre-Columbian times (PROSE, 2021). From the ethnohistorical record, we know that, at least in Mexico, chayote has been cultivated since pre-Colombian times. The first description of chayote was probably that of Francisco Hernández, who was in Mexico from 1550 to 1560, but the crop was not introduced into the Southern part of the continent until after the arrival of the Spanish (Newstrom, 1986, 1991). Reports of explorations carried out during different periods by various people and institutions all concur that the widest variety of cultivated chayote is found in southern Mexico, Guatemala and Costa Rica, at altitudes of 500-1500 m (Newstrom 1985, 1986). The wild taxa of *Sechium* that are morphologically closest to chayote include the so-called 'wild types' of *S. edule* which grow in the Southern part of Mexico (Lira Saade, 1996).

In the eighteenth and nineteenth centuries, the Spanish introduced it in Costa Rica and took it to Europe, from where it spread to Asia and Africa. In the late nineteenth century (Anon., 2021). It has now spread throughout the tropics and subtropics, including South-East Asia, but is most important in tropical America (PROSE, 2021). Among the peasant crops there is great genetic diversity that is expressed mainly in the shape, color and texture of the surface of the fruits (shape - globose, ovoid, subovoid, pyriform and elongated pyriform; sizes 4.3-26.5 cm of long, 3-11 cm wide; color –from white to pale yellow and from dark to light green; with or without spines) (Lira Saade 1996). Five different fruits colors have been found in chayote fruits on-farm. Pale yellow is more common and farmers call dark green chayote as Kaalo Iskhush ((Joshi *et al*., 2020). Chayote (*Sechium edule*) is cultivated throughout tropical and subtropical regions of the world. The chayote fruit is mostly used cooked. When cooked, chayote is usually handled like summer squash; it is generally lightly cooked to retain the crispy consistency. Raw chayote may be added to salads or salsas, most often marinated with lemon or lime juice, but is often regarded as especially unpalatable and tough in texture. Whether raw or cooked, chayote is a good source of vitamin C. It is also utilized in pharmaceutical, cosmetic and food industries because it is an excellent source of minerals, dietary fibers, protein, vitamins, carotenoids, polysaccharides, phenolic and flavonoid compounds, and other nutrients. The alternative names are given to this crop wherever it is cultivated.

Chayote cannot be stored as seed for much longer than one month since it is viviparous, the seed having no dormancy and germinating within the fruit. Long-term maintenance of germplasm collections must therefore be in the form of living plants, or as tissue cultures under slow growth conditions. Germplasm collections are at present held by CATIE (Turrialba, Costa Rica), Chapingo Regional Centre (Huatusco, Vera Cruz, Mexico), INIA (Celaya, Guanajuato, Mexico) and EMBRAPA (Brasilia, Brazil). Genetic erosion of chayote in its region of indigenous cultivation is accelerating as a result of rapidly increasing commercialization and the replacement of landraces by a few improved cultivars (PROSE, 2021). Commercial production is limited by some disease problems. A breeding programme for fruit quality and disease resistances is needed, but, logically, private seed companies are not interested in chayote because it is viviparous. A bland cultivar is required for the industrial market and a tasty one for the table vegetable market. Further collection and evaluation of landraces in Mexico and Central America is also required (PROSE, 2021).

ORIGIN AND DISTRIBUTION

From the ethnohistorical record, we know that, at least in Mexico, chayote has been cultivated since pre-Colombian times. The first description of chayote was probably that of Francisco Hernández, who was in Mexico from 1550 to 1560, but the crop was not introduced into the Southern part of the continent until after the arrival of the Spanish (Newstrom, 1986, 1991). Linguistic evidence for this is provided by the common names given to the species in different parts of Latin America. These clearly indicate that the species was originally concentrated in Mexico and Central America. In many cases, these same names (especially that of Nahuatl origin, 'chayote') with only slight modifications, are used in other areas of the world where the species was introduced. Pre-Colombian decorated pottery has been found in Mexico and Central America which clearly depicts chayote (Newstrom, 1991). The centre of origin and domestication of *Sechium edule* is southern Mexico and Guatemala, where wild types are still found. The Aztecs and Mayas already cultivated chayote in pre-Columbian times, but fossil records are lacking. It has now spread throughout the tropics and subtropics. In tropical Africa it occurs in many areas as a minor fruit and leaf vegetable, e.g. in East Africa, Madagascar and the Mascarene Islands. In Réunion and Mauritius it is locally naturalized (Engels and Jeffrey,1993). There does not appear to be any archaeological evidence to establish how long S. edule has been cultivated. It seems that the fleshy fruit, with its single soft testa seed, does not lend itself to conservation and, until now, the presence of pollen grains or other structures of this species at archaeological sites has not been reported. Instead, the most commonly used sources for establishing the possible origin of this crop have been ethnohistoric, artistic and linguistic, together with information on the ecogeographic distribution of the genetic diversity of both the wild and cultivated species (Lira Saade, 1996; Lira Saade, 2021).

It is the ecogeographic distribution of *S. edule* under cultivation, and that of its wild relatives, however, which provides the greatest evidence for establishing the centre of origin of this crop. Reports of explorations carried out during different periods by various people and institutions all concur that the widest variety of cultivated chayote is found in southern Mexico, Guatemala and Costa Rica, at altitudes of 500-1500 m (Newstrom 1985, 1986). As far as the distribution of the wild species and its relation to chayote is concerned, there appears to be little doubt that the crop must have originated in this area. As shown above, most of these species, and especially those most morphologically similar to chayote, are known to grow within the geographic and altitude limits mentioned previously. The wild taxa of *Sechium* that are morphologically closest to chayote include the so-called 'wild types' of *S. edule* which grow in the Southern part of Mexico (Lira Saade, 1996). The genus Sechium is distributed and was domesticated in the highlands of Mesoamerica (500-1500 m), from central and southern Mexico, northern Guatemala, southern Nicaragua, much of Costa Rica, and western Panama (Vavilov, 1992). It is mainly concentrated in the north of this region and Costa Rica (Lira Saade 1996).

Chayote cultivation is widely distributed in Mesoamerica. It was introduced into the Antilles and South America between the eighteenth and nineteenth centuries. The chayote was introduced into Europe whence it was taken to Africa, Asia and Australia, while its introduction into the United States dates from the late nineteenth century (Lira Saade, 2021). No one knows exactly when cultivation of chayote began. It seems that it was grown widely in Mexico and Central America by the Aztecs and Mayans before the Spanish colonizers arrived to America. In the eighteenth and nineteenth centuries, the Spanish introduced it in Costa Rica and took it to Europe, from where it spread to Asia and Africa in the late nineteenth century (Anon., 2021). It has now spread throughout the tropics and subtropics, including South-East Asia, but is most important in tropical America (PROSE, 2021). The chayote has its origins in the Aztecs and Mayans of Mesoamerica. Today, the chayote is grown in many tropical and subtropical countries. However, there is no archaeological evidence for the Chayote from which their age could be inferred. Reports from conquistadors suggest a pre-Columbian use (Wikipedia, 2022a). The chayote is known to have been introduced into South America during the 18th and 19th centuries (Bukasov 1981; Newstrom 1986, 1991). It is possible that it was introduced into the Caribbean prior to this since the first formal mention in the literature was that, this species was widely cultivated throughout Jamaica. During this same period, chayote was introduced into Europe and, from there, it was taken to Africa, Asia and Australia. However, it was not introduced into the United States until the end of the 19th century (Flores,1989; Newstrom, 1991). Putative wild populations of *S. edule* and related wild species are found in Central America, and therefore this region is most likely the centre of origin of chayote. Chayote was already a common cultivated vegetable among the Aztecs in pre-Columbian times (PROSE, 2021).

TAXONOMY

The most recent classification of the Cucurbitaceae (Jeffrey 1990) places the genus *Sechium*, to which chayote belongs, in the subtribe Sicyinae of the tribe Sicyeae, along with the genera *Microsechium, Parasicyos, Sechiopsis, Sicyosperma* and *Sicyos*. The members of this subtribe are characterized by having spiny pollen, a single pendulous ovule and single-seeded fruits. When the first monograph on the Cucurbitaceae was published, *Sechium* was considered monospecific and only to contain *S. edule*. This species was originally discovered in Jamaica, and it was classified simultaneously as *Sicyos edulis* by Jacquin and as *Chocho edulis* by Adanson. Later, changed it to *C. edulis* and placed it in the genus *Chayota*.

A few years later, this species was included in Sechium, and it is still known as S. edule (Jacq.) Swartz. Chayote belongs to the Family- Cucurbitácea, Subfamily- Sicyoideae, Genus- Sechium and Species edule (Ortega-Paczka *et al*., 1998). During many years it was assumed that *Sechium* was a monotypic genus, whose only species was S. edule Swartz; Jeffrey (1978) however, included six other species with the sections *Frantzia* and *Polakowskia*. Despite Jeffrey's efforts (1978) to merge some genera and species related to *Sechium*, several authors considered that at least *Polakowskia* and *Frantzia* are rather distant from the original center of Sechium and are taxonomically different. The following taxa are considered synonyms for Sechium: Sicyos edulis Jacq., Chayota edulis Jacq., *Sechium americanum* Poir., *Cucumis acutangulus Descourt*., and *Sechium chayota* Hemsley (Flores 1989;) though these have fallen into disuse.

Species of *Sechium:* The Plant List includes 17 scientific plant names of species rank for the genus *Sechium*. Of these 11 are accepted species names (Plant List, 2022*)* (Table 1). *Sechium* is a well-defined genus composed of 11 species (Table 2).

Table 1. Proposed taxonomic classifications of *Sechium* and related genera (Lira Saade, 1996)

1.*Sechium amazonicum*	10.*Sechium panamense*
2.*Sechium americanum*	11.*Sechium peruvianum*
3.*Sechium chayota*	12.*Sechium peruvium*
4.*Sechium chinantlense*	13.*Sechium pittieri*
5.*Sechium compositum* (Donn. Sm.) C. Jeffrey	14.*Sechium tacaco* (Pittier) C. Jeffrey
6.*Sechium edule* (Jacq.) Sw.	15.*Sechium talamancensis*
7.*Sechium hintonii* (Paul G. Wilson) C. Jeffrey	16.*Sechium venosum*
8.*Sechium jamaicense* J. St.-Hil.	17.*Sechium villosum*
9.*Sechium mexicanum*	

Table 2. Taxonomic classification of the genus Sechium (Lira Saade 1996; Plant List. 2010**: cultivated species*) Section Sechium**

S. compositum (J.D. Smith) C. Jeffrey
S. chinantlense Lira & Chiang
S. edule (Jacq.) Swartz (wild and cultivated) *
S. hintonii (P.G. Wilson) C. Jeffrey
S. tacaco (Pittier) C. Jeffrey *
S. talamacense (Wunderlin) C. Jeffrey
Franzia Section:
S. panamense (Wunderlin) Lira & Chiang
S. pittieri (Cogn.) C. Jeffrey *
S. venosum (L.D. Gómez) Lira & Chiang
S. villosum (Wunderlin) C. Jeffrey
Sechium sp.

Of these, nine are wild species distributed throughout Central and Southern Mexico, up to Panama. The two cultivated species are *S. edule and S. tacaco.* Another two species that are morphologically similar to chayote are *S. compositum* and *S. hintonii*; the former is endemic to the states of Mexico and Guerrero and the latter is only known from the Mexican state of Chiapas and neighbouring areas of Guatemala. These two species are similar to cultivated chayote in their floral nectary and androecium structure, but their fruit, although also fibrous and bitter, do not have the apex cleft mentioned above. The remaining wild species of Sechium are morphologically more similar to the other cultivated species, S. tacaco (Lira Saade, 1996; Lira Saade, 2021). Some details of the accepted species in the genus *Sechium* are as follows (Mercado *et al*. 1993; Lira Saade, 1996; Lira Saade, 2021; Centelles, 2021**;** Anon., 2021; Wikipedia, 2021):

***Sechium edule*:** It is the most widely cultivated. It is known differently in different parts of the world. For example: In Mexico: chayote, Huasquila, Shamu and many names; In Colombia: chayote, potato or potato cider poor; In Bolivia: Japanese pumpkin; In the West Indies: chayote, tayote. chocho or Mirliton; In Argentina: air potato

Sechium hintonii: It is natural from the state of Chiapas, Mexico and neighboring areas of Guatemala. It is a species of very arid areas. *Sechium hintonii* is a species endemic to a small area of Mexico. This species has been found on sites at altitudes of 1300-1510 m asl, in a climatic-vegetation transition zone. The climate in this region is hot to semi-hot. The site in the State of Mexico could be described as an ecotone, between deciduous seasonal forest and *Quercus* forest, but it is seriously threatened by seasonal agricultural activities. No information is available and all that can be said is that, as in the case of wild types of *S. edule*, this species could be a source of resistance to diseases and pests. It is not known, unfortunately, whether it can be crossed with chayote. All that is known in this respect is that its haploid chromosome number is *n* =14. *Sechium hintonii* is clearly an endangered species, as it is endemic to a relatively small area, with known populations that thrive only in areas which are currently seriously affected by deforestation and agricultural activities. In addition, germplasm collections which would at least guarantee its conservation ex situ do not exist.

***Sechium tacaco*: Grown in Costa Rica.**

Sechium compositum: Natural from Chiapas in Mexico and northern Guatemala. This species grows in the mountains. It differs from other chayotes for being a fruit that endures and keeps well after being harvested. It is known by the name of "horse Chayote". Distribution of *S. compositum* covers some of the Southern part of the State of Chiapas in Mexico, as well as neighbouring areas in Guatemala. The *S. compositum* fruits have been described in the literature as longitudinally ridged, with prickles on the ridges.

In Chiapas, the chopped-up roots are mixed with water, and used as a soap substitute and to kill horse fleas. The fruit of *S. compositum* can be stored for several months, with no recorded effect on turgidity or humidity. Attempting to incorporate this characteristic into cultivated chayote may be of interest in solving storage or conservation problems. Cross-breeding between this species and cultivated chayote has not been explored. However, a hybrid plant obtained from the cross between *S. compositum* and a cultivated plant of *S. edule* has been reported. The haploid chromosome number of this species is *n* =14.

Sechium chinantlense: Natural from northern Oaxaca, Mexico, where it is known as "Chayote bush" or "Head of Chango". It is a species in danger of extinction. This species is endemic to a very small region of Mexico, in the north of the State of Oaxaca. It thrives at altitudes of 20-800 m. In lower-lying areas, it grows in rainforest, The plants of this species are found in areas with high relative humidity, *S. chinantlense,* a diploid number of 2 *n* =30 has been reported.

Sechium panamense: It is a kind of squash that grows in the Panama state of Chiriqui over 2000 m altitude.

***Sechium pittieri*:** Native of Costa Rica, where it is known with the name " Spook tacaco", it is one of the favorite foods of the native Guetares, who collect its fruits and use. They also use their tender leaves.

Sechium talamacense: Details are not available

Sechium venosum: Details are not available

Sechium villosum: Details are not available

***Sechium mexicanum*:** Details are not available.

Recently it has been accepted that within the genus *Sechium* there are ten species, eight of which are wild (*S. chinantlense*, *S. compositum*, *S. hintonii*, *S. talamancense*, *S. panamense*, *S. pittieri*, *S. venosum*, *S. vilosum*) and two cultivated (*S. tacaco* and *S. edule*), which are divided up from Mexico to Panama (Lira-Saade 1996).

Wild types of *Sechium edule:* The 'wild' types of S. edule type of population thrives in the States of Veracruz, Puebla, Hidalgo and Oaxaca in south- ern Mexico, at heights of 500-1700 m a.s.l. Wild types of S. edule have very similar (or in some cases almost identical) morphological characteristics to those of the cultivated types of this species. The flowers of these plants, for example, although slightly bigger than those of cultivated plants, have an identical staminal structure. Their fruit also has an apex cleft from which the plantule sprouts, once the seed has germinated. The most significant morphological differences between cultivated and wild chayote are the difference in size of the vegetative and reproductive structures. Wild plants are more robust, for example, and their leaves, flowers and staminate inflorescence are bigger than those found in cultivated plants. Yellow or white fruits, for example, have not been recorded for these plants. Moreover, as pointed out above, the pulp has a bitter taste and is usually more fibrous. Such differences are even more accentuated in the populations from Oaxaca. The fruits, as well as having fibrous pulp and a bitter taste, are more homogeneous in shape (globulate), colour (dark green) and prickles (very prickly). Another important difference between these wild populations is their chromosome number: for those of Veracruz the haploid number reported is n =12, while for those of Oaxaca the haploid number of n =13 has been determined. Studies have not been carried out on the potential these plants might have as a resource for improving chayote. However, given their morphological similarity, and their potential for successful hybridization with cultivated chayote plants, these populations should be among the first to be evaluated, especially for resistance to disease and pests. Hybridization programs with cultivated types should clearly be started (Palacios, 1987; Lira Saade, 1996; Lira Saade, 2021). The wild species differ from cultivated ones. Wild species are bigger and stronger in general. Wild fruits only germinate when they rot on the ground, while cultivated fruits germinate before they rot, even on the same tree or after cutting, if not in a cold environment. Species cultivated in warm climates bloom in spring and produce fruit in summer, while wild species blooming takes place from spring to early winter and produce fruit from late summer to early winter (Anon., 2021). There are two types of chayote. Common chayote is the type you find in the supermarket and in people's gardens. Wild chayotes grow by streams and rivers. You often find them in ravines. Most wild varieties are more vigorous and the fruit is larger. Wild fruits sometimes have small thorns. Closely related to the common chayote, the skin is usually prickly, but can be smooth as well. This variety stores for a long time (Craig Taylor. 2021).

In India, the vegetable is called *chow chow* among other names; in the east and north east, it is simply known as *squash* and is a very popular vegetable used in both vegetarian and non vegetarian dishes. In other parts of the world, the English name is often *chou chou* (e.g. in Mauritius), or a variant thereof (e.g. *chuchu* in Brazil). In Madagascar and the western Indian Ocean, it is called "soasety" (Wikipedia, 2022).

Synonyms of *Sechium edule*
Sicyos edulis Jacq.,
Chayota edulis Jacq.,
Sechium americanum Poir.,
Cucumis acutangulus Descourt., and
Sechium chayota Hemsley .
(Flores, 1989).

Botanical Varieties of *Sechium edule*: An important feature in the species is its broad variation with respect to form and color of fruits, many of which are only known on local markets. The economic importance of each chayote type is mainly based on local preference, which – though in most cases it is very limited – has permitted to maintain its phenotypic identity and ethno-botanical nomenclature. Cook (1901) recognized on the Caribbean islands "varieties" of green and cream-yellow chayote growing in the high and cool parts; he also identified pyriform and spherical fruits as well as differences in size and coloring of flowers; the cream-white "varieties" had small white flowers, whereas the flowers of the green fruits were larger and yellow. Although the settlers had incorporated them into their diet, they did not cultivate them. Later, basing on Gardener's Chronicle and Agriculture Gazette (1865) Cook found in Puerto Rico what he called five "varieties", which he described by their morphological variation as "Round white", "Pointed green", "Broad green", and "Oval green". In Mexico, popular nomenclature classifies chayotes by their color, as "black" those of dark green epidermis, "green" those of light green, and "white" the ones of creamyellow epidermis; by their appearance (smooth or prickly), and by their flavor ("neutral", "sweet", and "bitter") (Cadena-Iniguez 2005). Based on a morpho-structural, biochemical, physiological, and genetic analysis, Cadena-Iñiguez (2007) proposed an arrangement of the infraspecific *S. edule* complex under a classification system into ten botanical varietal groups (Fig 1).

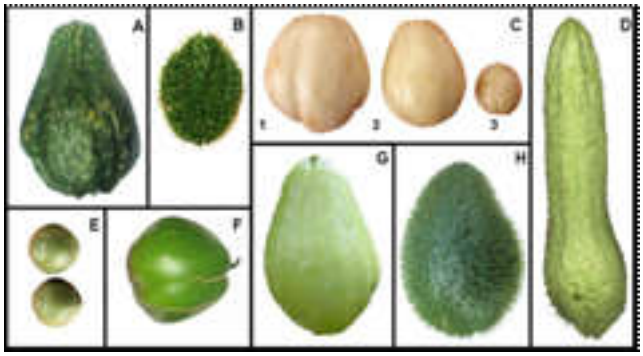


Fig. 1. Botanical varieties of *Sechium edule* (Jacq.) Sw.: *nigrum xalapensis* (xalapa black) (A); *amarus silvestrys* (bitter wild) (B); *albus levis* (smooth yellow) (C1); *albus dulcis* (cambray) (C2); *albus minor* (castilla white) (C3); *nigrum maxima* (caldero for soup) (D); *nigrum minor* (castilla green) (E); *nigrum levis* (castilla black) (F); *virens levis* (smooth green) (G); *nigrum spinosum* (prickly green) (H)

A morphological and anatomical variation analysis was carried out with leaves and fruits of *Sechium edule*, collected in the Central region of Veracruz, Mexico. The collected fruits were classified in eight groups according to their typical characteristics **(Fig. 2).**

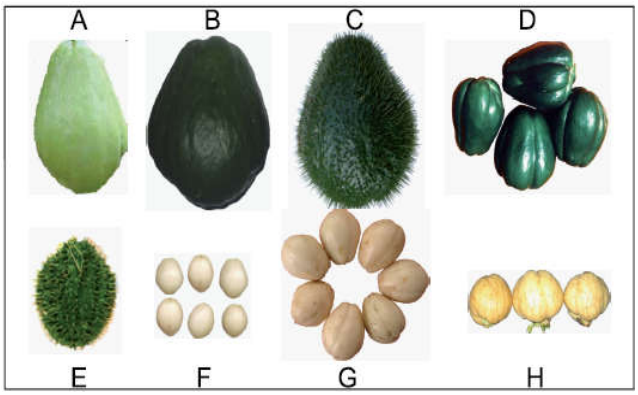


Fig. 2. Fruits of seven varieties and a wild relative: A) *virens levis*, B) *nigrum xalapensis*, C) *nigrum spinosum*, D) *nigrum levis*, E) *Wild relative*, F) *albus minor*, G) *albus dulcis*, H) *albus levis*

The results showed that the phenotypical distinction of the studied infraspecific *S.edule* complex is related to morphological and anatomical changes in order to improve the adaptive specialization of the different chayote types with respect to the environment, and suggests that cultivated chayotes have followed different routes in the process of co-evolution with man, showing stable variation patterns in the so-called "green" and "yellow" groups. Considering the phenotypic variability existing in the analyzed characters, a certain prediction may be proposed about the direction the variation patterns may follow facing the transference of chayotes to environments of lower altitudes than mountain cloud forest, and parallel traits to the phenotype by domestication effect cannot be discarded since the types

did not move on their own to environments other than the original one (Cadena-Iñiguez *et al*., 2008). Avendaño Arrazate *et al*. (2010) have described the ten botanical varieties of chayote as follows (Fig. 3):

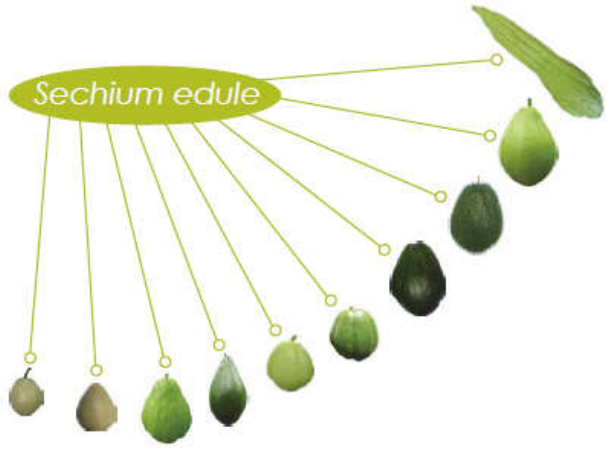


Fig. 3. Botanical varieties of *Sechium edule* (Sl.No. 1- 10)

***Sechium edule* var. albus minor:** Cream white fruit (pantone 1205c), pyriformis, lesser size than the rest, from 3.2 to 4.1 cm in length, 3.0 to 3.3 cm wide and 2.7 to 3.2 cm thick; totally glabrous no ribs present nor basal cleft. Light green peduncle with pubescent. Mesocarp cream slightly flavored sweet (8.0 ° Bx) with very adherent fiber.

***Sechium edule* var. albus dulcis:** Yellow pyriform fruit cream (pantone 1205c), from 8.0 to 15.3 cm in length, 4.8 to 8.8 cm wide and from 3.8 to 7.3 cm thick; glabrous, with five ribs not very marked and basal cleft not very deep. Glabrous peduncle light green with striations green yellow. Colored mesocarp cream white, medium flavor sweet (7.2 ° Bx), with the presence of fiber moderately adherent.

***Sechium edule* var. albus levis:** Pyriform fruit from 6.1 to 16.6 cm in length, from 5.3 to 10.4 cm wide and 4.6 to 8.7 cm thick; totally hairless with presence of ribs not marked and cleft very noticeable baseline, cream yellow (pantone 1205c). Light green peduncle with yellow-green striations, low pubescence. White mesocarp flavored cream slightly sweet (7.6 ° Bx) with presence of bonded fiber.

***Sechium edule* var. nigrum minor:** Light green fruit to dark green (pantone 374c, 574c and 586c), the shape is obovate slightly pyriform, with dimensions from 4.5 to 13.2 cm in length, 3.1 to 6.9 cm wide and from 2.8 to 6.2 cm thick; totally glabrous, does not present ribs nor basal cleft. Light green peduncle low pubescence. Light green mesocarp moderately flavored sweet and medium fiber.

***Sechium edule* var. nigrum conus:** The fruit is conical from 5.4 to 7.1 cm in length, 3.3 to 5.0 cm wide, 3.0 to 4.6 cm thick; light green to dark green (pantone 371c and 574c), without the presence of ribs, nor basal cleft. Dark green peduncle with low pubescence. Dark green mesocarp and taste moderately sweet (7.2 ° Bx).

***Sechium edule* var. nigrum levis:** Light green fruit to dark green (pantone 575c, 575c and 576c), predominantly pyriform, medium elongated from 7.1 to 9.7 cm in length, 4.6 to 7.8 cm wide and from 4.2 to 7.0 cm thick; without ribs, with basal cleft not very marked. Dark green peduncle moderately pubescent. Light green mesocarp and neutral flavor (5.7 ° Bx).

***Sechium edule* var. nigrum xalapensis:** Dark green pyriform fruit (pantone 373, 574c, 575c and 5605c), from 5.5 to 26.6 cm in length, 4.4 to 18 cm wide and 4.0 to 10.7 cm thick. Presence of five ribs not very marked and basal cleft very marked. Peduncle moderately pubescent.

***Sechium edule* var. nigrum spinosum:** Of green pyriform fruit light to dark green (pantone 350c, 364c, 370u, 377u and 1205c), with dimensions from 5.8 to 17.1 cm in length, 5.0 to 12.2 cm wide and 3.6 to 9.7 cm thick; with high density of thorns and five ribs not very marked and basal cleft very marked. Very low pubescence on the peduncle. Green mesocarp light to dark green with neutral flavor to moderately sweet (6.43 ° Bx) with very fiber attached to the mesocarp.

***Sechium edule* var. nigrum maxima:** Light green pyriform fruit (pantone 373c and 7492c), from 12.1 to 33.7 cm with an average 19.99 cm in length, 8.1 to 11.3 cm wide and 6.3 to 8.8 cm thick. Totally hairless with presence of five ribs and basal cleft very noticeable. Light green peduncle low pubescence, green mesocarp very clear with a neutral flavor with medium fiber attached to the mesocarp.

***Sechium edule* var. virens levis:** The size of the fruit goes from 9.30 to 18.30 cm in length, from 6.0 to 11.40 cm wide, and from 5.40 to 9.60 cm thick; pyriform in shape light green (pantone 373c), with five ribs not very marked, basal cleft not very deep. Light green peduncle with very low pubescence. Light green mesocarp with neutral flavor and fiber moderately attached to the mesocarp. In an effort to put the infraspecific (crossing between subspecies) complex presented in *S. edule* in order, Lira *et al*. (1999) proposed a new taxonomic arrangement, grouping the cultivated types in the subspecies *S. edule* ssp. *edule* and the wild one as *S. edule* ssp. *silvestrys*. These authors based this separation on the morphological and chromosomal differences through identification of karyotypes in pollen grains. Regrettably, in this proposal it was not indicated which cultivated type or types were included in the analysis, infraspecific hybrids, and products of spontaneous crossings among chayotes, with different phenotypes and degrees of domestication, possibly being involved, since there is no high genetic differentiation between anthesis of the pistillated flower and staminated flower that provoke hybridization among the different types of chayote (Gamboa 2005). Chayote fruit is bitter and both spiny and spineless types have been found. Chayote cultivars do not breed true, although it has been observed that cultivars do not segregate significantly from one generation to the next because of the relative isolation of chayote plants from one another when planted in home gardens. Many types with different fruit characters are known. Commercially grown chayote consists of two types: one with a medium-sized, pale green, smooth, pear-shaped fruit and one with a small, white, smooth, globular fruit (Engels, 2021). Chayote cultivars do not breed true, although it has been observed that cultivars do not segregate significantly from one generation to the next because of the relative isolation of chayote plants from one another when planted in home gardens. When planted together, complete panmixy (random mating within a breeding population) can be observed. Substantial efforts made at CATIE (Costa Rica) to describe cultivars on the basis of fruit characteristics proved to be of limited relevance because of the extraordinary variability, with continuous variation in almost all the characters. The variable fruit characters include size (7-20 cm long), weight (100-1000 g), colour (continuous range from white to dark green), shape, fruit-wall features (spines, lenticels, grooves and ridges), flavour and texture. Nevertheless, farmers "classify" the genotypes by a combination of such fruit characteristics. Instead of speaking of cultivars, it seems best to consider those types as landraces or as primitive populations. At least 25 landraces exist in Central America. Commercially grown chayote consists of two types: a medium sized, light-green, smooth, pear-shaped fruit and a small, white, smooth, globular one. Several types can be distinguished in South-East Asia. For example, in West Java (Indonesia) the common type is dark green and almost glabrous, but more spiny and lighter green types can be found. A complete white type, less tender and spiny, is sometimes grown as a botanical curiosity (PROSE, 2021).

BOTANICAL DESCRIPTION

S. edule is an uprising perennial plant with tendrils and tuberous roots. Its stems are several meters long, slightly compressed and longitudinally furrowed; green, when they are young, and brownish-gray at maturing; each knot has a leaf, one unisexual inflorescence, and a tendril ramified in two and up to five smaller branches. The leaves with long petiole are simple, lobed or angular, palm-shaped with branched vein structure.

Flowers are unisexual, axillary and occasionally staminate and pistillate at the same knot, or flowers of both sexes on the same axis. The fruit is pendulous, large, obovoid or pyriform, with a variable number of longitudinal depressions, white surface, light or dark brilliant green; it may be glabrous, with fine hair or with a variable number of spines and only one seed (Maffioli 1981; Flores 1989; Lira-Saade 1996). Monoecious, perennial herb, sprawling or climbing with large, 2–5-branched tendrils; root large, tuberous; stem up to 15 m long, longitudinally grooved. Leaves arranged spirally, simple; stipules absent; petiole 3–25 cm long; blade broadly ovate-circular in outline, 7–25 cm in diameter, 3–7-angular or lobed, base deeply cordate, margins obtusely toothed, scabrid hairy, 5–7-veined from the base. Flowers unisexual, regular, 5-merous; male flowers in an axillary raceme, small, greenish or cream, stamens 3, with filaments united; female flowers usually solitary on short pedicel, corolla c. 0.5 cm in diameter, ovary inferior, 1-celled, style short, stigma headlike. Fruit a fleshy berry, variable in shape but commonly pear-shaped, 4–27 cm long, somewhat ribbed, smooth or shortly spiny, dark green to almost white, pulp white or greenish-white, 1-seeded. Seed ovoid to ellipsoid, compressed, 2.5–5 cm long, white (Engels and Jeffrey, 1993). The chayote is a herbaceous, perennial, monoecious, vigorous creeper or climbing plant. It grows from a single, thick root, which produces adventitious tuberous roots. The stems are angular-grooved and glabrous, and several grow simultaneously from a single root, at least in the cultivated plants. They thicken towards the base and appear woody, while towards the apex there are many thin, firm, herbaceous branches. The leaves have grooved petioles, 8-15 cm long, and are glabrous; the blade is a firm papiraceous-membranous, ovate-cordate to suborbicular, 10-30 cm long, and almost as wide at the widest point, slightly 3-5 angular-lobed with pointed to acuminate lobes, the margins are totally to slightly dentate, and the base is cordate-rectangular, with the sinus open to semi-closed by the bases of the lateral lobes; both blade surfaces are pubescent when young, later becoming glabrescent, although the adaxial one is persistently puberulent on the veins. Like almost all Cucurbitaceae, the chayote plant develops tendrils for support. These are sturdy, 3-5 branched, furrowed and essentially glabrous (Lira Saade, 1996; Lira Saade, 2021; PROSE, 2021).

Chayote is a fast-growing climbing vine with characteristic tendrils. It bears small white unisexual flowers and green pear-shaped fruits with furrows. Each fruit is about 7.5 to 10 cm (about 3 to 4 inches) long and contains one seed embedded in the green to green-white flesh. Some varieties have hairy or spiny fruits (Britanica, 2022). The chayote vine can be grown on the ground, but as a climbing plant, it will grow onto anything, and can easily rise as high as 12 meters when support is provided. It has heart-shaped leaves, 10–25 cm wide and tendrils on the stem. The plant bears male flowers in clusters and solitary female flowers; sometimes two female flowers. In the most common variety, the fruit is roughly pear-shaped, somewhat flattened and with coarse wrinkles, ranging from 10 to 25 cm in length, with thin green skin fused with green to white flesh, and a single, large, flattened pit. Some varieties have spiny fruits. Depending on the variety, a single fruit can weigh up to 1.2 kg. The flesh has a fairly bland taste, and the texture is described as a cross between a potato and a cucumber (WIKI, 2022). The perennial climber with coarse hairs grows very quickly in suitable locations and can cover several dozen square meters depending on the base of the vine. If it climbs on a tree, the chayote can certainly grow up to five meters high. The chayote forms a rhizome from which it will sprout again in spring in seasonal locations. The heart-shaped, stalked, and simple leaves can grow to be hand-sized, about 15–25 cm. The ribbed petioles are about 7-20 cm. long. The leaves are ovate to rounded in outline. They are edged with a few small and three to seven large teeth or small lobes and are usually pointed or tipped. The leaves are hairy on top of the veins. Shoots with dry leaves often hang on the plant, the tendrils of which have not encountered any climbing opportunities. The bare tendrils are three to five parts. The young leaves are hairy and then bare. The white to yellow, fivefold, short-stalked double perianth flowers appear in the leaf axils (Wikipedia, 2022a). The flowers are unisexual; the staminate flowers are arranged in pedunculate and erect racemes, 10-30 cm long or more in wild plants, and usually with the flowers arranged in fascicular or subracemose clusters disposed at intervals along the rachis; the pedicels are 1-2 mm long and are puberulent; the receptacle is patelliform, 1-2 mm long or less, 4-5 mm wide and glabrous, with five narrow triangular sepals usually patent to re- flexed in buds, which are 4 mm long and almost 1 mm wide. There are also five petals, patent, green to greenish-white, which are widely triangular, obtuse to acute, 6- 7 mm long and 2-3 mm wide. The pistillate flowers develop in the same axilla as the staminate ones. They are usually solitary, although occasionally they might grow in pairs or, on rare occasions, three grow from the same pedicel; the pedicel is thin, grooved, glabrous and is 1-3.5 cm long, growing up to 8-9 cm in the fruit. Many different shapes of ovary are found, from completely unarmed and glabrous to variously indumented or armed; the perianth is like that of the staminate flower, but reduced in the receptacle; the styles are joined together in a thin column, and the stigma is subglobose and 2-lobate; the nectaries of the receptacle base are similar to those of the staminate flowers (Lira Saade, 1996; Lira Saade, 2021; PROSE, 2021). The female flower looks like a small fruit right behind the flower. If pollination occurs, this little fruit will start to develop and grow on to become a mature fruit. If the female flower does not get pollinated, it will just shrivel away and fall off of the vine. The front of the female flower shows the long sticky stigmas in the center that will collect the pollen and lead to the development of the fruit. It is much easier to tell the female flowers from the male flowers by examining the back of the flowers. Female flower shows a prominent "fruit" behind the flower. The elongated immature fruit behind the flower is easy to see. The stamens are five with fused filaments along almost all of the length, forming a thick column, which normally separates into five short branches (although sometimes three, and more rarely four, are found); the anthers develop at the apex of the short branches of the filaments, they are oblong and when three are found, two of them are bi-thecous and one mono-thecous, and when there are more than three, apparently all are bi-thecous, the thecas are flexuous and the connective has some scattered short hairs with an enlarged base. A total of 10 pore-like uncovered nectaries are found at the base of the receptacle surrounding the staminal column. These are densely puberulent to tomentose on the upper surface, and only slightly projected beneath, in the form of a sac (Lira Saade, 1996; Lira Saade, 2021; PROSE, 2021). There is no "baby fruit" behind the flower on the male flower. There is likely to be 1-2 male flowers. If you are going to hand pollinate, you can take off the entire flower and then rub it on the female flowers. From the front you can see all of the pollen-covered anthers on the male flower.

Telling the difference between female flowers and male flowers isn't complicated, but it takes a little patience to get started. Female flowers have a swollen area just beneath the flower that might look like tiny fruit. The male flowers don't have a swollen area. The male flowers, which appear in racemes, grow together with the female flower, alone or in pairs, on the same plant. The plants are therefore monoecious. The green calyx lobes are narrow triangular and the petals are triangular to oblong. The five stamens of the male flowers are tubular and have short branches above. The one-chamber ovary of the female flowers is inferior, the stigma is lobed. Hairy nectaries are present in the flower cup. The plant is insect pollinated (Wikipedia, 2022a). The fruits grow either individually or in pairs (rarely in greater numbers) on a shared peduncle. They are fleshy or fleshy-fibrous, may have longitudinal ridges or furrows, and come in many different shapes (globose, ovoid, subovoid, pyriform, elongated pyriform), sizes (4.3-26.5 cm long, 3-11 cm wide), and colors (from white to pale yellow – colors not found in wild populations – to dark or light green); they may be unarmed and smooth, or with varied indumentum or armature, although they generally conserve the characteristics of the ovary. They may have woody ridges or lenticels on the surface, especially when ripe; the pulp is pale green or whitish and tastes bitter in wild plants and pleasant, sweet or insipid in cultivated plants; the seed is ovoid, compressed and smooth (Lira Saade, 1996; Lira Saade, 2021; PROSE, 2021). The fruit of *S. edule* is viviparous, viz. the seeds germinate inside the fruit even when it is still on the plant.

This characteristic does not occur in any of the wild species, in which the seeds germinate asynchronically (not occurring at the same time.) after falling to the ground. A possible explanation for the vivipairism of the cultivate species is that the process of domestication may have resulted in suppression of the dormancy mechanisms (Lira Saade, 1996; Lira Saade, 2021; PROSE, 2021). The single-seeded fruits, berries (pseudo-fruit, tankberry) usually hang below the foliage and are about 5-25 cm tall when ripe. They vary in shape, size and color depending on the variety. The fruit, which is often wrinkled and more or less ribbed, usually has an egg- to pear-shaped shape, more rarely rounded. The thin, waxy and smooth to sometimes slightly hairy to soft-spiky skin is usually greenish. Sometimes, even in cultivars, it has a whitish or yellow color. Dark green chayotes can have shorter, soft to harder spines. The inside of the fruit is pale green-whitish and tastes very faintly of a mixture of potatoes and cucumbers. Some varieties taste like kohlrabi and can be eaten raw or cooked (Wikipedia, 2022a). Seed is solitary, ovoid to ellipsoid, 2.5-5 cm long, compressed, white, germinating within the fruit, usually while the fruit is still attached to the plant; in some genotypes seed-coat with fibres radiating into the flesh, in others obsolescent and the flesh fibreless (PROSE, 2021).

The soft-skinned, ovoid, flat and smooth, yellowish core (seed) about 2.5-5 cm in size, from which the plant sprout by itself, given the right humidity, without any substrate, even on the mother plant (only in cultivated plants) (Real viviparity), is also edible. Unlike many other plants in the cucurbit family, the chayote has only one seed (Wikipedia, 2022a) (Fig. 4). A wide variation in the *S. edule* chromosome number has been documented in the literature. Some studies agree that the haploid and diploid numbers of this species are n =12 and $2n$ =24 respectively, while others report accounts of n =13 and $2n$ =26 (Goldblatt 1990), $2n$ =28 (Giusti *et al.* 1978) or $2n$ =22 (Singh 1990). The chromosome number is 2n = 24, 26 or 28 (Wikipedia, 2022a).

Flower Biology and Pollinators: To judge from the number of detailed studies available, flower biology and pollinators must rank among the most researched auto-ecological aspects of *S. edule* (Giusti *et al.* 1978; Wille *et al.* 1983; Newstrom 1986, 1989). Some of the conclusions reached by these studies are of relevance to chayote cultivation and conservation.

Fig. 4. Botanical description of chayote

Among cultivated types, for example, variations have been found in the sexual rate of production of staminate flowers and pistillate flowers. These appear to be the result of genetic, environmental and seasonal factors, as well as the age of the plant. A better understanding of these factors would be important when improving the crop, and, in particular, in the selection of types with high productivity of female flowers and, therefore, of fruits (Lira Saade, 1996; Lira Saade, 2021). As far as pollination is concerned, it is known that this is carried out by several insect species. Additionally, there appears to be no difference in fruit production rates between plants with open pollination and those which are self- or cross-pollinated (Newstrom 1986; Ramírez *et al*. 1990). On the other hand, it seems that fruit production is not affected by the number of pollen grains applied to the stigma, or by how often they are applied. It also has been shown that when chayote was grown under greenhouse conditions, in the absence of pollinating insects, immature fruits failed to develop and abscised prematurely (Aung *et al*. 1990). The fact that chayote pollination depends on insects may be one of the reasons why it has spread so successfully, but it also makes it very difficult to preserve pure strains, which is important not only for commercial or traditional plantation, but also for gene banks. The relative importance of chayote pollinators has been observed to increase not just with eco-geographical and environmental factors such as altitude and latitude, but also with the use of pesticides (Giusti *et al*. 1978; Wille *et al*. 1983; Newstrom 1986). Thus, some species of bees of the genus *Trigona* that have been identified as very efficient chayote pollinators are found mostly at medium to high altitudes, which are pesticide-free. In contrast, other important pollinators, such as *Apis mellifera,* are most commonly found mainly in commercial plantations, where pesticides are frequently used. Secondary pollinators of chayote include wasps from the genera *Polybia, Synoeca* and *Parachrataegus* as well as other smaller species of *Trigona* (Lira Saade, 2021).

Growth and Development: Chayote is a long-lived perennial, but in cultivation it is recommended to renew it at least every 3 years because of disease problems. The tubers do not develop until the second year, and do not develop well in perpetually wet climates. In regions with a season of arrested growth, they can reach 10 kg in weight and they resemble yam tubers. Flowering starts 1-2 months after germination. Chayote is predominantly cross-pollinated, but is self-compatible. It is a renowned honey-producing plant, loved by beekeepers because it flowers abundantly throughout the year. Fruit development takes 1-2 months after pollination. In good conditions, chayote plants grow profusely and can form a dense foliage cover on trellis, producing hundreds of hanging fruits. The seed germinates in the ripe fruit while still on the mother plant. This phenomenon is called viviparous germination (PROSE, 2021).

GENETIC DIVERSITY

Eleven characteristics *of* the physiologically ripe fruit (at the moment of visible vivipary) were studied. The descriptor states of the descriptors 9, 10, and 11 are expressed on a scale from 2 (weak expression) to 6 (strong expression). The value 1 is used to indicate the absence of an expression. The descriptors, 1, 9, 10, and 11 were scored by simple observation. For the determination of the correct shape, drawings were used as references. The order of the classes corresponds with a decrease in length of the fruit in relation to the width. The color of the fruit was described with the help of a color chart and, for practical reasons, transferred into the given classes. The spine density refers to the number of spines present on a certain surface unit of the fruits. The longitudinal furrows are the grooves which extend from the base of the apex of the fruit. The reticulation refers to the frequency of " corky" spots on the fruit surface; this character increases with aging. The descriptor numbers 1, 8, 9, 10, and 11 were treated as quantitative, nondiscrete characteristics, since the values are subjective estimates of positions along continua (Table 3) (Engels, 1983).

Table 3: The scored descriptors and their respective classes or states of the chayote fruit as used in this study

Descriptor name	Descriptor states/ Descriptor name measurement unit
1. Fruit shape	1 = pyriform 2 = subpyriform 3 = ovoid
2. Fruit length	4 = rounded 5 = flattened
3. Fruit width at widest part	Cm
	Cm
4. Fruit thickness at widest part	cm
	--
5. Fruit width/fruit length ratio	--
	g
6 . Fruit ratio of length from base to widest point/total length	1 = whitish 2 = light green 3 = green
7. Fruit weight	4 = dark green
8 . Fruit color	1 = absent 2 = very low 4 = intermediate
9. Spine density	6 — very high 1 = absent 2 = very superficial
10. Longitudinal furrow depth	4 = intermediate 6 = very deep 1 = absent
11. Reticulation	2 = very little 4 = intermediate 6 = very intense

The large number of extreme values found in the chayotes from Costa Rica can be explained in part by the more intensive collection; on the other hand, it demonstrates the high genetic diversity of this crop in Central America (Fig. 4a) (Engels, 1983).

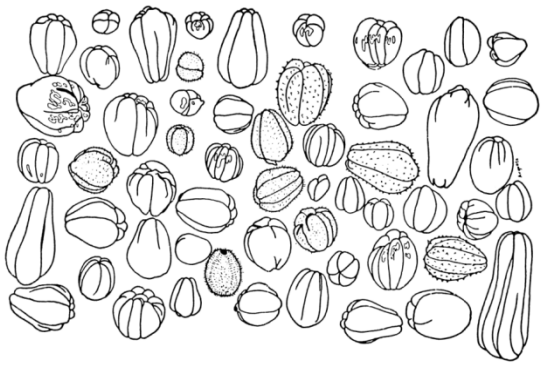


Fig. 4a. Phenotypic variation of Central American Chayotes

Chayote is a Middle American species, being Mexico one of the centers of biological diversity, and the states of Veracruz, Chiapas, and Oaxaca showing the highest levels. In the central region of Veracruz, significant variation for fruit size, fruit form and color, flavor (bitter, neutral, and slightly sweet), smooth and with spines has been reported. Likewise, leaf polymorphism, different petiole coloring, leaf vein structure, vines, and flower have been reported (Cadena-Iñiguez *et al*., 2008). Among the peasant crops there is great genetic diversity that is expressed mainly in the shape, color and texture of the surface of the fruits (shape -globose, ovoid, subovoid, pyriform and elongated pyriform; sizes 4.3-26.5 cm of long, 3-11 cm wide; color –from white to pale yellow and from dark to light green; with or without spines. The types of chayote (they are not considered cultivars or varieties due to their low genetic stability) are: quelite (for export), black criollo, white criollo and cocoro (Fig. 5, 6, 7) (Lira Saade 1996). Genetic variation for 11 fruit characteristics of Central American chayotes *{Sechium edule* Sw.) was similar in Costa Rica, Honduras, Guatemala, and Mexico. Costa Rica possessed many types belonging to the extremes of the total range.

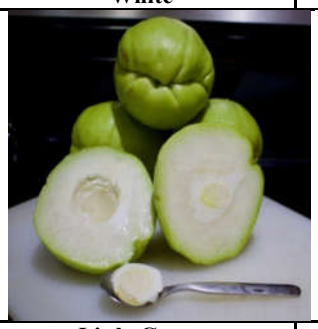
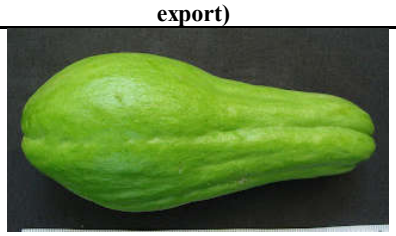
		
White	White	Light Yellow
		
Yellow	Light Green	Green
		
Dark Green	Black	

Fig. 5. Fruit color

		
Globose-shaped fruits (known as "potato" chayote	Globose-shaped fruits (known as "potato" chayote	Ovoid shaped fruit (known as "quelite" chayote or for export)
		
Ovoid shaped fruit (known as "quelite" chayote or for export)	Pyriform shaped fruits	Pyriform shaped fruits
		
Elongated pyriform fruit	Elongated pyriform fruit	Fruits with thorns

Continue …

Fruits with thorns

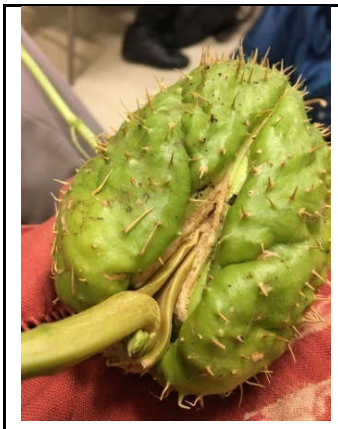
Black Creole

White creole

Cocoro (the small one; sold as a mini vegetable)

Contest for the largest chayote (fruits larger than 30 cm in diameter).

Fig. 6: Fruit shape



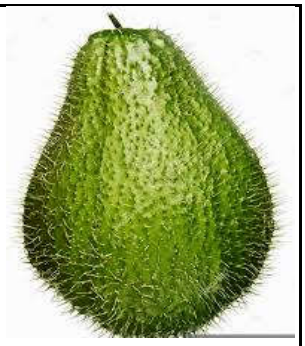


Fig. 7. Thorny/Prickly/Spiny Fruits

Fortunately, some detailed studies were published (Engels 1983; Newstrom 1986) documenting the variation in the samples collected in Mexico and Central America and making it possible to analyze this.

These collections were, without any doubt, very representative of the diversity of this crop since they included samples from different areas of Mexico and Central America where this crop has originated and developed its distinctive features (Lira Saade, 1996; Lira Saade, 2021).

In addition, the characteristics of the samples studied show the significant variation of external features of the fruits such as color, shape, size and number of spines and / or lenticels present on the surface. In some cases (Newstrom 1986) information is given on the internal characteristics of the fruit such as fiber content and consistency of the flesh, and reference is also made to plant productivity and even to the taste of the fruit flesh (Newstrom 1986). Although these collections were intended mainly to conserve the diversity of cultivated S. edule plants, the Costa Rica collection also had one S. compositum and several S. tacaco accessions (Lira Saade, 1996; Lira Saade, 2021). The fruits of 74 landraces of chayote with different characteristics were collected from the different parts of Sikkim, West Bengal, Meghalaya, Arunachal Pradesh and Nepal during September–October 2013 and 2014. The results on genetic diversity analysis of the chayote accessions of NEH region has shown moderate to high genetic similarity as shown by values of Jaccard's similarity coefficient and PCA. Fifty-six landraces from the entire region included in this study form a large cluster. The grouping of accessions observed was not found according to their geographic distribution. Since the genetic drift and selection in different ecological niche may create greater genetic variability; it could be a reason for clustering of accessions from different geographic regions is same (Joshi *et al*., 2020). Diversity of chayote was assessed on-farm, and on-station using 9 morphological and 20 random amplified polymorphic DNA (RAPD) markers in addition to use values. Cluster and principal component analyses were done using both morphological and genotypic data separately. Five different fruits colors have been found in chayote fruits on-farm. Pale yellow is more common and farmers call dark green chayote as Kaalo Iskhush (Fig. 8, 9) ((Joshi *et al*., 2020). *Seto Ishkush* (chayote with white fruit) formed a separate cluster, indicating unique accession.

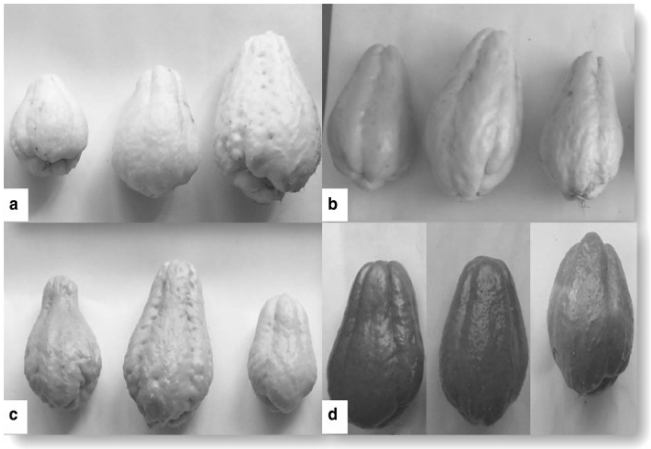


Fig. 8: Major group of chayote germplasm based on fruits colours a) Pale yellow, b) light green, c) green and d) dark green

Fig. 9: **Diversity of fruit color, shape and size in Nepal**

The highest genetic diversity was found between *Hariyo Ishkush* and *Golkaade Ishkush*. The total number of amplified DNA bands varied from 2 (OPC-20) to 10 (OPC-11) with an average of 5.7 bands per primer. The size of bands generated ranged from 100 bp to 3000 bp. A total of 85 amplified bands were found and all bands were polymorphism. The polymorphism information content (PIC) ranged from 0.22 to 0.46. Three major clusters were formed based on RAPD information. Among the five conservation methods, field gene bank was found effective in Nepal (Joshi *et al*., 2020). Six major varieties of chayote (Fig. 10) were collected from local market (Gangtok, India). These samples exhibit light green, yellow, deep green in colour as shown in the figure. Some varieties were smooth and some had spines on the surface. Due to these variations, the six selected varieties were designated as Yellow smooth (YS), Long smooth (LS), Green Smooth (GS), Long green spine (LGS), Yellow long spine (YLS) and Deep green spine (DGS) in the present study. From the study, it was revealed that YS variety was found to be of lowest size and LGS variety was of highest size. Majority of the chayote varieties studied were of regular shape. Varietal effect on both shape and size were found to be significant. Firmness and cutting forces showed significant varietal difference between the tested varieties whereas no significant variation was found for puncturing force and toughness among the selected chayote varieties. The findings of the present study would be very useful in the design of suitable primary processing equipment for chayote (Debbarma and Jena, 2018). Sixteen chow-chow/chayote accessions collected from different locations in Sikkim (Fig. 11) were studied for fifteen morphological and biochemical characters. Highest fruit weight was recorded in entry S8 (461g) followed by S9 (416g) and S1 (399.09g). Highest dry matter content was found in the entry S5. Entries S2, S3, S10 and S11 contained higher ascorbic acid content in their fruits. Twelve polymorphic RAPD markers were used for differentiating the 16 accessions, generated a total of 25 bands (2 bands per primer). The UPGMA dendrogram obtained from the cluster analysis using Jaccard's similarity coefficient divided the accessions into four clusters. The morphological or biochemical characters of the accessions did not show association with the RAPD data (Kapoor *et al*., 2014). The considerable diversity formed by traditional growers contrasts with the relative homogeneity observed in fruit produced on commercial plantations. In these cases, the fruit must comply with the quality requirements demanded by the market: pyriform, light green, smooth, about 15 cm long and 450 g in weight; with no physical damage or blemishes caused by pathogens; and with a suitable texture and sweet and pleasant flavour (Lira Saade, 2021).

Genetic Resources: During collection trips throughout Central America from 1975 to 1980, several hundred accessions were obtained. These accessions are maintained in a living collection at Turrialba by the Plant Genetic Resources Unit of CATIE (Engels, 1983). Chayote cannot be stored as seed for much longer than one month since it is viviparous, the seed having no dormancy and germinating within the fruit. Long-term maintenance of germplasm collections must therefore be in the form of living plants, or as tissue cultures under slow growth conditions. Germplasm collections are at present held by CATIE (Turrialba, Costa Rica), Chapingo Regional Centre (Huatusco, Vera Cruz, Mexico), INIA (Celaya, Guanajuato, Mexico) and EMBRAPA (Brasilia, Brazil). Genetic erosion of chayote in its region of indigenous cultivation is accelerating as a result of rapidly increasing commercialization and the replacement of landraces by a few improved cultivars (PROSE, 2021). The germination characteristics of *S. edule* seeds do not allow them to be preserved using simple, orthodox methods. This means that the specimens have to be preserved in field collections which require careful handling. Fortunately, there are still institutions in the world that are endeavouring to preserve this important genetic stock, at least insofar as the variation of the cultivated species is concerned. Thus, in Mexico there is the collection in the hands of the UACH in Veracruz, with around 150 specimens of cultivated types from Puebla, Veracruz, Oaxaca and Chiapas. This is the only collection which currently preserves plants of some of the most important wild relatives of the chayote, such as *S. compositum* and the wild types of S. *edule.*

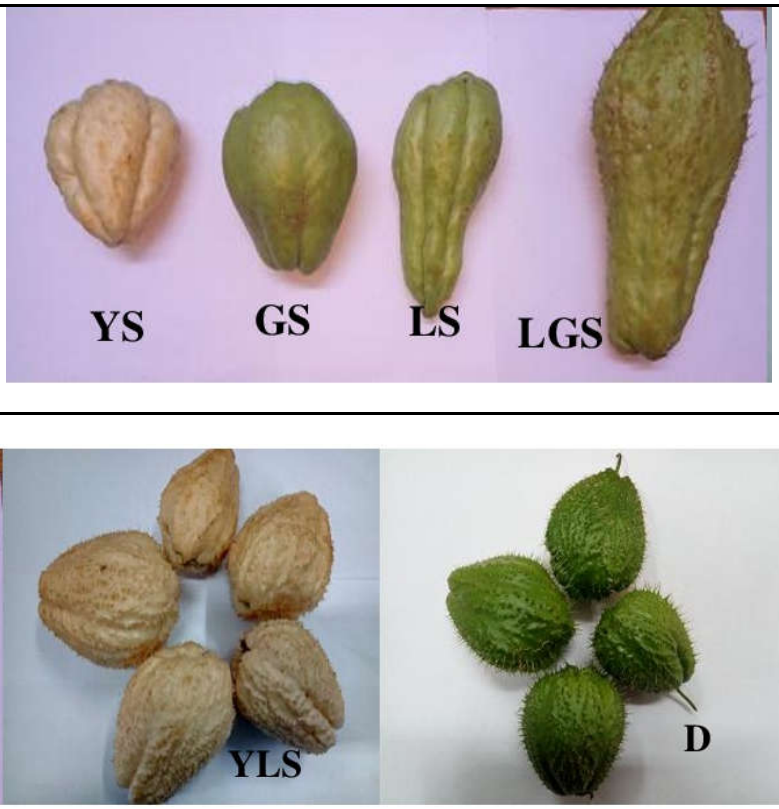


Fig. 10: **Selected varieties of chayote**

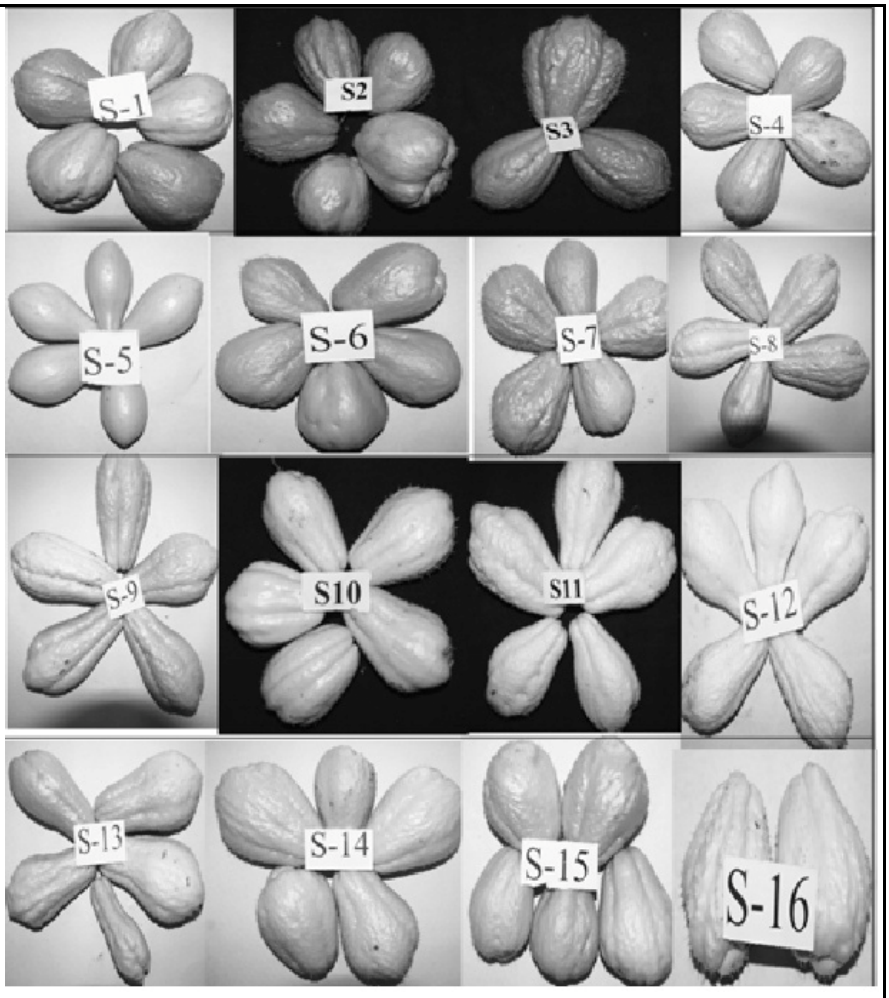


Fig. 11. Local chow –chow/chayote germplasm in Sikkim (Serial. No SI-1 to S16)

Two other institutions caring for collections of *S. edule* are, the Instituto Superior de Ciencias Agropecuarias of Nicaragua (Centro Experimental Campos Azules) and the Centro Nacional de Pesquisas de Hortalizas, EMBRAPA, Brazil (Lira Saade, 2021).

In spite of failures experienced to date in the *ex situ* conservation of *Sechium* genetic resources, interest in the subject has not been completely lost. In Costa Rica, for example, *in vitro* conservation was another method which was explored to see if there was any way it could be used as an alternative to field gene bank collections. Although the preliminary results obtained are still at experimental level, they appear to be promising. These results showed that it is possible to stop the growth of explants by submitting them to individual and / or combined treatment using osmotic stress (4-8% sucrose), low temperature (16-22 °C) or acetylsalicylate acid (10^{-9} up to 10^{-3}M). The most effective combinations, which neither damaged nor caused morphological change in the explants, were osmotic pressure at 6% sucrose and a temperature of 18 °C (Lira Saade, 1996). In 1992, a new chayote germplasm collection was set up in the Ujarras Valley in Costa Rica. This is an extensive conservation initiative based on the Costa Rican *Sechium* Germplasm Bank Project which was set up by private and governmental institutions from Costa Rica and Spain (National University of Costa Rica, Coopechayote R.L. and the Spanish International Cooperation Agency) with the support of the Costa Rican National Commission for Plant Genetic Resources.

The project has been well received and it has recently been joined by other institutions from Costa Rica such as The Association of Sustainable Agricultural Producers of the Ujarras Valley (in place of Coopechayote R.L.), the University of Costa Rica and the Ministry of Agriculture and Poultry. The main objective of this project is not just to set up a field gene bank collection of cultivated chayotes in Costa Rica, but also to form a world reservoir of genetic resources of the genus *Sechium*. One of the essential parts of the project will be to collect systematically germplasm for the entire genus (Lira Saade, 1996). Also in 1992, another chayote gene bank was set up in Nepal, as a result of a chayote breeding program funded by the US Agency for International Development USAID), and led by Moha Dutta Sharma of the Institute of Agriculture and Animal Sciences (IAAS), Tribhuvan University. The three main objectives of this project are to:

- Evaluate germplasm collected from Mexico, Costa Rica and India, in order to select plants demonstrating adaptability to annual cultivation (early maturity, compact habit), marketable qualities (excellent flavour, appropriate size and texture), and desirable agronomic characters (high yield, resistance to drought and heat);
- Develop cultural practices to optimize fruit, tuber, or shoot production in tropical, subtropical and temperate regions of Nepal;
- To disseminate the improved lines and agronomic information resulting from the project to subsistence and commercial growers, research scientists and government agencies in Nepal and abroad. Currently, 200 accessions from Mexico, Costa Rica, South India and Nepal are growing in this gene bank and they have been evaluated and selected (Sharma *et al*. 1995).

According to Sharma *et al*. (1995), the Nepalese gene bank has several advantages for long-term conservation. The most important one is that the collection contains only chayote, so there is no competition from other major crops. On the other hand, since chayote is not native to Nepal, the pests and diseases might be much rarer than in its native regions. Another advantage is the association of the gene bank with an active breeding program conducted by experienced chayote specialists and a team of other scientists (entomologists, plant pathologists and horticulturists) from Nepal research centers (Fig. 12). Conservation and greater knowledge of *S. edule* germplasm, expressed in its infra-specific variation, represents the main reservoir for future works of genetic improvement. In the decade of the eighties germplasm banks were created in different countries: Mexico, Nepal, India, and Costa Rica. It is well-known that only in the hills of Nepal, India, there is *in situ* germplasm bank of chayotes (Baral *et al*. 1994; Sharma *et al*. 1995). Two other institutions caring for collections of *S.edule* are the Instituto Superior de Ciencias Agropecuarias of Nicaragua (Experimental Center Blue Fields) and the Centro Nacional de Pesquisas de Hortalizas (EMBRAPA, Brazil); in Costa Rica, Although the nutritional value of the fruit is not high, the steady and secure production of not only fruits but also shoot tips makes chayote a locally appreciated vegetable. The edible roots diversify its use even more. Therefore, it is worthwhile to preserve as well as possible the genetic diversity in its center of origin (Engels, 1983).

BREEDING

Commercial production is limited by some disease problems. A breeding programme for fruit quality and disease resistances is needed, but, logically, private seed companies are not interested in chayote because it is viviparous. A bland cultivar is required for the industrial market and a tasty one for the table vegetable market. Further collection and evaluation of landraces in Mexico and Central America is also required (PROSE, 2021). One of the most important topics of the genetic improvement is cytology. The size of the chromosomes for *S. edule* varies from 0.7 to 1.9 um and secondary constrictions are present in two chromosomes. The number of chromosomes is 2n=28, nevertheless Sugiura (1938), Sobti and Singh (1961) have reported as 2n=24. This discrepancy has been attributed to the translocations of meroaneuploids, which consist in the formation of one chromosome from the fusion of two. *S. edule* presents a wide range of biological types or botanical varieties and *nigrum spinosum, nigrum xalapensis,* and *virens levis* are commercially cultivated, the latter, known as smooth green chayote, is the only one traded on the international market. With respect to the advances of genetic improvement, the existence of clones in Costa Rica and the use of these materials has diminished in the medium term the profitability of the crop, due to uniformity of the genetic material, which has provoked genetic erosion, that is why it is suggested to be avoided (Engels, 1983).

Genetic improvement of chayote has been used by producers anciently in an informal way; nevertheless, it was reported that in 1989 in Costa Rica an export program of genetic improvement was initiated in Valle de Ujarrás, where the characteristics to be improved were: organoleptic, resistance to pests and diseases, archetype, and yield components (number and length of stems per plant, internode length, quality, weight and number of fruits per vine). This program was carried out in different phases, beginning with collection and selection of plants, establishment of a germplasm bank, improving of the methodology to generate clones, obtaining of synthetic varieties, pure lines, hybrids, and their production in a commercial way.

Two hundred and fifty plants of commercial orchards were selected, called "mother plants", 34 of which were chosen for asexual propagation through cuttings; subsequently, they were sown in the same valley to be characterized and selected. Asexual reproduction was a basic tool in the program due to allowing for the conservation of the collections and obtaining of clones. The experimentally outstanding clones were: EY13, SA15, EY17, SA21, UJ27, UJ28, and UJ29; the experimentally obtained yields fluctuated between 56.4 and 202.5 tons per ha, whereas the outstanding synthetic varieties were: VS17, VS28, and VS29, characterized by having good adaptability, yield, and in some cases, excellent fruit quality. The lines were obtained from two self-fertilizations, without reporting hybrids. Based on the experience of previous improvement, countries like Honduras, Nicaragua, and Panama are receiving biological material from Costa Rica in order to formally enter the international market (Brenes-Hine, 2002). Newstrom (1986) proposed the development of two different breeding lines: the first focused in producing unflavoured fruits for industrial purposes, and the other on producing tasty fruits for vegetable use. On the other hand, as an alternative to the development, improvement and production of new phenotypes, it was also proposed to collect and evaluate a comprehensive sample of these phenotypes in Mexico and Central America.

Fig. 12. Plant Genetic Resource: Variability in *Sechium edule* for fruit shape, size and color

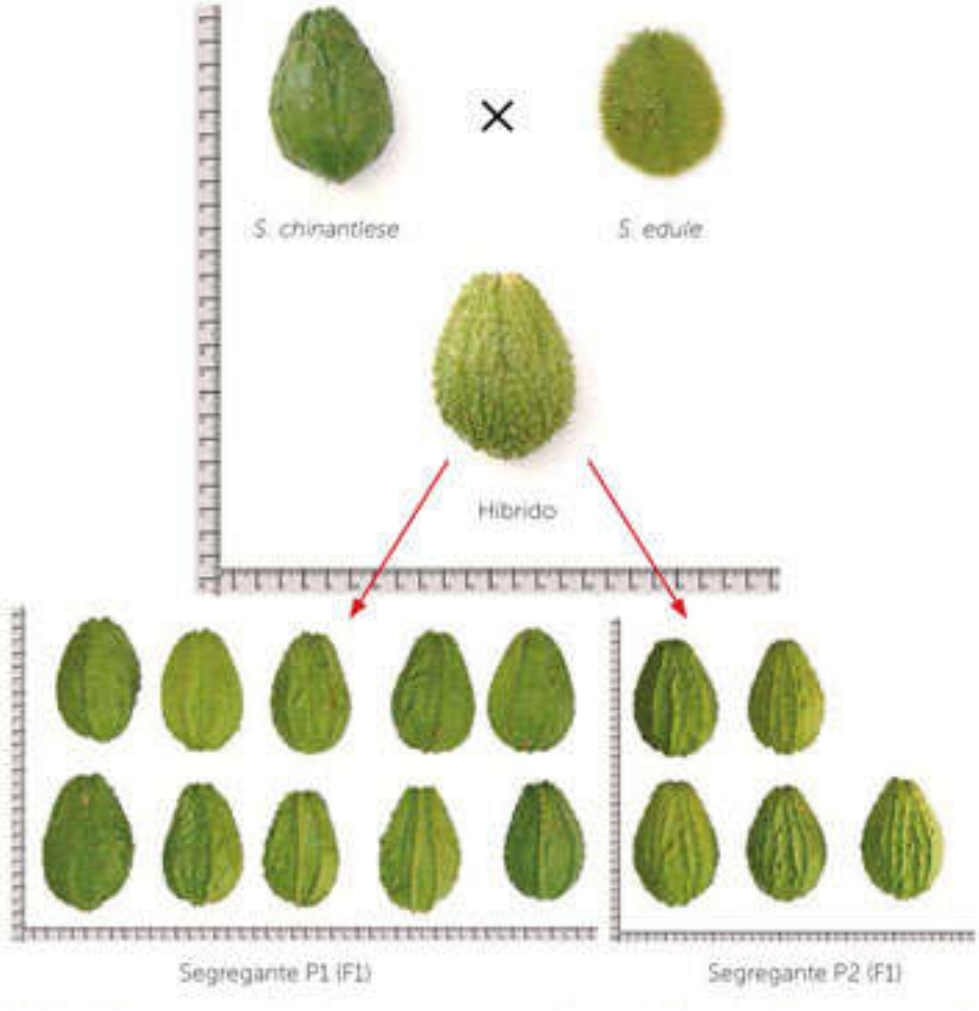


Fig. 13. *S. chinantlense x S. edule*; F1 Hybrid; Segregate P1 (F1), & Segregate P2 (F1)

An additional point of view to this respect has been pointed out by Aung *et al*. (1990), who suggested the possibility of selecting chayotes on the basis of root characters such as length and starch content, which might be related to different types of chayotes as well as to their growing conditions (Lira Saade, 1996).

Inter-Specific and Infra-Specific Hybridization: No program of hybridization between wild and cultivated varieties of chayote has yet been undertaken, but because the varieties are so closely related, hybridization is potentially successful and could result in disease- and pest-resistant varieties (Evan Gillespie, 2021). The origin of variation is addressed from the perspective of the domestication process and the influence of the environment, cultures and production systems as entities that generate variants in chayote (*Sechium edule* (Jacq.) Sw), whose morphological variation is dynamic and evolutionary process is continuous; and this is attributed both to the consumer and to climate change, the pressure that generates variants of anthropocentric interest and adaptation to new environments or conditions. A series of inter-specific crosses were carried out between *S. edule*, and the wild types: *S. compositum* and *S. chinantlense*, showing that the morphological variation in chayote is dynamic and its evolutionary process is continuous, proof of this is that the wild, semi-domesticated and domesticated variants coexist and are crossbreeding naturally, thus promoting new variants (Fig. 13) (Avendaño-Arrazate *et al*., 2017). Fruits of the Perla Negra cultivar, whose genetic lineage comes from a process of improvement of biological variants of the varietal group *Sechium edule* var. *nigrum minor*, were crossed with the group *Sechium edule* var. *amarus silvestrys*. Once the cultivar was stabilized, the fruits were collected. The presence of the terpene and flavonoid groups in the methanolic extract of the Perla Negra cultivar was confirmed. The Perla Negra cultivar inherited biological activity from its parents, which was likely reinforced by epigenetic changes. The compounds identified in the fractions with biological activity were Cucurbitacins D, E, B, and I for the terpene fractions and Rutin, Phlorizidin, Myricetin, Quercetin, Naringenin, Phloretin, Apigenin, and Galangin for the flavonoid fractions. Therefore, the antiproliferative effect shown by the Perla Negra cultivar opens the possibility of being investigated as a possible anticancer agent (Salazar-Aguilar *et al*., 2017). In an effort to put the infraspecific (crossing between subspecies) complex presented in *S. edule* in order, Lira *et al*. (1999) proposed a new taxonomic arrangement, grouping the cultivated types in the subspecies *S. edule* ssp. *edule* and the wild one as *S. edule* ssp. *silvestrys*. These authors based this separation on the morphological and chromosomal differences through identification of karyotypes in pollen grains. Regrettably, in this proposal it was not indicated which cultivated type or types were included in the analysis, infraspecific hybrids, and products of spontaneous crossings among chayotes, with different phenotypes and degrees of domestication, possibly being involved, since there is no high genetic differentiation between anthesis of the pistillated flower and staminated flower that provoke hybridization among the different types of chayote (Gamboa 2005).

Commercial Varieties of Chayote: There are different varieties grown according to the regions: the most common variety gives a pale green fruit in the shape of a pear; In Guatemala and Honduras, a variety of white color on the inside and cream on the outside is known as Perulero.

Its consistency is softer and juicier than the traditional green chayote; there is also a darker, more spiny variety (La Ferme De Léo. 2021). The popular culture of the Central region of Veracruz, has classified the Chayote grown into three large groups: white, green and spiny, emphasizing that the first two are generally smooth. Botanically, the chayote fruit is a berry, with various shapes (obovate or piriform) and sizes, with variable presence of depressions longitudinal popularly called "Furrows" (Flores, 1989). The color of the epidermis can be white, green light or dark and bright; in addition to be glabrous or finely pubescent with a variable number of spines and from a single seed (Lira-Saade, 1996; Cadena-Iñiguez *et al*., 2008). Evan Gillespie (2021) has mentioned 4 common and popular varieties of chayote as follows:

Chayote de Caballo: Chayote de caballo (*Sechium compositum*) is closely related to the common chayote, and it grows in locations similar to the habitat of wild varieties of chayote. Its fruit is usually ridged and prickly, but as with common chayote, the fruit can vary and is sometimes smooth. The fruit of this species can be stored for long periods of time; hybridization with common chayote, again, hasn't been attempted, but the longevity of its fruit makes chayote de caballo an attractive candidate for cross-breeding programs. Closely related to the common chayote, the skin is usually prickly, but can be smooth as well. This variety stores for a long time.

Chayotillo: Chayotillo (*Sechium hintonii*) is another species that is closely related to common chayote. Very little is known about this type of chayote, but it is a potential source of disease resistance for cultivated chayote via cross-breeding. Its genetic structure differs from that of common chayote, however, and hybridization between the species may not be possible. This is a rare variety that has some disease resistance. It looks similar to the common variety and can be smooth or prickly.

Cabeza de Chango: Cabeza de chango (*Sechium chinantlense*), like chayotillo, is an uncommon species; it grows only in a small area of Oaxaca in Mexico. This type of chayote seems to be closely related to chayote de caballo, but it seems to be genetically incompatible with the common chayote. Consequently, hybridization with the goal of transferring this species' tolerance of high humidity to cultivated chayote is unlikely to be successful. More common to Mexico, this variety survives high humidity

Perulero: Perulero (*Sechium edule*) is light yellow to white in color. Originally grown in Guatemala, it is now grown across North America, as well.

The primary varieties grown in the United States are Florida Green and Monticello White. Imported varieties are often prickly or hairy with grooves, but chayote grown in Florida typically has smooth skin (PBS, 2021). There is in the American market a wide range of varieties of chayote, as a result of the hybridization and selection of different species. Even the scientists themselves find much difficulty in systematizing. However, a practical classification, among many, carried out by the producers of this vegetable, classify them as: 1) Tree bark pale green; 2) Fruits with dark green rind; 3) Fruits with whitish bark; 4) Fruits pear shaped; 5) Fruits rounded; 6) Fruits with spines; 7) Fruit without spines; 8) Fruits rough; and 9) Fruit smooth (Anon., 2021). In India, there is no variety of chayote yet released. The few varieties released outside India are Florida Green and Monticello White. The different strains or commercial varieties of chayote can be determined in fruit shape, presence and density of spines, and texture of the skin. Fruit shapes are globular, globular to flat, elongated and long elongated with small, medium or large sizes. Fruits either have no spines, sparse, medium or dense. Likewise, fruits may have smooth or rough skin, and with or without ridges. These Chayote Strains are (Tibor Ra, 2017; Magsasaka, 2021):

- **BPI Ch1-** fruits are big, elongated with intermediate furrows, dense spines at the entire fruit and with rough skin.
- **BPI Ch2-** fruits are medium, globular, little bit flat with intermediate furrows and sparse spines at the apex and bottom, and with rough skin.
- **BPI Ch3-** fruits are medium, globular, little bit flat with shallow furrows, sparse spines at the apex and bottom with smooth skin.
- **BPI Ch4-** big fruits, elongated to long-elongated with shallow furrows, none to sparse spines at the bottom with smooth skin.
- **BPI Ch5-** medium fruits, elongated with shallow furrows, sparse spines at the apex and bottom with rough skin.
- **BPI Ch6-** medium fruits, globular, little bit flat with shallow furrows but dense spines at the entire fruit and with rough skin.
- **BPI Ch7-** fruits are medium, elongated with shallow furrows, no spines with smooth skin.
- **BPI Ch8-** medium fruits, globular to elongated with intermediate furrows, sparse spines at the apex and bottom with rough skin.

- **BPI Ch9-** small fruits, elongated with intermediate furrows, sparse spines at the entire fruit and with rough skin.
- **BPI Ch10-** small fruits, elongated with intermediate furrows, none to sparse spines at the apex and bottom with smooth skin.
- **BPI Ch 11-** this strain is the latest introduction from Australia. It has medium fruits, globular with shallow furrows but dense and firm spines at the entire fruit, and with dark green and rough skin.

Efforts made at CATIE (Costa Rica) to describe cultivars on the basis of fruit characteristics proved to be of limited relevance because of the extraordinary variability, with continuous variation in almost all characters, including size (4–27 cm long), weight (60–1200 g), colour (continuous range from white to dark green), shape (pear-shaped, ovoid, flattened globular), fruit-wall features (spines, lenticels, grooves and ridges), flavour and texture. In Ghana a type called 'Ivory White' is grown. Bland cultivars are required for the industrial market and tasty ones for the table-vegetable market (Engels, 2021). Wild types of chayote grow in ravines, near rivers and streams, and in other damp areas in Mesoamerica. They are structurally identical to cultivated varieties of the plant, but they are typically more vigorous growers and have larger leaves, flowers and fruit. The fruit of some wild varieties also differ considerably from the fruit of cultivated plants; wild fruit may be prickly, dark green and bitter, for example (Evan Gillespie, 2021).

Areas of Production and Consumption: Chayote is widely cultivated throughout the Americas where, as mentioned above, it was cultivated by the Aztecs long before the Spanish arrived. It is thought that its presence in the northern part of Central America is the result of Aztec and Mayan influence in this region, and it is known that the Spanish introduced it into Costa Rica (Bukasov, 1981). Currently, chayote is cultivated in some parts of the United States such as California, Louisiana and Southern Florida (Newstrom 1991), and in the Old World it is cultivated at least in India (Chakravarty 1990), Nepal (Sharma *et al*. 1995), China, Papua New Guinea, Southeast Asia, Taiwan (Aung *et al*. 1990; Engels and Jeffrey 1993) and some European countries such as Italy and ex-Yugoslavia (Lira Saade, 1996). In addition to Costa Rica, followed by Guatemala and Mexico, which are the first chayotes producing countries around the world, the Dominican Republic, Brazil and Peru are also producing countries in Latin America. Chayote is also grown, though in smaller quantities, in other parts of the world, such as India and China in Asia and Italy in Europe. In the United States it is grown in warmer southern areas (mainly California and Florida) but most of the chayote consumed in this country comes from exports from American countries, Costa Rica remains the fundamental one (Anon., 2021). In India, chow-chow is widely grown in Madurai and Nilgiri district of Tamil Nadu, Karnataka, West Bengal, Mandi district of Himachal Pradesh and entire north-eastern hills region. Mizoram is the leading state with an estimated area of 845 ha and 10,985 metric tonnes production. Though, it is a native of Mexico but considerable diversity is found in NEH region particularly, Meghalaya, Mizoram and Sikkim (Rai *et al*., 2005).

Production and International Trade: In quantity chayote is one of the leading market vegetables in Central and South America and in South-East Asia, but its commercial value is low. There is considerable international trade, e.g. for export to Europe and the United States. In tropical Africa, it is locally of some importance, e.g. in Sierra Leone, Ghana, Malawi, Réunion and Mauritius, but no statistical data on production or trade are available (Engels and Jeffrey,1993). Chayote is the fifth most important commercial vegetable in Brazil where 170 000 t were produced in 1978. Mexico produced ca. 12 000 t in 1978. Costa Rica produced less but is the leading exporter: ca. 4600 t in 1982, mainly to the United States, valued at US$ 1.5 million. It is important in all South-East Asian countries as a cheap, easy-to-produce vegetable both for home consumption and for city markets. No statistics are available for South-East Asia; chayote data are usually combined with all other gourds and pumpkins. In the Indonesian highlands it is, in quantity, the most important vegetable produced (PROSE, 2021).

USES

Chayote is mainly grown for its immature or almost mature fruits, harvested before enlargement of the seed, and eaten as a cooked vegetable. In tropical America and Asia also young, small fruits and young leaves and shoots are used as vegetables, whereas the tuberous roots are consumed especially in Central America. In Jamaica the seeds are eaten fried or roasted. In the Mascarene Islands chayote shoots are an important component of local dishes, besides the fruits. The fruits vary in flavour from bland or starchy to sweetish, depending on the cultivar. Fruits of bland cultivars are used industrially as food filler for pastes and sauces. Because of its low energy value, chayote is gaining importance as a dietary food in hospitals and nursing homes. Chayote fruits are also considered good baby food. The seed is nutlike in flavour and a source of protein. Fruits, shoots and tubers are used as fodder for pigs, poultry and cattle. In the past, fibres from the stem have been used to make baskets and hats and – as reported from Ghana – as binding material in the construction of mud houses. The tubers are a potent diuretic and are also applied for pulmonary ailments and relief of intestinal inflammation (Engels and Jeffrey,1993). Chayote is grown mainly for its: 1). fruits, and 2). shoots. The fruit has a very important role as food supply in the regional and national levels especially during calamities. Likewise, fruits can be processed into wines, pies, kimchi, pickles and candies in the locality but in a backyard scale. The vines can also be manufactured into bags and hats for its flexibility and strength while the infusion of leaves can dissolve kidney stones and assist in the treatment of arteriosclerosis and hypertension **(**Tibor Ra, 2017**).** The chayote is one of the few plants all parts of which are eaten. It is mostly cooked. The shell can be cooked and, if it is not too tough, also eaten. Because of its neutral taste, chayote can be used as a side dish. The core is sometimes served separately as a delicacy. The fruit can also be eaten raw, grilled or fried. The root of the chayote is also considered a specialty.

The young leaves are also edible and can be added to soups or cooked like spinach. Sweets are also made from the chayote, such as candied chayote or chayote compote. The chayote cannot be stored for a long period of time because it germinates very quickly. In the medicine In traditional herbal medicine, the leaves are used to prepare a tea to relieve kidney stones. In the craft Hats are made from the dried stems on the French island of Réunion (Wikipedia, 2022a). The chayote fruit is mostly used cooked. When cooked, chayote is usually handled like summer squash; it is generally lightly cooked to retain the crispy consistency. Raw chayote may be added to salads or salsas, most often marinated ith lemon or lime juice, but is often regarded as unpalatable and tough in texture. Whether raw or cooked, chayote is a good source of vitamin C. Although most people are familiar only with the fruit as being edible, the root, stem, seeds and leaves are edible as well. The tubers of the plant are eaten like potatoes and other root vegetables, while the shoots and leaves are often consumed in salads and stir fries, especially in Asia (Wikipedia, 2022).

NUTRITIONAL VALUE

The edible portion of chayote fruits is about 86%. The average nutritional composition of fruits per 100 g edible portion is: water 94 g, energy 80 kJ (19 kcal), protein 0.8 g, fat 0.1 g, carbohydrate 4.5 g, dietary fibre 1.7 g, Ca 17 mg, Mg 12 mg, P 18 mg, Fe 0.3 mg, Zn 0.7 mg, vitamin A 56 IU, thiamin 0.03 mg, riboflavin 0.03 mg, niacin 0.47 mg, folate 93 µg, ascorbic acid 7.7 mg. The young leaves and shoots contain per 100 g: water 90 g, energy 251 kJ (60 kcal), protein 4.0 g, fat 0.4 g, carbohydrate 4.7 g, fibre 1.2 g, Ca 58 mg, 108 mg, Fe 2.5 mg, vitamin A 615 µg, thiamin 0.08 mg, riboflavin 0.18 mg, niacin 1.1 mg, ascorbic acid 16 mg. The tuberous roots contain per 100 g edible portion (73% of total): water 80 g, energy 331 kJ (79 kcal), protein 2.0 g, fat 0.2 g, carbohydrate 17.8 g, fibre 0.4 g, Ca 7 mg, P 34 mg, Fe 0.8 mg, thiamin 0.05 mg, riboflavin 0.03 mg, niacin 0.9 mg, ascorbic acid 19 mg. Extracts of *Sechium edule* showed antimutagenic activity in a Salmonella typhimurium assay. The ribosome-inactivating protein sechiumin was purified from the seeds.

It has been suggested that this compound could be used for the preparation of immunotoxin as a potential cancer chemotherapeutic agent. Fruit extracts exhibited hypotensive effect in tests with rats. Chayote may cause hypokalaemia in pregnancy (Engels and Jeffrey, 1993). The edible parts of the crop have low fiber, protein and vitamin contents than other plants. However, calories and carbohydrate contents are high, chiefly in the young stems, roots and seeds, while the micronutrients and macronutrients supplied by the fruit are adequate **(**Tibor Ra, 2017**).** The chayote mainly contains water and therefore has a very low physiological calorific value. It is high in amino acids, vitamin C, and the minerals potassium, calcium, and iron. The fruit contains about 2% protein and very little starch, so the protein to starch ratio in the chayote is significantly higher compared to the similarly used potato. The stems contain a lot of vitamin A (Wikipedia, 2022a). Chayote is a nutritious food that contains several vitamins and minerals such as folate, vitamin C, and is an excellent source of fiber. The fruit is versatile, easy to use, and provides a boost of healthy nutrition along with an interesting flavor and texture. Chayote Nutrition Facts (for 1 cup (132g) of raw 1" chayote pieces).

Calories: 25, Fat: 0.2 g, Sodium: 2.6 mg, Carbohydrates: 6 g, Fiber: 2.2 g, Sugars: 2.2 g, Protein: 1.1 g, Folate: 122.8 mcg and Vitamin C: 10.2 mg (Frey, 2022).

Carbs: Most of the calories in chayote come from carbohydrates. There are a total of 6 grams of carbs in a one-cup serving and over two grams of healthy fiber. You'll also get a small amount of starch and just over 2 grams of naturally occurring sugar. Chayote is a low-glycemic food. The glycemic load of a single cup serving is estimated to range between one and two, regardless of whether it is cooked or raw. A low glycemic food is digested and metabolized slowly and therefore raises blood sugar at a slower rate than foods with higher glycemic indexes (Frey, 2022).

Fats: There is less than one gram of fat in a cup of raw chayote and the very small amount is polyunsaturated. Polyunsaturated fats come from plant sources and are considered to be a healthier source of fat than saturated fat. Health experts advise replacing saturated fats with polyunsaturated fats when possible to boost heart health and reduce the risk of chronic diseases. If chayote is prepared with fats (as many recipes suggest), the fat content will increase, and if butter or another animal fat is used in the preparation, you'll also increase your intake of saturated fat (Frey, 2022).

Protein: Chayote is not a significant source of protein, providing just over one gram per serving (Frey, 2022).

Vitamins and Minerals: Chayote provides a number of health-boosting vitamins and minerals. A single serving of chayote provides 123 micrograms of folate, or 31% of the recommended daily intake. You'll also get over 10 grams, or about 17% of your recommended intake, of vitamin C. Other vitamins in chayote include vitamin K, vitamin B6, pantothenic acid, thiamin, riboflavin, niacin, and vitamin E. Minerals in chayote include manganese, copper, zinc, potassium, and magnesium. There is also a small amount of calcium, iron, and phosphorus in chayote (Frey, 2022).

Calories: One cup (132g) of raw chayote provides 25 calories. Chayote is a high-volume food containing 95% water and few calories. Carbohydrate is the main calorie source with 5%, followed by 1% from protein and 0% from fat (Frey, 2022).

HEALTH BENEFITS

Fiber: Like many other types of squash, chayote is a good source of fiber. Fiber helps you to feel full and satisfied after eating so that it is easier to maintain a healthy weight. Fiber is also an important nutrient for a healthy digestive system. Studies have established the use of chayote and chayote roots as a quality source of both starch and fiber (Frey, 2022).

Source of polyphenols: A 2019 review published in *Food Chemistry* investigated chayote's nutritional, phytochemical, and pharmacological properties. Researchers determined that the fruit provides a broad spectrum of polyphenols including phenolic acids, tannins, and stilbenes. Polyphenols are known to have antiallergic, anti-inflammatory, antiviral, anticarcinogenic, and hypoglycemic effects in the body.

Researchers also note that clinical and epidemiological studies have established an inverse relationship between the consumption of chayote and the prevalence of chronic diseases. However, the study authors noted that more research is needed to fully understand the medicinal and nutritional potential of chayote and chayote byproducts.

May fight inflammation: Another 2019 study investigated the potential benefits of chayote consumption in older adults. The research published in the journal *Antioxidants* concluded that consumption of dried chayote may provide antioxidant and anti-inflammatory effects in older adults with metabolic syndrome (Frey, 2022).

May reduce blood pressure: There is some evidence that consuming the juice of chayote may reduce blood pressure in hypertensive adults.[6] Researchers believe this is due to the potassium content in chayote which is 365 milligrams per 100 grams of fruit. More research is needed (Frey, 2022).

May reduce blood glucose: A study on the effects of chayote on blood sugar in pre-diabetic people showed that blood glucose was significantly reduced when provided with chayote.[7] This was a single study that needs to be reproduced to draw definitive conclusions (Frey, 2022).

CULTIVATION

Like other members of the gourd family, chayote has a sprawling habit, and requires sufficient room. The roots are also highly susceptible to rot, especially in containers, and the plant in general is finicky to grow. However, in Australia and New Zealand it is an easily grown yard or garden plant, set on a chicken wire support or strung against a fence. In Trinidad and Tobago, it is grown in the mountainous areas strung from wire lines. In Latin America, chayote is widely cultivated. Depending on variety and region, yield reaches from 10 to 115 t/ha (Wikipedia, 2022).

Direct germination from the fruit. The chayote is mainly grown as a vegetable. For this purpose, a framework is usually created on which the plant can climb. The scaffolding is so high that you can move under it to harvest. The fruit is then harvested from beneath the foliage. The chayote is a popular plant in permaculture as it provides a high yield for little effort.

For planting, it only has to be laid on the ground, the fruits do not have to be dug up, all parts of the plant are edible and it grows fruitfully for several years without care. It also provides shade for semi-shade-loving vegetables, which can be grown under its canopy if a trellis is built to allow for spacing between each plant. A plant can bear up to 200-300 fruits. Commercial plantings achieve yields per hectare of up to about 28 tons per year. The tropical plant is also popular in the temperate zone as a garden vegetable such as squash (Wikipedia, 2022a).

PROSPECTS

Chayote is a multipurpose, high-yielding and easy-to-produce vegetable, suitable for home gardens and market production, meriting promotion in tropical India. Because of its low energy value, chayote is gaining importance as a dietary food in hospitals and nursing homes. Its use as a food filler for pastes seems to be promising (Engels and Jeffrey, 1993).

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