1 Origin, History, Composition and Processing

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1.1 Origin and History

Carica papaya belongs to the family *Caricaceae* which consists of 34 species (and one formally named hybrid) and six genera (*Carica*, *Jacaratia*, *Horovitzia*, *Jarilla*, *Vasconcellea* and *Cylicomorpha*) (Carvalho and Renner, 2014). It has been suggested that the genus *Carica* was separated from its sister clade (*Vasconcellea* and *Jacaratia*) 25 million years ago, and since then it has had its own lineage (Carvalho and Renner, 2012; Pérez-Sarabia *et al*., 2017). The closest relatives to *C. papaya* are *Jarilla* and *Horovitzia*, both of which have a Mexican origin (Carvalho and Renner, 2014). The largest genus in the family *Vasconcellea* comprises 20 species and a naturally occurring hybrid, *Vasconcellea* × *heilbornii* (Badillo, 2000; Van Droogenbroeck *et al*., 2002). The centre of species diversity of the *Vasconcellea* genus is in north-western South America, especially Ecuador, Colombia and Peru. The genus *Jacaratia* comprises seven species, and is widespread in the lowlands of the Neotropics with only one species, *Jacaratia chocoensis* that is found at altitudes up to 1300 m in the Andes. *Jarilla* comprises three herbaceous species with perennial tubers that resprout annually during the wet season (Diaz-Luna and Lomeli-Sencion, 1992).

The first botanic record of *C. papaya* was made in 1753 by Linneaus (the Herbarium of the Missouri Botanical Garden – Tropicos.org, 2019) but this does not include historical botanic records deposited in local or national herbaria (Fernández *et al*., 2012). *C. papaya* L. is considered native to southern Mexico and Central America (Northern Mesoamerica) (Carvalho and Renner, 2012, 2014; Fuentes and Santamaria, 2014; Chávez-Pesqueira and Nuñez-Farfán, 2016). Wild papaya plants can be observed in populations distributed in several localities of the Mayan region (Yucatán and south of Mexico). Wild plants can be observed on the roadside and especially on the edges of roads and rural roads (Fig. 1.1). Wild papaya plants, native or non-domesticated, can be observed in ruderal vegetation (roadsides), and in successional vegetation or secondary vegetation. *C. papaya* wild plants are found with other plant species typical of the vegetation of the medium subperennifolia forest, subcaducifolia and deciduous or caducifolia low forest (dry forest) or secondary vegetation (G. Fuentes and J.M. Santamaria, personal observations; Flora de la Península de Yucatán – CICY, 2010). The wild populations

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Fig. 1.1. Wild populations of *Carica papaya* found at the Yucatán Peninsula. The picture shows the vegetation found in its natural environment. (A) male plant (with flowers) and (B) female plant (with a lot of fruits) (both taken in late February 2019). (C) plant with fruits and leaves in low tropical deciduous forest and (D) plants in the month of May.

that can be found in Yucatán normally have three or four individuals, but populations with up to 40 individuals can also be found. Wild populations of *C. papaya* can survive in adverse environments such as burning habitats, or in environments with temperatures above 40°C, or even in environments with prolonged drought (April and May in Yucatán, Mexico) (Alcocer, 2013; Girón, 2015; Chávez-Pesqueira and Nuñez-Farfán, 2016). In the dry season when other species such as trees and shrubs can be found without leaves, the wild papaya plants are found with leaves and flowers, and most of the papaya plants have a great number of fruits that survive until the rainy season in late June.

Interestingly, wild papaya plants have some characteristics that differ from those of papaya plants found in backyards of Yucatán towns. Wild plants cross pollinate, generating a very particular group with characteristics from wild and cultivated plants (feral populations). Semi-wild papaya plants can be found in backyards of many houses in the Mayan community. However, older people in the community who have traditional knowledge suggest a loss of traditional knowledge about the reproduction and sexuality of this species. This loss has implications for the conservation of the germplasm of this species (Moo, 2015). Two characteristics of these fruits are: (i) fruits of larger size than those from wild plants; and (ii) the fact that it is possible to find fruits that are borne on hermaphrodite plants. On the contrary in wild *C. papaya* populations, fruits are rounded and small and only female and male plants are found.

An isozyme analysis of numerous papaya accessions, while revealing limited genetic diversity, showed that wild papaya plants from Yucatán, Belize, Guatemala and Honduras were more related to each other than to domesticated plants from the same region (Morshidi *et al*., 1995).

The origin of *C. papaya* is in the north of Mesoamerica and the later domestication and cultivation also involved the adaptation of wild papaya to climate change over time (Zizumbo-Villarreal *et al*., 2014). The domestication in many forms by different groups in different environments expanded its genetic diversity. *C. papaya* is found in different environments, records of papaya plants (herbarium data) can be found from 1000 to 1981 m above sea level (masl), from the Mexican states of Chiapas, Guerrero, Oaxaca and Veracruz (3% of records). However, a large number of records are located at low elevations, between 0 and 200 masl (41% of records). The states with a high number of records (herbarium samples) are Veracruz (21%), Chiapas (20%), Oaxaca (18%), Campeche (9%), Tabasco (6%), Quintana Roo (6%) and Yucatán (5%) (Herbario Nacional de México, UNAM, 2019). On the other hand, it is interesting that wild *C. papaya* plants are dioecious (with female and male plants), and pollen must be transported by a vector and/or by air to carry out pollination. There are a lot of male plants (Y) in the Yucatán vegetation. In Yucatán it is possible to find wild *C. papaya* plants bearing very small rounded fruits (2–3 cm long).

Wild papaya plants should be a great reservoir of potential genes that may have been 'lost' (not expressed or repressed) during the domestication process. These wild plants are in contact with adverse physical environmental conditions (abiotic agents) and with other animals (biotic agents), and their genetic base is broadened in order to survive these conditions (Fig. 1.2). By having the genome of a commercial papaya sequenced (Ming *et al*., 2008), it is very interesting to know the genome of a wild papaya.

Even if 100% of national requirements are currently satisfied with domestic production in relation to the varieties or types that are grown, one of the great challenges has been to diversify the species (i.e. to generate varieties or types of papaya that can already either meet demands or offer products for particular needs). For example, fruit with a high content of lycopene versus a fruit with a high content of β-carotene or fruits that are about the size of a mango that could be consumed individually by a single person or a fruit that can be used as vector of vaccines.

C. papaya is thus one of the genetic resources provided by Mexico and Central America to the world. The papaya (pitzáhuac or chichihualtzapotl in Nahuatl), that can be translated as 'zapotenodriza' in Spanish, is a fruit native to Mexico and Central America (Mesoameric zone) that has been used since the pre-Hispanic period (Vargas, 2014). The Spanish distributed this fruit around the world (particularly in Asia and Europe) since the 16th century, so that it is now known in most places around the world (González and del Amo, 2012).

In pre-Hispanic México, the main plants included in the Mesoamerican diet were: nopales, quelites, sweet potatoes, algae, mushrooms, tamarindo, capulines, tejocotes, jicama, chirimoya, guanabana, mesquite, sunflower, guava, mamey, papaya, jicama, pineapple, banana, zapote, as well as grasshoppers and maguey worms, among others (Giordano, 2018). *C. papaya* is a fruit associated with the traditional agriculture of the lowland Maya that currently have wild populations or wild ancestors within the Mayan area (Colunga-García and Zizumbo-Villareal, 2004; González and del Amo, 2012).

1.2 Composition and Uses

It seems that papaya is a crop with a lot of potential as many countries are interested

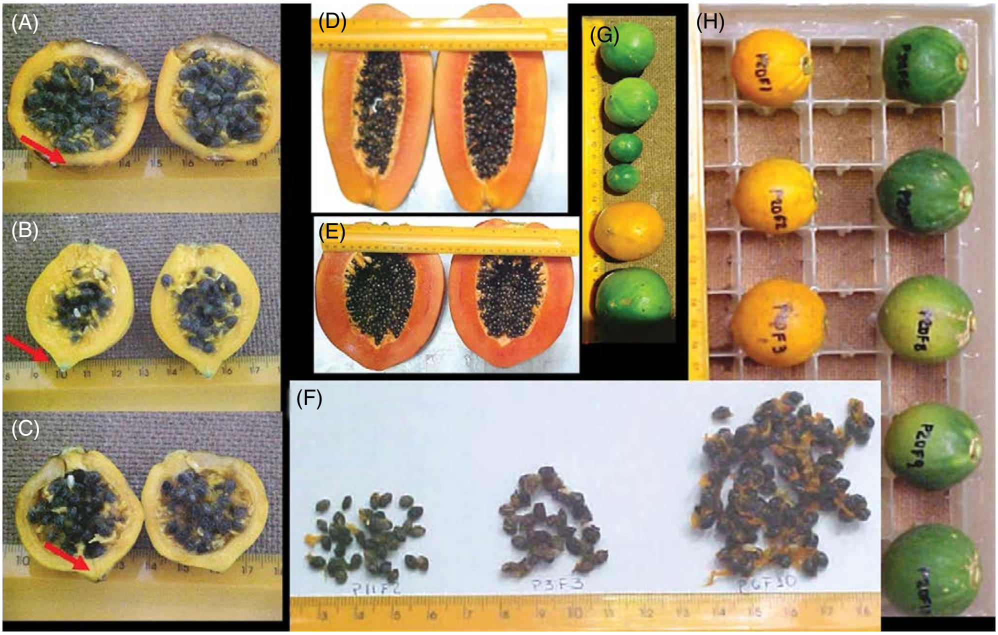

Fig. 1.2. Fruits (A, B, C) and seeds (F) from wild *C. papaya* plants collected in Yucatán. Note the morphological (and probably genetic) diversity of seed sizes and fruit shapes and sizes found at different locations in the Yucatán Peninsula (G, H). The red arrows show the diversity of fruit shapes. As a reference, fruits from hermaphrodite plants and female plants from commercial cultivated plants (D, E) are also shown.

in consuming papaya fruit. This interest may increase as the knowledge of its great benefits for nutrition and health may increase. For example, papaya is a relative low-price source of lycopene, β-carotene, polyphenols, many vitamins and fibre. Thus, it is likely that papaya will be consumed in future years not only for its flavour, but also for its nutritional and nutraceutical properties.

Papaya is a rich source of many nutrients and vitamins. The fruit is an excellent source of vitamins such as vitamin C, and is rich in folic acid (FDC, 2020). The fruit also contains a relatively high content of dietary fibre (Desjardins, 2019). The ripe fruit content is about 8% sugar, mostly in the form of glucose, fructose and sucrose. In ripe fruits, sucrose is the predominant sugar (Selvaraj *et al.*, 1982). Ripe fruit is rich in vitamin C at levels which are close to those found in orange (FDC, 2020) and quite comparable to mango and strawberry (Septembre-Malaterre *et al.*, 2016). Papaya contains high levels of minerals such as calcium, potassium, phosphorus and iron (Table 1.1). The fruit is also rich in protein (0.4–1.1 g 100 g^{-1} fresh weight (FW)) compared with other tropical fruits (Desjardins, 2019). These proteins are essentially cysteine-type proteases, which have long been used by Mayans for medicinal purposes (Perez, 2009). Non-volatile organic acids form the major portion (about 80–90%) of total acidity in fruits. Citric and malic are the predominant acids, but the presence of tartaric, malonic, fumaric and succinic acids was also noted (Chittiraichelvan and Shanmugavelu, 1978; Selvaraj *et al.*, 1982).

The fruit contain polyphenols, provitamin A carotenoids and glucosinolates known for their antioxidant action (Desjardins, 2019). In terms of extractable polyphenol, papaya contains essentially glycosides of hydroxycinnamic acids like coumaric acid, ferulic acid, caffeoyl-hexosides, protocatechuic-hexosides and some flavonols (Gayosso-Garcia Sancho *et al.*, 2011; Calvache *et al.*, 2016). Isorhamnetin, rutin, quercetin and myricetin are the main flavonols found in papaya (Rivera-Pastrana *et al.*, 2010).

Table 1.1. Nutritional composition of raw papaya fruit. From FDC, 2020.

Nutrient	Amount per 100 g FW[a]
Protein (g)	0.47
Total lipid (fat) (g)	0.26
Energy (kcal)	43.0
Carbohydrate (g)	10.82
Dietary fibre (g)	1.7
Minerals	
Calcium (mg)	20.0
Iron (mg)	0.25
Phosphorus (mg)	10.0
Potassium (mg)	182.0
Magnesium (mg)	21.0
Vitamins	
Thiamine (mg)	0.023
Riboflavin (mg)	0.027
Niacin (mg)	0.357
Vitamin C (mg)	60.9
Folate (µg)	37.0
Vitamin A (µg)	47.0

[a]FW, Fresh weight.

The flesh colour of papaya, red or yellow, is due to carotenoids. The red-fleshed papaya contains lycopene, β-cryptoxanthin, β-carotene-5-6-epoxide and zeta-carotene (Chandrika *et al*., 2003). Red-pulped papaya accumulated more lycopene, with contents reaching as much as 3000 µg 100 g^{-1} FW. Red-pulped genotypes show low contents of yellow pigments, such as β-cryptoxanthin, zeaxanthin and violaxanthin (Chan-León *et al*., 2017). β-Carotene of papayas is approximately three times more bioavailable than that of carrots and tomatoes (Schweiggert *et al*., 2019). An increased bioavailability of lycopene from red-coloured papaya could be explained by the fact that lycopene crystals in papaya were smaller when compared with those found in tomato (Schweiggert *et al*., 2014). Papaya is therefore a valuable source of lycopene and provitamin A carotenoids, and it could be used to reduce the incidence of vitamin A deficiency, in particular in developing countries (Desjardins, 2019; Schweiggert *et al*., 2019).

Papaya also contains glucotropaeolin, a glucosinolate that upon hydrolysis by the enzyme myrosinase produces benzyl isothiocyanate (Spencer and Seigler, 1984). The peel of papaya contained as much as 125 mg 100 g^{-1} FW glucotropaeolin, an amount equivalent to the consumption of 100 g fresh broccoli containing glucoraphanin (Rossetto *et al*., 2008). Papaya is a good source of serotonin (0.99 mg 100 g^{-1} FW), which has been associated with enabling the gut to mediate reflex activity and also decreasing the risk of thrombosis (Santigo-Silva *et al*., 2011).

Papaya has been used in traditional medicine to treat many disorders. Leaves, bark, roots, latex, fruits and seeds contain specific phytochemicals that are bioactive against many diseases. Experiments have shown that papaya possesses anthelmintic, antiprotozoan, antibacterial, antifungal, antiviral, anti-inflammatory, antibacterial, antihypertensive, hypoglycaemic and hypolipidaemic, wound healing, antitumour, free-radical scavenging, antisickling, neuroprotective, diuretic, abortifacient and antifertility activities (Desjardins, 2019). It has been reported to prevent cancer (Pathak *et al*., 2014), and to regulate lipidaemia (Esmael *et al*., 2015), type 2 diabetes (Aruoma *et al*., 2010), cardiovascular disease (Jarisarapurin *et al*., 2019), macular degeneration (Gouado *et al*., 2007) and gastric lesions (Murakami *et al*., 2012). Both seed and pulp of papaya have bacteriostatic properties against several enteropathogens such as *Bacillus subtilis*, *Salmonella typhi*, *Staphylococcus aureus*, *Proteus vulgaris*, *Pseudomonas aeruginosa* and *Klebsiella pneumoniae* determined via the agar cup plate method (Osato *et al*., 1993). Subenthiran *et al*. (2013) investigated the platelet increasing property of *C. papaya* leaves juice (CPLJ) on patients with dengue fever (DF) and dengue haemorrhagic fever (DHF). They concluded that CPLJ significantly accelerates the rate of increase in platelet counts in patients with DF and DHF. The anthelmintic activity of papaya seed has been predominantly attributed to carpine (an alkaloid) and carpasemine (later identified as benzyl thiourea) (Boshra and Tajul, 2013). Chinoy *et al*. (2006) reported the antifertility, anti-implantation and abortifacient properties of extracts of papaya seeds.

Research carried out over the years in different laboratories around the world has demonstrated that consumption of papaya definitely provides positive effects against a number of chronic diseases. The exact modes of action of the different bioactive compounds on health are slowly being unraveled. It is becoming clear that their preventive influence is mediated not only by their effect on antioxidant capacity, but also the effect of papaya polyphenols is gaining much credence (Desjardins, 2019).

Using the combined techniques of gas chromatography and mass spectrometry, Flath and Forrey (1977) identified as many as 106 volatile components in papaya fruit. Most of the components are present in low concentrations, which varied among the cultivars and locality (MacLeod and Pieris, 1983). Linalool has been identified as the major volatile component in cultivar 'Solo' (Franco and Rodriguez-Amaya, 1993). Kelebek *et al.* (2015) identified a total of 46 and 42 aroma compounds including esters, alcohols, terpenes, lactones, acids, carbonyl compounds and volatile phenols in papaya cultivars 'Solo-42' and 'Tainung', respectively. The major aroma components of mountain papaya (*Vasconcellea pubescens*) have been identified as ethyl butyrate, butanol, ethyl acetate, butyl acetate and methyl butyrate (Morales and Duque, 1987). These aspects are also discussed in Chapter 11, this volume.

1.3 Processing

The prospect of increasing the production of papaya in many countries, and their relatively short postharvest life as fresh commodities, raises expectations for increased processing opportunities of this crop. Papaya can be processed to obtain many preserved products such as candy, jams, jellies, dried and canned papaya. It can also be converted to ready-to-drink beverages and nectar (Devika *et al.*, 2015).

1.3.1 Candy

Fruits are peeled, trimmed and cut longitudinally into pieces. The fruits are then soaked overnight in lime water (saturated calcium oxide solution), blanched in boiling water for 3 min and soaked in a 30°Brix sucrose solution at a ratio of 1:1.5 (fruit:sucrose solution) for 10–12 h with 1000 ppm of sodium metabisulfite, 0.5% salt and adjusted with citric acid to pH 3.5. The slices are held at 40°, 50° and 60°Brix with addition of extra sugar (Chavasit *et al.*, 2002). The process of impregnation with sugar must not be hurried otherwise the fruit will shrivel and be unfit for glazing and crystallizing (Kumar *et al.*, 2019).

1.3.2 Jam

Jams are fruit preserves, which consist of 45 parts prepared fruit with 55 parts of sugar concentrate to make 65% or higher solids, resulting in a semi-solid product (Devika *et al.*, 2015). Papaya jam is prepared by cooking peeled ripe papaya slices with an equal weight of sugar. Citric acid at 5 g kg^{-1} of pulp is added to improve the sugar acid ratio which also helps in the production of inverted sugars that prevent sugar crystallization in the jam during storage. Cooking the fruit pulp and sugar mixture is continued until it attains a thick consistency, which usually corresponds to a 65–68°Brix. Clean, dry and sterilized glass jars are filled with the hot jam, sealed airtight and cooled (Lal and Das, 1956).

1.3.3 Dehydrated

Papaya slices pretreated by steeping in 70°Brix sucrose solution along with 1000 ppm of SO_2 yielded a good product with 50% retention of carotenoids. The product had 0.42% acidity, 32% reducing sugars, 70% total sugars, 600 ppm SO_2 and 18.2% moisture, with a rehydration ratio 1:2.1 (Mehtha and Tomar, 1980). Osmotic dehydration has received greater attention in recent years as an effective method of preservation which is a simple process, facilitating processing with retention of the initial fruit characteristics (i.e. colour, aroma, texture and nutritional composition) (Singh *et al*., 2015). Papaya slices treated with a 60°Brix sucrose solution as the osmotic agent at 50°C temperature with 30 min immersion followed by further drying in dryer at 70°C showed the papaya slices were easily rehydrated and there was good nutrient retention, texture, colour, taste and acceptability (Singh *et al*., 2015).

1.3.4 Minimal processing

Minimally processed freshly cut papaya that is ready to eat and for consumption after storage with instant sensory and nutritional properties have great potential. Papaya cubes treated with sanitizing agent (dipped in 100 ppm sodium hypochlorite for 5 min) and antioxidant (soaked in 5% w/v citric acid for 30 s) and packed in 19 µm semipermeable film and kept at 5 ± 1°C, 85% relative humidity, can be stored up to 16 days with the colour, flavour, taste and quality of the fruit intact (Singh *et al*., 2010).

1.3.5 Beverages

Formulation of different types of papaya juice blend (with mango, guava, lime) and nectars have been reported by different researchers. A blend of 15% papaya and 15% mango nectars has been reported to have high acceptability (Mostafa *et al*., 1997). The process of beverage preparation involves peeling and macerating peeled tissue in 25% water, straining through a 0.8 mm sieve, adjustment of the pH of the juice with citric acid and flavour adjustment with sucrose. For acceptability the fresh juice should be maintained at pH 3.9 and 10% sucrose (w/v). Heating for 6 min at 72 ± 2°C is required to achieve commercial pasteurization. Adding sodium benzoate (125 mg/100 ml) extended the shelf life up to 80 weeks at 30°C (Okoli and Ezenweke, 1990).

Nectar produced with 37.5% papaya pulp, 7.5% passion fruit juice and 5% acerola pulp with 15% sucrose added had a high vitamin C content and presented good sensory acceptance suggesting commercial potential (Matsura *et al*., 2004).

1.3.6 Papain

Papaya contains significant amounts of the proteolytic enzymes papain and chymopapain. They have diverse uses as meat tenderizers, digestive medicine, in brewing applications, the manufacture of chewing gums, and in pharmaceutical applications in the skincare and tanning industry (Nakasone and Paull, 1998). The mountain papaya (genus *Vasconcellea*) is a potential source of papain (Drew *et al*., 1997). The pericarp of the fruit is composed of laticifers which develop close to the vascular bundles. The laticifers are ramified throughout the fruit. They secrete latex which contains papain. The papain is extracted from the fully grown unripe fruit by making superficial and longitudinal incisions in the fruit; the white liquid that drips from the fruit is called latex. Latex is collected and sun dried or dried in chambers until the moisture content is reduced to 5% or 8%, and this is known as crude papain (Jacquet *et al*., 1989). Fruits should be tapped at intervals of about 4–7 days. Latex is collected in steel/glass trays. The latex is stored at -20°C after adding NaOH at 0.3 M to avoid oxidation. Before being used by the food industry, crude papain is purified by precipitation of papain with an organic solvent. The yield of crude papain from raw green papaya is reported to be around 0.025% (Nanjundaswamy and Mahadeviah, 1993).

Papain from papaya latex is purified by removal of material insoluble in the extract at pH 9.0, an ammonium sulfate precipitation by three recrystallizations. Kimmel and Smith (1954) stated that the resulting protein contains three components: (i) active papain; (ii) activatable papain; and (iii) non-activatable papain. In active papain, the thiol group is fully reduced. Activatable papain, which itself is inactive, can be converted to active papain by reaction with thiols. However, non-activatable papain cannot by activated to an enzymatically active material by addition of thiols (Kimmel and Smith, 1954). The crude papain is purified by dissolving in water and precipiting with alcohol (Rehm and Read, 1986).

1.4 Conclusion

Increasing evidence points to the fact that Mexico and Central America are the centre of origin of *C. papaya*. In fact, it is only in Yucatán, Mexico and some places in Central America where wild *C. papaya* populations can be found. The fruit of *C. papaya* was consumed by Mayan pre-Hispanic civilizations and they also used it for its curative properties.

It appears that the Spanish brought this fruit to Asia and Europe since the 16th century. Since then, it has been grown in most tropical countries throughout the world. The importance of papaya has increased greatly in the last decade, and it is now the third most consumed fruit worldwide.

It can be expected that this trend of increasing production and consumption of papaya will be maintained in future years, as there is increasing evidence that this fruit is not only accepted for its organoleptic properties but it also appears that its routine consumption may assist the consumer in preventing the occurrence of important diseases such as diabetes.

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