Avocado History, Biodiversity and Production

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1 Introduction

The name avocado originates from the Aztec word "Ahuacatl" *and* "*ahoacaqua-huitl*". Ancient Aztec, Olmec and Maya cultures praised avocado as one of the 'gifts of God'. The prehistoric fruit was under cultivation in North, South and Central Americas for thousands of years. From there, avocado dispersed to Europe and the rest of the world. Seed remains found in ancient human settlements in the Tehuacan Valley suggest that the avocado could have been used as early as 8000–7000 BC and possibly domesticated at least 5000 BC by Mesoamerican groups (Smith1966, 1969). The most ancient evidence of the use of the avocado tree (*Persea Americana*; Lauraceae) in Mesoamerica is about 10,000 years ago, in Coaxcatlan, Puebla (Mexico) (Knight 2002; Galindo-Tovar et al. 2007; Landon 2009).

1.1 Avocado History

The avocado (*Persea gratissima* or *P. americana*) gets its name from the Latin American Nahuatl word *ahuacatl* meaning "*testicle*," an obvious reference to the shape of the fruit. It was discovered in Mexico approximately 291 BC. The more easily-pronounced name of *avocado* is attributed to Sir Henry Sloane, who created it in 1669. The word itself first appeared in American print in 1697 (Galindo-Tovar et al. 2007). Early Spanish explorers discovered the Aztecs enjoying avocados, but it was long considered a tasteless food. The Aztecs also used avocados as a sexual stimulant. It was the Spanish explorers who brought the avocado to the English.

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The first Florida crops are credited to horticulturist Henry Perrine who planted groves in 1833. However, avocados did not become a commercial crop until the early 1900s (Knight and Campbell 1999; Knight 2002). Except in California, Florida and Hawaii where they were commonly grown. In early 1950s, the avocado became accepted as a salad item and consumption became more prevalent (Scora et al. 1970).

The diversity of the avocado has also been known since pre-Hispanic times. Benavente, in his "Historia de los Indios de la Nueva España" ([1536] 2003), made a distinction among different avocado types: "the ones common in all this land and all the year, are like early figs. Other avocados are as big as large pears and are as good as best fruit in the New Spain (Mexico). There are others as big as a small pumpkin; ones with a big seed and little flesh and others with more flesh". Sahagún ([1570] 2002) also described three different types of avocado: the *ahuacatl* or *ahuacacahuitl* has dark green leaves and the fruit is black in the outside and white and green in the inside; the *tlacazolahuacatl* is like the former but bigger; and the *quilahuacatl* is green in the outside and very good to eat. Other chroniclers not only described the different avocado types but situated them geographically (Galindo-Tovar et al. 2007). Friar José Acosta, in 1590, in his "Historia Natural y Moral de las Indias" differentiated between the Mexican avocado and the one from Peru. He described the avocados from Peru as big fruits with a hard shell that peels easily and the ones from Mexico as mostly small with a thin shell that peels like an apple (Acosta [1590] 1985). These descriptions agree, respectively, with the West Indian and Mexican avocados described by Bergh and Ellstrand (1986). It is also interesting the way Friar Bernabé de Cobo, in his book "Historia del Nuevo Mundo" ([1653] 1956), described three different avocado types: "The palta in Yucatan is a tree of very attractive appearance, of the size of a large fig tree; its leaf is similar to that of the mulberry and its fruit is one of the finest in the Indies; in some regions it becomes as big as a small squash or large citron. The palta has a thin skin, more tender and flexible than that of a Ceuta lemon, green externally and when the fruit is quite ripe, peeling readily. It has large seed, either in the Indies or Europe, spindle shaped, a reddish white substance, tender like the meat of a chestnut and covered with a grayish parchment. It has the flavor of bitter almonds and when pressed it yields an oil like that of the almond. Between the seed and the outer skin is the meat, slightly thicker than one's finger except at the neck where it is very thick. It is of whitish green color, tender, buttery and very soft. Some people eat it with sugar or salt, others just as it comes from the tree, it being of such good flavor that it requires no seasoning. And although it is very pleasant to taste, it should be eaten in moderation because it is considered to be heavy and indigestible. The best paltas come from hot, dry regions; in Peru they grow in the Valley of Lea. A second kind of paltas is a large, round one that is produced in the province of Guatemala and which does not have as smooth skin as the first. The third is a small palta found in Mexico, which in size, color and form resembles a breva fig (first fruit of the fig tree); some are round and others elongated, with skin as thin and smooth as that of a plum. In some regions they cut the immature Palta in small bits and put it in brine, to take the place of olives. The tree wood is useful in building and for fuel". These avocado descriptions also resemble the ones made by Bergh and Ellstrand in 1986: the palta in Yucatan would be the West Indian avocado; the second kind of palta the Guatemalan type; and the third the Mexican type. Current varieties and rootstocks for avocado cultivation in the world are the products of various breeding programs based on exploration, collections, conservation and evaluation trials throughout their regions of origin and dispersion, (Mijares and López 1998; Knight 2002). Indeed, many modern commercial plantings are new varieties and cultivars, obtained by hybridization of various materials collected in Mexico and Central America. The description of avocado cultivars, methods of vegetative propagation, cultivation and varietal improvement are well documented (Knight 2002; Lahav and Lavi 2002).

1.2 Origin and Distribution

The genus *Persea* belongs to the Lauraceae family, one of the oldest known flowering plants. At present, about 81 species of *Persea* are recognized as valid. Most of the *Persea* species originated in the New World, but *P. indica* apparently originated in the Canary-Madeira-Azores islands. Some species originated in Southeast Asia. *Persea* has been divided further into subgenus *Persea* (includes *P. americana*, the commercial avocado) and subgenus Eriodaphne (a group of species of which most are immune to avocado root rot, but unfortunately are graft incompatible to avocado). Nearly all have tiny fruits lacking palatable flesh (Kopp 1966; Storey et al. 1986). Nearly all species within the genus *Persea* are native to the Americas (Kopp 1966). The species are scattered from northern Mexico through the southeastern United States, east through the West Indies, south through Central America, Colombia, Venezuela, the Guyana's and Brazil as well as Ecuador, Peru, Bolivia and Chile. How one species (*P. indica*) got to the Canary, Madeira and Azores Islands and how several *Persea* got to southeastern Asia, is not well understood (Kopp 1966; Williams 1976; Bergh and Ellstrand 1986; Scora and Bergh 1992; Landon 2009). From its natural habitat it has spread worldwide to almost all tropical and subtropical regions of the world. Plant distribution and taxonomic evidence are compatible with the assumption that the avocado originated in south central Mexico or nearby region (Storey et al. 1986). Speciation has occurred mainly in the highlands, mountain regions of Mexico and Guatemala (North of Guatemala City and Antigua). Distribution of wild species of *Persea americana* expands from the Mexican highlands, through the lowlands of Central America (e.g. Guatemala and Costa Rica) (Popenoe and Williams 1947; Ben-Ya'acov et al. 2003; Knight 2002) (Fig. 1). Systematic botanists and ethnobotanists agree that the avocado was unknown off the continental mainland before discovery of the New World by Columbus. None of the early chroniclers of voyages in the West Indies mentioned it and the various tribes of Amerindians inhabiting the islands had no native name for it.

Fig. 1 Centers of origin for the three avocado subspecies (races)

Three main proposed centers of origin (center of biodiversity) for cultivated avocado i.e. Mexican center, Guatemalan center and the hot and humid lowlands of Central or northern South America center (Popenoe 1934; Storey et al. 1986; Galindo-Tovar et al. 2007; Chen et al. 2009).

1.3 Mexican Center

The primary gene center for *Persea americana* comprises the central highland regions of Mexico. The important species originating from this tract are *P. drymifolia, P. flocossa, P. floccosa, tolimanensis* and *P. zentmyerii*. Most of the Mexican avocado cultivars/varieties belong to *P. drymifolia* which were domesticated from wild *P. americana* found in México (Kopp 1966; Scora et al. 1970). However, the progenitors of these avocado varieties probably migrated from west Gondwana, Southern hemisphere (Scora and Bergh 1992; Galindo-Tovar et al. 2007; Landon 2009). The Mexican race, *P. americana var. drymifolia*, is thought to be the primordial race of commercial avocado.

Fig. 2 Avocado trees at the USDA National Germplasm Repository gene bank in Miami, FL

1.3.1 The Mexican Race

There are no pure Mexican varieties grown commercially for fruit in California (Bender 2012). However, genes from the Mexican race are important components in the Mexican-Guatemalan hybrid cultivars such as 'Hass' and 'Fuerte'. Two important traits from the Mexican race were passed on to the hybrids. These are the addition of more cold hardiness to the Guatemalan race and move on the harvest season of the Guatemalans by half a year (Popenoe 1919). This is the hardiest type in cultivation and presently the only one in California that ripens during late fall and early winter. It was introduced to California from Mexico, where it appears to be by far the common and abundant type. Some varieties have unusually rich flavor and excellent quality; in others there is an objectionable amount of fiber in the flesh. The oil content runs as high as 33% and averages considerably higher than other types. The tree (Fig. 2) usually growths vigorously and is, very resilient, withstanding in some instances temperatures as low as 18° or 20° without injury. Because the fruits are usually under one-half pound in weight, the tree is able to carry an immense number of them, 4000 sometimes being produced in a single crop. The fruits are usually oval or pear-shaped, ranging from 3 to 10 ounces in weight and green or dark purple in color. The skin is about as thick as that of an apple. The seed is sometimes loose in the cavity, with loose seed coats. The plant and fruits are characterized by an anise-like odor. If picked at the proper time, fruits of this type can be shipped reasonable distances without difficulty, but they do not hold up so well in market as do the thick-skinned. They are excellent fruits for home use, and because they ripen at a season when no other type is available in the market, they are commercially attractive. The tree comes into bearing earlier than other types, sometimes at 2 or 3 years from seed, and in the case of budded trees, usually within 2 years. Seeds from the Mexican race of avocado have been used as rootstocks in California since the beginning of the industry. Nurserymen like the big seeds and fast-growing qualities and growers have found that Mexican rootstocks usually have better and more consistent production than the Guatemalan and West Indian rootstocks. Of the three races, Mexican seedling rootstocks perform best in the colder soils. Mexican rootstocks are the least tolerant to soil salinity. There are no pure Mexican varieties grown commercially in California or Florida (Bender 2012; Crane et al. 2013). However, genes from the Mexican race are important components in the Mexican-Guatemalan hybrid cultivars such as 'Hass' and 'Fuerte' (Bender 2012). Two important traits from the Mexican race are imparted into the hybrids. These are the addition of more cold hardiness to the Guatemalan race and advancing the harvest season of the Guatemalans by half a year (Bergh and Ellstrand 1986; Bender 2012).

1.4 Guatemalan Center

This center includes Guatemalan mountains tracts and lowlands. *P. nubigena* and *P. nubigena var guatemalensis*, belong to this center (Popenoe 1935; Storey et al.1986). The Guatemalan race apparently developed in the highland region of Guatemala north of Guatemala City and Antigua (Popenoe 1917).The Guatemalan race of avocado is native to the highlands of Central America and is less cold tolerant than the Mexican race. Their leaves have no anise scent, and the young foliage is often reddish. The seed is almost never loose in the cavity. A characteristic of the Guatemalan race is the much longer time to fruit maturity (compared to the other races). Guatemalan cultivars such as 'Nabal' and 'Reed' may take 15 months or more from bloom to maturity (Bergh and Ellstrand 1986). Historically, this characteristic was used in California to advantage to stretch out the harvest season: hybrids with strong Mexican traits are harvested in the winter; Guatemalan cultivars such as Reed, Nabal, Dickinson, Queen and Anaheim are harvested 6–9 months later, in the summer; and Hass (a mostly Guatemalan hybrid) fills in between the two seasons (Bender 2012). A disadvantage to the Guatemalan cultivars is their thicker, woody skins (not all cultivars have this trait). One of the problems with the thick skins is that the consumer cannot tell when the fruit had softened enough for eating (Popenoe 1935; Schieber and Zentmyer 1980); (Bergh and Ellstrand 1986). The hard-shelled 'Dickinson' cultivar is tested for softening by inserting a toothpick into the stem end of the fruit (Bender 2012). The rigidity of the peels does not allow easy peeling; peels are "chipped-off" instead of peeled. The popular 'Reed' cultivar has a thinner skin, but is still very shell-like (Popenoe 1935).

1.4.1 The Guatemalan Race

Commercially, this is doubtless the most valuable type cultivated in California and is the most extensively planted variety, which is peculiar in that it carries its fruits through the winter and into the following summer, thus requiring 12–16 months to ripen (Bender 2012). While the Mexican type blooms in winter and ripens its fruits the following summer and the West Indian type blooms in spring and ripens its fruits in summer, the Guatemalan type blooms in late spring and hold its fruits over the following winter, sometimes as late as September and October of the following year (Bergh and Lahav 1996). The varieties of this type cultivated in California ripen from February to September. For fall and early winter other cultivars must be grown, unless afterward, cultivars of the Guatemalan type which will extend the season are acquired (Bender 2012). The California representatives of this type originated in Guatemala and in Southern Mexico, mainly in the vicinity of Atlixco, state of Puebla, Mexico, at an altitude of nearly 6000 ft above sea level (Popenoe 1919, 1935; Bergh and Lahav 1996). A large proportion of the varieties that originated in California came from seeds imported from Atlixco by John Murrieta of Los Angeles about 1900. Mr. Murrieta's work has had a more profound influence on California avocado culture than any other. Because of the Mexican origin of numerous Guatemalan varieties, some think this name to be inappropriate (Popenoe 1915). Inasmuch as these thick-skinned Mexican varieties belong to the Guatemalan type, however, they should certainly be called by this name, as it serves to show their relationship to other varieties of the same type. The characteristics that distinguish this type from the others are consistent, although it is sometimes difficult to distinguish one of the thinner skinned Guatemalan fruits with an almost smooth surface from a fruit of the West Indian type (Popenoe 1920, 1935). When the surface of the skin cannot reliably identify a fruit, the Guatemalan can usually be distinguished by the color of the fruit and by the character of the seed and its coats (Popenoe 1919, 1935; Bergh 1975). The tree is easily distinguished from that of the Mexican type by the absence of anise like fragrance in the leaves (Popenoe 1935; Kopp 1966; Bergh 1975; Bergh and Lahav 1996). The type seems to be about equidistant in hardiness between the West Indian and the Mexican. There is a slight difference in toughness among the different Guatemalan cultivars. The fruits of this type have a thick skin that is often woody and brittle. The surface is usually rough, sometimes covered with wart-like protrusion around the base, but in a few cases almost smooth. The flesh is usually free from fiber and of good flavor. It is scarcely as rich and oily as the average fruit of the Mexican type, but is very pleasant and satisfactory overall. The seed is usually not large in proportion to the size of the fruit and is almost never loose in the cavity (Popenoe 1919, 1935; Bergh 1975; Bergh and Lahav 1996; Nakasone and Paull 1998; Ospina 2002; Janick 2005).

1.5 West Indian Center

This center includes the hot and humid lowlands from Guatemala through Costa Rica and northern South America (Peru, Ecuador, Colombia and Costa Rica). According to Kopp (1966) *Persea americana var americana* Mill. is widespread in this center. *P americana var americana* is known by many names (*syn. P. gratissima, P. edulis, Persea persea, Persea lyogina* and *Persea americana var. angustifolia.* In spite of its name, this is the most tropical of the three races, and is assumed to have developed somewhere in this area.

1.5.1 The West Indian Race

West Indian avocados are prevalent throughout the lowlands of Tropical America. Naturalized seedlings occur in suitable habitats, particularly in association with human activity, along roadsides, or as remnant trees left after the clearing of forests. Although of local interest and potential genetic value, collecting these highly variable and often horticulturally inferior individuals is not realistic in light of the archeological evidence for the selection for specific horticultural traits across the last 10,000 years (Smith 1966, 1969). The leaves have no anise scent, and fruit size ranges from small to very large. Seeds are relatively large and are sometimes loose in the cavity. The fruits have relatively low oil content and are frequently reported to be “watery” by customers (Popenoe 1935). This race is the most cold-sensitive of the avocado races; and pure cultivars do not grow well in California (Bender 2012). Selections of this race appear to have greater salt tolerance and may be useful as rootstocks if selections can be found that can tolerate the colder soils in California. Trees of the West Indian type are more prone to frost than those of the Guatemalan type; vastly more so than the thin-skinned, small fruited Mexican type (Popenoe 1934, 1935). Its foliage it is often difficult to distinguish from the Guatemalan, but as a rule the leaves are somewhat smaller in California, they are also crowded more closely together on the branches and the wood is of lighter in color (Bender 2012; Boris et al. 2013). The foliage, too, is usually a lighter shade of green. The fruits of this type vary in form, being pear-shaped, oval or round. In color they are usually yellowish green or maroon (Popenoe 1935). The skin is leathery and separates readily from the flesh, but it is not as thick or woody as in the Guatemalan type. The flesh is often rather watery in seedlings and not as richly flavored as in the Guatemalan type, but in some of the best varieties the quality is good (Popenoe 1952). There is one defect that is not usually found in the Guatemalan type, i.e., the seed is large and often loose in the cavity. It seems that this type would not become of commercially important in California (Popenoe 1928). It is the principal one cultivated in Florida, the well-known varieties, ‘Trapp’ and ‘Pollok’ being representatives of it (Campbell and Malo 1979; Knigth and Campbell 1999; Crane et al. 2013). It is the one cultivated in Cuba and other West Indian Islands and along the coast of Central and South America. West Indian cultivars and hybrids are well-adapted to southern Florida and provide fruit on the market just ahead of the California winter fruit (Campbell and Malo 1976; Knigth and Campbell 1999; Crane et al. 2013). Selections have been made in Florida to stretch out their harvest season, but a given cultivar will be on the market for just a few weeks. Thus, the Florida industry relies on early, mid and late season West Indian cultivars (Wolfe et al. 1949; Campbell and Malo 1976; Knigth and Campbell 1999; Crane et al. 2013).

2 Taxonomy

The genus is of African Gondwanaland origin and its ancestral species was distributed to Asia and via Europe to North America and via Antarctica to South America probably in Palaeocene times (Scora 1992); Galindo-Tovar et al. 2007). When the Americas joined in the late Neocene, the genus was again united. Mountain building in Central America created new habitats in which, speciation could take place (Kopp 1966; Scora and Bergh 1992). In subgenus *Persea* three species are recognized, *P. schiedeana* Nees, *P. parvifolia* Williams and *P. americana* Mill. The latter species is polymorphic and consists of several separate taxa that may be considered botanical varieties or subspecies, and which are referred to as 'horticultural' races in the popular literature (Scora et al. 2002). Within this group are the varieties that make up the commercial avocados, namely *P. americana* var. *americana* Mill., the West Indian or Lowland (Scora and Bergh 1992) avocado; var. *drymifolia* (Schlect+Cham.) Blake, the Mexican avocado; and var. *guatemalensis* Williams, the Guatemalan avocado; all three are regarded as geographical ecotypes. Additionally, var. *nubigena* (Williams) Kopp, var. *steyermarkii* Allen, var. *zentmyerii* Schieber and Bergh and var. *tolimanensis* Zentmyer and Schieber are recognized as separate varieties of *Persea americana* Mill (Bergh and Lahav 1996). These latter four are believed to have contributed to the ancestry of var. *guatemalensis* (Schieber and Bergh 1987). Another wild botanical variety is *floccosa* Mez. Doubtless more taxa will be described as germplasm exploration continues (Ben-Ya'acov et al. 1992). One new taxon is the endemic form of *P. americana* var. *americana* in Costa Rica, where the typical vars. *drymifolia* and *guatemalensis* are almost absent. This endemic '*aguacate de montana*', which is intermediate between the Guatemalan and West Indian (Lowland) avocados, should be recognized as *P. americana* var. *costaricensis* according to Ben-Ya'acov et al. (1995).

3 Biodiversity and Genetic Resources

Biological diversity is the variety in life on the earth that includes all genes, species and ecosystems. Biodiversity provides recreational, psychological, emotional and spiritual enjoyment to human beings (Tuxill and Nabhan 2001; Borokoni 2013).

Plant genetic resources of cultivated crop plants as well as wild relatives have significant value to mankind, as they provide food, fuel, shelter and industrial products (Gross and Olson 2009; Vaughan et al. 2007). Furthermore, plant breeders require genetic variation (genotypes) for plant improvement. Genetic diversity in wild relatives is very essential because they contain genes resistance to biotic and abiotic stresses. Thus, all unique accessions need to be collected, characterized and preserved (Engelmann 1991; Ben-Ya'acov et al. 1992; Vaughan et al. 2007; Engelman 2013). Genetic diversity is the key component of any agricultural production system. The diversity in plant species consists of traditional varieties, wild relatives and other wild species (Altieri et al. 1987; Merrick LC 1990; Hoisington et al. 1999). Many factors are relevant to the role of landraces in agriculture and biology such as physical environment (latitude, altitude, and climate) and social environment (monoculture, deforestation, population etc.) and species and its utilization (Tuxill and Nabhan 2001; Agora and Rao 1998; Padulosi et al. 2012; Borokini 2013). Further, avocado landraces practically disappeared and cultivation of the traditional varieties increasingly declined first in orchards and gardens and eventually in all areas Mexico and Central America. To meet the demand for more food and to provide a reservoir of genetic variation to the breeders for finding particular characters such as resistance of genes for diseases, pests and for adaptation to wider ecological conditions, it will be necessary to make better use of a broader range of the world's plant genetic diversity (Merrick 1990; Cooper et al. 2001; Vaughan et al. 2007; Miller and Gross 2011).

Germplasm resources of fruit plants are in some cases threatened to the point of extinction (Bennett 1965; Agora and Rao 1998; Normah et al. 2002). Such reductions have serious implication for food security in the long term. Therefore, conservation and sustainable use of genetic resources is important to meet the demand for future food security (Baranski 2013; CGIAR 2013)

3.1 Status of Genetic Uniformity/Variability in Genus Persea

The degree of genetic uniformity of avocado in Mexico and Central America is extremely high, and thus avocado production is extremely vulnerable to extinction (Ben-Ya'acov et al. 1995; Ben-Ya'acov et al. 2003). Most of the major cultivars belong to a single Mexican avocado species (*P. drymifolia*) (Popenoe 1935, 1963; Scora and Bergh 1992; Bender 2012). Approximately 85–90 % of commercial production is accounted for by a single cultivar, 'Hass' (Knight 2002; Bender 2012). Moreover, high genetic similarity exists among several Mexican and Guatemalan avocado cultivars ('Hass', 'Bacon') probably because they have the same progenitors and share the same genetic pool (Lavi et al. 2003; Schnell et al. 2003; Taah et al. 2004; Borrone et al. 2007). On the other hand, *P. drymifolia and guartemalensis* and subspecies that belong to Mexican and Guatemalan avocado have rich diversity. These are naturally occurring interspecific hybrids that are also found near the center of diversity/origin. Molecular studies of genetic diversity and relationships among limited numbers of *P. drymifolia and guatemalensis* varieties indicate a relatively high degree of genetic similarity (Clegg 1992; Sharon et al. 1997); however, the degree of similarity among major *P. americana* varieties is relatively low (Lavi 1991; Mhameed et al. 1997). The techniques of protein electrophoresis and isoelectric focusing of isozymes have been used to characterize genotypes. DNA-based molecular markers (e.g. RAPD, AFLP, RFLP etc.) or unique DNA primers (SSR, ISSR, SCAR, CAPS, SNPs etc.) are being used to assess genotypic diversity, genetic relationships and to identify unique genotypes (Schnell et al. 2003; Borrone et al. 2007; Mhameed et al. 1997; Sharon 1997; Fiedler et al. 1998; Abraham and Takrama 2013). Further recently Dr. David Kuhn at the USDA-ARS in Miami, Florida, has developed an avocado single nucleotide polymorphism (SNP)-array based on polymorphisms in the gene coding regions of Hass, Bacon, Simmonds and Tonnage (Arpaia and Harley 2012). This array contains 6000SNPs that have been positioned on the avocado genetic map. In addition, Dr. Luis Herrera's research group at the Centro De Investigacion y Estudios Avanzados, CIEA, Mexico, is continuing to work on the sequencing, assembling and annotation of the avocado genome. Using the initial genome sequence as a reference, additional avocado genotypes are being targeted for sequencing (Arpaia and Harley 2012). The potential of genus *Persea* remains largely unexplored in Mexico and Central America. Thus, a range of genetic variation exists in these subspecies. Like other subtropical and tropical fruit species, avocado exists in mountainous regions and lowlands of Mexico and Central America in cultivated, wild, naturalized and indigenous forms and a need to be explored (Ben-Ya'acov et al. 1992, 2003).

3.2 Threats to Persea feral germplasm

The genetic resources of avocado are very important for breeding programs of new rootstocks and cultivars, so it is urgent to rescue many types of avocados and related species from the rapid devastation of the forests and jungles. The genetic resources of plants, particularly fruit plants, are vanishing rapidly worldwide, resulting in a large-scale depletion of variability (Merrick 1990; Cruz-Cruz et al 2013; Olsen and Wendel 2013) There are many reasons for such depletion, including deforestation, road laying, urbanization and the introduction of new varieties. Fruit trees in Brazil, Mexico, Central and South America are also threatened by logging and fuel wood gathering (Miller and Gross 2011; Miller and Schall 2006). The Red List of the International Union for the Conservation of Nature (IUCN) currently contains only six *Persea* taxa threatened in different countries including Azores, Madeira and Canary Islands in Macronesia (*P. indica*), Ecuador (wild populations of *P. campii and comferta*,) (Muriel and Pitman 2004) although efforts have been made to maintain these genetic resources by *in situ* and *ex situ* preservations in these countries. Genetically uniform modern varieties are replacing the highly diverse local varieties and landraces in traditional agro-ecosystem, and primitive varieties are being discarded after termination of breeding projects. Bowman (1992) revealed that a low level of variability in cultivated avocado genotypes highlights the need to widen the genetic base of avocado germplasm as to preserve an adequate level of genetic extension in avocado breeding programs. *Persea* germplasm is a rich source of genetic variability that has accumulated through hybridization, mutation and seed-based propagation. Wild populations of *Persea* species are threatened in their natural habitat, with about several avocado cultivars lost in the nineteenth century, continuing even today (Ben-Ya'acov et al. 1992). Moreover, due to various pests and pathogens, a valuable and highly resistant to various abiotic stresses, avocado germplasm has been lost (Ben-Ya'acov et al. 1992). Such germplasm represents basis for tolerance to extreme cold, heat, drought, diseases and pests. Detailed attention to safety and preservation of genetic resources is needed on purely scientific lines for the diverse and rich avocado germplasm present in Mexico, Central America and northen South America (Pliego-Alfaro et al. 1987). Study to understand the diverse germplasm present in the area, its characterization through morphological and advanced molecular genetic studies, is also desired.

4 Characterization and Assessment of Germplasm

Genetic variation is indispensable for effective management and use of genetic resources (Vaughan et al. 2007). Diversity in fruit species is assessed on the basis of phenotypical morphological traits (Arora and Rao 1998) and molecular techniques based on isozyme patterns and protein profile like SDS-PAGE and by using DNA based molecular techniques like RFLPs, AFLPs, RAPDs, ISSRs; SSRs and SNPs, etc. The information regarding genetic diversity in *Persea* germplasm characterized by these methods is useful for efficient management, preservation and also for breeding purpose (Ashworth and Clegg 2003).

4.1 Morphological Characterization

Polygenic morphological and pomological characteristics serve as genetic markers for germplasm characterizations (Ahmed et al. 2009). The evaluation of morphological characters unaided to evaluate genetic diversity may not be very effective. Wide genetic variability in avocado has already been observed in characterization of seedlings for morphological, physiological and phenological traits (Ayala-Silva et al. 2007; Guillen et al. 2011; Nkansah et al. 2013). The diversity based on phenological and morphological characters usually varies with environment. Evaluation of these traits requires ample characterization of genotypes prior to identification (Altieri and Merrick 1987). Morphological and phenological characters aid in the collection of basic information for improvement through breeding program and further evaluation (Ayala-Silva et al. 2004; Postman et al. 2006; Ayala Silva et al. 2007; Sato et al. 2010). Systematic characterization and evaluation of plant genetic resources are fundamentals for effective use of the materials through conventional methods or modern techniques.

Polygenetic and environmental factors need to be evaluated, as has been done in many fruit crops, such as sweet cherry (Hansche and Beres 1966), peach (De Souza et al. 1998) and grapes (Sato et al. 2000). Variability in morphological characteristics is very important for evaluation of avocado genotypes. A majority of the wild avocado genotypes are highly heterogeneous and a number of ecotypes can be distinguished, for instance variability in leaves, flowering, fruits, nutritional composition and resistance against insects and diseases (Williams 1976). Each ecotype needs to be characterized for all existing variation within genotypes (Chen et al. 2009; Borrone et al. 2007; Ahmed et al. 2009). Quantitative characteristics of leaves alone are sufficient to identify avocado species (Bergh 1969; Bergh 1980; Storey et al. 1986). Genotypes of avocado are classified into two groups based on the time of blooming, i.e. early, medium and late flowering types and flowering is based on the type of flower (A or B). Although blooming time is under phylogenetic control (Peterson 1956), variability exists in flowering period (Bergh and Ellstrad 1986; Bergh and Lahav 1996). Flowering time is also affected by environmental factors like mean temperature, differences in chilling prerequisite for breaking bud dormancy, age and vigor of tree and catastrophes, like heavy rainfall and hail storms (Peterson 1956). Diversity in fruit shapes of wild and cultivated varieties exists in both mexican (*P. drymifolia*) and Guatemalan (*P. guatemalensis)* avocados (Popenoe 1920, 1935; Berg and Ellstrand 1986). Fruit morphology is reportedly mostly under polygenetic control (Storey et al. 1986). However, variation in other quantitative and qualitative characteristics of fruit like nutritional components (sugars, soluble contents, vitamins, organic acids) and other quality parameters (aroma, texture, flesh color, flavor and keeping quality) also exist among genotypes (Knight 2002).

Significant differences in morphological characters of several cultivars of avocado (Popenoe 1919, 1920; Popenoe and Williams 1947) have been observed. Storey and Berg (1986) found that several cultivars exhibited remarkable diversity in their tree, foliar, flowers, fruit characteristics, harvesting time and shelf life. The assessment of the genetic diversity in fruit species of seedling origin might assist in the conservation of original habitats and also new sources of genes for resistance and fruit quality, thought to be present within these materials and be available for breeding program (Ben-Ya'acov et al. 2003; Ben-Ya'acov 1998). Gomez-Lopez 1999 and Gomez-Lopez 2002 characterized 190 accessions of wild avocados collected from different agro-ecological zones of Mexico for preliminary evaluation and long conservation in the field gene bank. Ben-Ya'acov et al. (1992) explored various areas in Mexico and Central America for several wild and local varieties of avocado and thought that high-yielding varieties could be selected and a useful gene bank could be developed in Mexico and Israel for breeding purposes. Morphological characterization provides a base and a thought of germplasm of specific plant species about variability and genetic diversity. These characters can be used as a foundation for additional molecular level studies to confirm these morphological characters of the studied germplasm (Arpaia 1997; Cooper et al. 2001; Schnell 2003, 2007).

5 Conservation of Germplasm Introduction

Worldwide awareness of the value of plant genetic resources has increased over the last few decades, along with the acknowledgement that they are under considerable threat (Normah et al. 2002; Miller and Schaal 2006; Drew et al. 2007; Padulosi et al. 2012). Several major international conventions, commencing with the Convention on Biological Diversity (CBD) in 1992 (CBD 1992), have sought to provide a forum for the concerned parties to bring issues of conservation of plant biodiversity into sharper focus at many levels. By 1995, more than 4 million plant accessions had been collected worldwide, consisting mostly of commercial plant species and their wild relatives (FAO 2013). Although this is impressive, several limitations remain. Over 90 % of collections worldwide are stored as seed and over 50 % consist of grains (Baranski 2013; Walters et al. 2013). Fruit crops and particularly tropical fruit species such as avocado, mango, mangosteen, litchi that are difficult to store as seed, are inadequately represented in national and international collections (Normah et al. 2002). The wild relatives of these species are nearly absent from most collections. Currently, the most appropriate method for conserving these genetic resources is by establishing them on field ex situ in genebanks under living field collections or in situ, where they remain protected (Altieri and Merrick 1987; Normah et al. 2002). Worldwide there are hundreds of tropical fruit species that are important for income generation, nutrition, medicine, timber, fuel and livestock feed (Cooper et al. 2001; Drew et al. 2007; Vaughan et al. 2007). In addition to the commercial fruit industry, there is also a wide range of native tropical and subtropical fruit species that have commercial potential are currently in a status of low economic importance (Arora and Rao 1998; Normah et al. 2002). Conservation of tropical fruit species is often difficult or impossible by traditional methods, such as seed banks or field genebanks. Many species have recalcitrant seeds that are high in moisture causing loss of viability when they are desiccated and chilled for storage purposes (Chen et al. 1989; Walters et al 2013). The seeds of other species have either no natural dormancy mechanism (i.e avocado, mango and rambutan), or have a short life of only a few days (mangosteen). Some species have no seeds (banana and breadfruit). *Nephelium lappaceum* and *N. ramboutan-ake* are seasonal fruit species that produce recalcitrant seeds. Thus, their seeds do not tolerate freezing temperatures and are desiccation sensitive (Normah et al. 2002). Currently, there is no single method available for the long-term storage of many of these seeds. Recently developed biotechnological techniques offer alternative strategies, including slow growth in vitro (in tissue culture) for medium-term conservation and cryopreservation (in liquid nitrogen, −196 °C) for long-term conservation (Solarzano 1989; Shibli et al. 2006; Reed 2008; Volk 2012) on the other hand, banana is the only tropical fruit species for which large numbers of accessions are currently held in vitro genebanks. For the most part tropical fruit species are held in field collections, which are vulnerable to disease, insect attack and natural disasters, such as typhoons (hurricanes), floods, cold weather and volcanic activity (Ayala-Silva and Schnell 2010; Ayala-Silva et al. 2013). Procedures to preserve them by in vitro culture and cryopreservation are mostly emerging.

Thus, the lack of appropriate methods for long-term and sustainable conservation is the major hurdle in effective conservation and use of tropical fruit species genetic resources (Arora and Rao 1998; Normah et al. 2002). Plant genetic resources in horticultural crops and their wild relatives are of immense value to mankind as they provide food, fuel, shelter and industrial products (Drew et al. 2007; CGIAR 2013). The plant breeders require reservoir of genetic variation (gene pools) for crop improvement. The larger the reservoir, the better are the chances of finding particular characters such as resistance genes for diseases, viruses, fungus and insects or for adaptation to wider ecological amplitudes and stress conditions (Prance and Nesbit 2005). However, in the wake of spread of high yielding varieties, this genetic variability encompassing landraces is increasingly getting eroded resulting in the large scale weakening of variability. This situation thus demands priority action to conserve such germplasm (Prance and Nesbit 2005; Vaughan et al. 2007; Gross and Olsen 2009). Worldwide apprehension about loss of precious genetic resources has encouraged international action to save prized food sources and breeding materials (Drew et al. 2007; CGIAR 2013; Hummer et al. 2011). Various countries have realized and paid attention to collect and preserve genetic resources. Consequently, repositories have been established in China, USA and France and the germplasm has been evaluated for agricultural and biological characters (CGIAR 2013). The process of genetic erosion in *Persea* germplasm has been recognized, and attempts have been made to conserve such a precious germplasm with minimal cost and resources and appropriate methods (Campbell and Malo 1976; Ben-Ya'acov et al. 1999; Ben-Ya'acov et al. 2003; Crane et al. 2013).

In vitro culture method has high degree of genetic steadiness and symbolizes an aseptic resource of plant multiplication (Reed 1990; 1995; Sahijram and Rajasekharan 1996; Reed et al. 2004; Reed 2008). A number of fruit plants are normally propagated vegetatively, and the clonal material carries variable gene combinations. These clones are maintained in field gene banks of which the traditional methods are expensive due to: (i) high labor costs, (ii) vulnerability to environmental hazards and (iii) requirement for large amount of space (Towill and Ross 1989). The most serious problem is the vulnerability of such clones to pests and pathogens, or natural disasters like earth quake and landslides, to which they are almost continuously exposed (Altieri and Merrick 1987). This can lead to unexpected loss of priceless germplasm. Such field gene banks do not represent the entire range of genetic variability within the respective genus (Ben-Ya'acov et al. 1995; Hoisington et al. 1999; Gross and Olsen 1999; Janick 2005). This has led to the consideration of *in vitro* techniques and cryopreservation for germplasm conservation (Janick 2005; Cruz-Cruz et al. 2013).

5.1 In Vivo Conservation

(Ex *situ)* conservation includes germplasm banks, botanical gardens, seed banks, DNA banks and techniques involving tissue culture, cryopreservation; incorporation of disease, pest and stress tolerance traits through genetic transformation and ecological restoration of rare plant species and their populations (Merrick 1990; Lavi et al. 2003; Miller and Schaal 2006; Miller and Gross 2011). *Ex situ* conservation has gained international recognition with its inclusion in Article 9 of the Convention on Biological Diversity (CBD 1992). Much of the diversity present in domesticated avocados is currently maintained in germplasm repositories and amateur collections, including a broad spectrum of the selection and propagation of superior genotypes derived from open-pollination progenies (i.e., 'chance seedlings') (Ben-Ya'acov et al. 1992; Postman et al. 2006; Ayala-Silva and Schnell 2010; Ayala-Silva et al. 2013). Avocado genetic resources are maintained ex situ in field repositories at great cost and are always under the threat of bad weather, pests and disease (Darda and Litz 2003; Ayala-Silva et al. 2004, 2010; Drew et al. 2007; Ayala-Silva and Schnell 2010; Ayala Silva et al. 2013). Although vast diversity of cultivars exists, avocado production worldwide is now largely based on the cultivation of a small number of commercial and edible cultivars, which are grafted onto less than a dozen different clonal rootstocks (Ben-Ya'acov et al. 1992; Ben-Ya'acov et al. 1995, 1999; Knight 2002; Bender 2012). Indeed, the major cultivars being grown in Florida, Hawaii and some other areas with similar climates are first or later generation hybrids of Guatemalan and West Indian races (Knight 2002; Crane et al. 2013). The main cultivars grown in California, Israel, South Africa and Australia and similar less tropical climates are hybrids of the Guatemalan and Mexican races (Bergh 1976; Knight 2002). Conservation of old varieties and native wild avocado species serves as a stock and source for gene banks for fruit propagation (Ben-Ya'acov et al. 1992; Ben-Ya'acov et al. 2003; Guillen et al. 2011). Identification, collection and preservation have particular importance in their maintenance (Ayala-Silva and Schnell 2010; Ayala-Silva et al. 2013). *In vivo* management of fruit trees in the form of orchard/ field trees or by establishing their nurseries allow confirmation of their morphological identity. This germplasm stock can be evaluated for resistance to pest, diseases and adverse environments (Ben-Ya'acov et al. 2003; Ayala Silva et al. 2004; Ayala Silva et al. 2007; Ayala Silva et al. 2010). Establishment of fruit nurseries of local germplasm and archaic cultivars is a way of fruit germplasm maintenance, in addition to botanical gardens, park, reserves and orchards. It is an effective method of germplasm collection and preservation to develop a fruit repository (Arora and Rao 1998; Normah et al. 2002; Ayala-Silva et al. 2004; Ayala Silva et al. 2007, 2010). *In vivo* conservation of genetic diversity of the existing collections in Mexico, Guatemala and other Central American countries (i.e. Nicaragua, Costa Rica, Honduras, El Salvador) needs to be reviewed for germplasm conservation and collection (Ben-Ya'acov et al. 1992; Ben-Ya'acov et al. 2003; Ayala-Silva et al. 2004; Ayala Silva et al. 2007; 2010; Guillén et al. 2011). The National Clonal Germplasm Repository (NCGR) in Miami, Florida holds three major taxa of *Persea* and their hybrids (Ayala-Silva et al. 2004; Ayala Silva et al. 2007, 2013; Ayala-Silva and Schnell 2010; Ayala Silva et al. 2013). Wild species around the world are represented by clonal collections and by *in vitro* preservation. Clonal genotypes including varieties cultivated for fruit and used as rootstocks are preserved as living trees, with nearly 5% of the clonal material duplicated as *in vitro* cultures (Sandoval and Villalobos 2002; Witjatsono et al. 2004). At the Miami germplasm repository, over 330 accessions of avocado cultivars are maintained; another 300 are maintained by the Fairchild Tropical Gardens Farm in Homestead Florida and by the University of California at the South Coast station in Irvine, California. In addition, Mexico and Israel maintain their own collections (Ben-Ya'acov et al. 2003; Ayala-Silva et al. 2004, 2007, 2010, 2013; Guillén et al. 2011).Their seedlings and offspring have been selected and were evaluated for different useful characteristics (Schnell et al. 2003). Different agro-ecological habitats in Mexico and Central America are very genetically diverse in tropical fruits, especially avocado. Collection and preservation *in vivo* are essential to preserve the genetic diversity for further use (Ben-Ya'acov et al. 2003; Guillén et al. 2011).

5.2 *In vitro Conservation*

The term tissue culture is commonly used in a very wide sense to include in vitro culture of plant cells, tissues as well as organs. Plant tissue culture is a method or technique to isolate parts of plants (protoplasm, cells, tissues, and organs) and grow them on artificial media in aseptic conditions in a controlled space so that parts of these plants can grow and develop into complete plants. Among other applications, tissue culture has been successfully linked to conservation and exchange of germplasm in horticulture. Avocado genetic resources are maintained ex situ in field repositories at great cost and always under threat of inclement weather, pests and diseases (Ben-Ya'acov et al. 2003; Ayala-Silva et al. 2004, 2010, 2013; Guillén et al. 2011). Cryopreservation is an important alternative method for long-term conservation of plant genetic resources (Reed 1990, 2002, 2004, 2008; Witjaksono et al. 2004). Moreover, it is an important storage method for biotechnology research, in which experimental materials (i.e., embryogenic cultures) lose morphogenic competence relatively quickly and cannot be stored reliably in vitro (Sahijram and Rajasekharan 1996; Reed 2001; Efende and Litz 2003; Witjaksono et al. 2004; Reed et al. 2005). The conventional methods of maintaining avocado germplasm under field, nursery and orchard conditions require extensive space and labor (Sandoval and Villalobos 2002; Ayala-Silva et al. 2010; Padulosi et al. 2012).

It is very difficult to conserve avocado germplasm by typical methods. *In vitro* tissue culture and cryopreservation techniques have been developed in the past decades; in vitro techniques have been widely developed for over thousands of different species (Reed 1990, 2004; Hummer et al. 2012). Tissue culture systems allow for axenic propagation of plant material with high multiplication rates. Virus-free plants can be obtained through meristem culture, in combination with thermotherapy (Reed 2008; Kapai et al. 2010; Hung and Trueman 2011; Volk 2012). The miniaturization of explants reduces space requirements and consequently labour costs for maintenance of germplasm collections (Mohamed-Yasseen 1993; Zulfiqar et al. 2009). Organized culture systems have a high degree of genetic stability and are more likely to be important for germplasm storage, especially of shoot tips or meristem cultures (Towill and Ross 1989).

In vitro techniques are employed to eliminate diseases. While most fungal and bacterial diseases are eliminated during surface sterilization and culture, viruses and viroids survive through successive multiplication if the mother plant is infected (Reed 2002; Kaviani 2011; Volk 2012). Most can be eliminated by meristem or shoot tip cultures, perhaps in combination with heat or cold therapy (Reed 2004; Volk 2012). Generally, two approaches are used to maintain germplasm collections *in vitro:* (i) minimal growth and (ii) cryopreservation (Reed 2002, 2004, 2008). *In vitro* culture has yielded positive results when juvenile material is used (Cooper 1987; Reed 1990, 2002, 2005; Barceló-Muñoz et al. 1990; Sahijram and Rajasekharan 1996; Reed 2002; Reed 2005); however, low results are obtained with adult explants (Cooper 1987; Pliego-Alfaro et al. 1987). Breeding of avocado rootstocks has been executed almost exclusively by seed. However, this process cannot guarantee the genetic homogeneity of the material because avocado breeds by cross-pollination, which produces highly heterozygotic seedlings (Peterson 1956; Sauls 1994; Lavi and Lahav 2003; Chen et al. 2009). For this reason, clonal propagation is essential when standardized plant rootstocks are required. Through this technique, rootstocks can be propagated that are resistant to adverse conditions such as drought, floods, saline, alkaline or acidic soils, or to diseases such as *Phytophthora* root rot (Pliego-Alfaro et al. 1987; Guillén et al. 2011).

Tissue culture propagation of avocado using axillary buds of adult avocado plants has been described (Barceló-Muñoz et al. 1999; Mohamed-Yasseen 1993; Efendi 2003); however the morphogenetic ability is better in immature tissues than in adult material (Pliego-Alfaro 1988; Mohamed-Yasseen 1993; Efendi 2003). Shoot tips from avocado seedlings and juvenile tissues have been used for in vitro establishment of different avocado materials (Cooper 1987; Pliego-Alfaro 1988; Barceló-Muñoz et al. 1990; Barceló-Muñoz and Pliego-Alfaro 2003). However, the use of juvenile tissues has the disadvantage of genetic variability due to seed propagation of stock plants (Pliego-Alfaro 1988; Zulfiqar et al. 2009), a problem that can be avoided by the effective regeneration from mature avocado explants. Minimal growth conditions for short- to medium-term storage can be performed by reducing temperature from normal incubating temperature to below up to 0 °C depending on the species, addition of growth 22 retardants or by osmotic stress with sucrose or mannitol and maintenance of cultures at a reduced nutritional status (Efendi 2003; Efendi and Litz 2003). The advantage of this approach is that cultures can be readily brought back to normal culture conditions to produce plants on demand. Because methods of micropropagation are now well recognized (Towil 1989; Stushnoff 1991; Witjaksono et al. 1998; Kapai et al. 2010), it is possible to preserve genetic resources of woody species as shoot tip cultures *in vitro* under conditions of minimal growth storage (also called "slow growth" storage or growth suppression) or cryopreservation, which represents a reliable source for maintenance of orchards as a practice of fruit tree conservation (Forsline et al. 1998; AI and Luo 2005; Ellis et al. 2006; Hung and Trueman 2011; Kapai et al. 2010; Kaviani 2011; Kaczmarczyc et al. 2012).

Cryopreservation at ultralow temperatures, e.g. in liquid nitrogen (LN) (−196 °C) offers the possibility for long-term storage with maximal phenotypic and genotypic stability (Towill 1989; Ellis et al. 2006; Benson 2008; Reed 2008). This method is relatively convenient and economical for maintaining a large number of genotypes. To secure avocado germplasm collections, short to medium and long term, *in vitro* storage methods like minimal growth and cryopreservation may be required (Efendi 2003; Effendi and Litz 2003; Drew et al. 2007; Guzmán-Garcia et al. 2012). The first report of successful *in vitro* propagation of avocado was of disks from mature avocado fruits grown on agar nutrient media (Scroeder 1955). *In vitro* conservation techniques, using slow growth storage, have been developed for a wide range of species, including temperate woody plants, fruit trees, horticultural and numerous tropical species (Forsline et al. 1998; Normah et al. 2002; Barceló-Munoz and Pliego-Alfaro 2003; Benson 2008; Guzmán-Garcia et al. 2012). Low temperature (5–12 °C) is suitable for *in vitro* storage of meristem culture of many tropical and subtropical species (Mohamed-Yasseen 1993; Normah et al. 2002; Reed 2004; Guzmán-Garcia et al. 2012). These preservation techniques (slow growth) are less costly and more safe to conserve germplasm (Reed 2008). *In vitro* storage based on slow growth techniques represent alternative strategies to conserve plant genetic resources (Shibli et al. 2006; Rai et al. 2008; Reed 2008; Hung and Trueman 2011). This approach is particularly useful when seed banking is not possible, such as with vegetatively propagated plants, recalcitrant seed species and plants with unavailable or non-viable seeds due to damage of grazing or diseases and large and fleshy seeds (Kaviani 2011; Walters et al. 2013). Slow growth techniques for germplasm preservation have been studied in many countries with respect to various fruit genotypes that are propagated when desired (Ahmed et al. 2010). A large number of tropical and subtropical fruit crop species have highly recalcitrant seeds that often exhibit viability times of just a few weeks (Baranski 2013; Walters et al. 2013). Several vegetatively propagated tropical fruits, including woody perennials, need to be conserved with their genetic fidelity intact. Maintenance and preservation of germplasm of fruits in field genebanks is difficult, expensive and labor-intensive (Ben-Ya'acov et al. 2003; Ayala-Silva et al. 2004, 2010, 2013; Postman et al. 2006; Ayala Silva et al. 2010; Guillén et al. 2011). In addition, the connection may also be vulnerable to natural perturbations. Although conservation of seeds of economically important crops has been practiced since ancient times, it suffers from severe limitations, like low seed viability and heterozygosity.

6 The Avocado Tree

The avocado is a fruit native to the tropical America and subtropical regions of North and South America, where it has been used for thousands of years as a high-priced article of food (Fig. 2). From its natural habitat it has spread worldwide to almost all tropical and subtropical regions of the world (Popenoe 1963; Williams 1976; Nakasone and Paull 1998; Knight 2002; Ospina 2002; Janick and Paul 2008;

Nkansah et al. 2013). *Persea americana* Mill. (Avocado) is a tree crop which originated from the tropics of the western hemisphere and has three general ecological races: Mexican, Guatemalan and West Indian adaptable to a wide range of climatic conditions (Bergh 1969; Morton 1987; Knight 2002; Ospina 2002; Janick and Paul 2008). Avocado trees grow well in areas with over 150 mm of annual rainfall and between 55 and 550 m above sea level. The tree reaches a height of 9–18 m and trunk diameter between 30 and 60 cm. Avocado is a plant of periodic growth where growth rates are affected by local conditions. In areas of constant humidity, avocado grows all year. In drier or cold regions, the tree can go through four annual growth stages and during certain periods can lose a lot of foliage; the main stage usually coincides with flowering (Berg and Ellstrand 1986; Sandoval and Villalobos 2002; Knight 2002; Crane et al. 2013). The new growth of shoots or sprigs occurs only on certain parts of the tree. In years with greater growth, the fruit harvest will be reduced; and in several cultivars the yield is markedly biennial (Condit 1916; Popenoe 1920; Kopp 1966; Williams 1976; Knight 2002; Guillén et al. 2011). The shoots or sprigs are cylindrical or prismatic and have alternative leaves which have axillary buds. The shape of the leaves varies considerably depending on the position. Wild species can reach 20 m in height. It grows well in soils that are loose, well-drained, slightly acid, and rich in organic matter. The tree grows at elevations from sea level to 2400 m, with average temperatures of 16–24 °C and annual precipitation of 800–1700 mm. Wild trees have a spherical crown, the flowers emerge in panicles that sprout from the new growth on the apex of the sprigs or from the axil of the leaves (Popenoe 1920, 1935; Wolfe et al. 1949; Williams 1976; Nakasone and Paull 1998; Ospina 2002; Janick and Paul 2008; Ashworth 2011; Crane et al. 2013). The axis of the panicle is strong and pubescent and carries several deciduous bracts. The tree yields many thousands of flowers per plant. The panicles open up for long periods of weeks or months. However, the number of flowers that yield fruit is 5 % or more. *Persea americana* may be propagated by seedling or grafting. Grafting is recommended for commercial plantings because the fruits of grafted trees have uniform characteristics in size and shape. The terminal bud graft is the easiest and most successful. To produce healthy and vigorous trees, seeds should be selected from good-sized fruits. These seeds should have a higher coefficient of germination and the subsequent seedlings should grow faster. To prevent dehydration, seeds should be planted immediately after extraction from the fruits. Seeds may be preserved in wooden trays with humid sand between 5 and 7 °C. To prevent disease, seeds should be disinfected in hot water (49 °C for 15 min); the ground should be treated with water vapor (90 °C for 4 h or 60 °C for 6 h); and all tools should be treated, possibly with sodium hypochlorite (Wolfe et al. 1949). Avocado is frequently cultivated on hillsides because minimum temperatures are higher than those on flat ground (Bender 2012) while cultivated trees, originating from graft are more tolerant. The avocado tree may be erect, usually to 9 m but sometimes 18 m or more, with a trunk 30–60 cm in diameter, (bigger in very old trees) or it may be short and scattering with branches beginning close to the ground. Almost evergreen, being shed briefly in dry seasons at blooming time. Mexican race are strongly anise-scented. Seedling trees of Guatemalan (var. *guatemalensis*) and West Indian (var.

americana) ecotypes, especially in their native rainforest environments, can reach heights exceeding 30 m, while Mexican (var. *drymifolia*) seedling trees are shorter at 15 m.

6.1 Leaves

Leaves are approximately 7.6–41.0 cm in length and variable in shape (elliptic, oval, lanceolate). They are often hairy (pubescent) and reddish when young, then become smooth, leathery, and dark green when mature (Kopp 1966). The leaves are alternate, dark-green and glossy on the upper surface, whitish on the underside; variable in shape (lanceolate, elliptic, oval, ovate or obovate), 7.5–40 cm long (Morton 1987; Janick and Paul 2008).

6.2 Inflorescence

The avocado has perfect flowers, each capable of producing pollen and developing fruit. But a pollination peculiarity makes it undesirable to plant solid blocks of single cultivars (Wolfe et al. 1949). The many-flowered lateral inflorescences (structures that hold the flowers) are borne in a pseudoterminal position. The central axis of the inflorescence terminates in a shoot. Flowers are perfect, yellowish-green, and 3/8 to 1/2 inch (1–1.3 cm) in diameter. The flowers are hermaphroditic, actinomorphic, greenish-whitish, with short and pubescent pedicels. The perianth is made up of one involucrum, which has interpreted itself as a calyx consisting of six parts that are acute, yellow, pubescent on both surfaces, and arranged in two groups of three. The exterior parts are the largest. It is in fact three sepals and three petals of very similar appearance. There are 12 stamens in four cycles; the first two are external and simple filaments whose anthers open up through four pores located toward the center of the flower. The third cycle consists of three stamens with the pores opened outward; its filaments have, at the base, an orange gland or nectary. The fourth cycle, the innermost one, is made up of staminodia. The pistil is made up of an ovoid, monocarpic, superior, monospermic, unilocular, white, and pubescent ovary, which ends in a short style with a globose stigma. Low fruit yield occurs because the stigmatia receive a few grains of fecundating pollen when the stamens and the pistils in each flower do not mature uniformly (Kopp 1966; Schroder 1952; Peterson 1956; Williams 1977; Bergh and Ellstrand 1986; Scora and Bergh 1990, 1992; Scora et al. 2002).

The flower of avocado is protogynous, e.g. its pistil is receptive before pollen shedding. The flower opens twice for several hours each time and each opening is separated by at least one overnight period. The flower is female during the first opening and male during the second opening. Avocado cultivars fall into one of two flowering groups: A or B (Wolfe et al. 1949; Peterson 1956; Lahav and Gazit 1994). Group A—the first (female opening) starts in the morning and ends before noon. Second (male) opening occurs in the afternoon of the next day; and Group B is the reverse pattern; the female opening happens in the afternoon and male opening next morning (Lahav and Lavi 2002). Length of flowering varies with cultivar and climate. The cooler the temperature, the longer the flowering period. Guatemalan cultivars mostly bloom later than the Mexicans or West Indians (Wolfe et al. 1949; Lahav and Lavi 2002).

6.3 Fruit

The fruit is a berry, consisting of a single large seed, surrounded by a buttery pulp. Indian and Mexican cultivars mature their fruit 150–240 days after flowering, whereas the Guatemalan type take more than 260 days. The skin is variable in thickness and texture. Fruit color at maturity may be green, yellow-green, black, purple or reddish, depending on cultivar. Generally the pulp is entirely pale to rich-yellow, buttery and bland or nutlike in flavor. In shape, the fruit is usually pyriform to oval and round, and the fruit weigh from a few ounces to 5 lbs (2.3 kg). Oil content diverge from 7.8 to 40 % on a fresh weight basis. The seed is oblate, round, conical or ovoid, 2–2 ½ inch (5–6.4 cm) long hard and heavy, ivory in color but enclosed in two brown, thin, papery seed coats often adhering to the flesh cavity. Depending on race type (i.e. Mexican, Guatemalan) the seed may be tight or loose (Popenoe 1935; Wolfe et al. 1949; Morton 1987; Ospina 2002; Janick and Paul 2008).

The time between flowering and harvesting of fruits depends on the race; the Guatemalan cultivars between 8 and 10 months, Mexican cultivars 7–10 months, whereas the West Indian cultivars are between 5–6 months. The fruit does not generally ripen until it falls or is picked from the tree (Campbell and Malo 1979; Morton 1987; Ospina 2002; Janick 2005; Crane et al. 2013). In Florida, the fruit is considered adequately mature for harvest when it reaches a specified calendar date and weight or size. The specific dates, weights, and sizes used to establish maturity vary by cultivar (Wolfe et al. 1949; Campbell and Malo 1976; Crane et al. 2013). Some cultivars may be stored on the trees and harvesting may be manipulated according to marketing schedule. However, West Indian cultivars have little or no storage time, whereas the Guatemalans and Mexican cultivars have a longer tree-storage capability (Janick 2005). The characteristics of the fruit are very variable, depending on the race and the variety. Pear shaped fruits prevail, but spherical and ovoid fruits also exist. They are usually irregular, and the side with more fibers or vascular bundles is thicker. The pericarp is made up of a cortex whose thickness and color vary from yellowish green to purple or almost black; the surface varies from smooth and shiny to corrugated and opaque. The mesocarp is a pulpy, soft mass, yellowish-greenish-white in color, with green pigmentation close to the cortex. The ovoid seed occupies a large part of the fruit; it is made up of two pulpy cotyledons and a small embryo; it contains no endosperm. The time between flowering and harvesting of fruits depends on the race: for the West Indian race it is between 5 and 6 months, for the Guatemalan race between 8 and 10 months, and for the Mexican race between 7 and 10 months (Popenoe 1935; Morton 1987; Ospina 2002; Janick and Paul 2008). The fruits are collected manually using ladders and scissors or knives. Pulling the fruit off can injure and damage it. Because the fruits are delicate, they should not be put on the ground without protection. The stem should be cut close to the fruit to prevent damage to other fruits when packed. Fruits harvested early should be placed in the dark and refrigerated (Crane et al. 2013). The humidity content in seeds with harvest ripeness is approximately 65 % (Ospina 2002; Janick and Paul 2008). The seeds are recalcitrant and lose their viability 2–3 weeks after removal from the fruit. However, the fruits can be stored for periods of more than 8 months in a dry room at 5 °C (Popenoe 1920; Wolfe et al. 1949). Viability can also be maintained for several months by covering the seeds with a powdered fungicide and storing them in wet sawdust or peat in polyethylene bags at 4–5 °C (Popenoe 1920). The critical humidity content (the point to which one can lower the humidity of the seed without losing its viability) is roughly 57.6 % for slow drying and 57.4 % for fast drying (Ospina 2002). The seeds should be pretreated by immersion in water at room temperature for 24 h. About 70 % of the seeds germinate underground in an average of 21 days (Popenoe 1920; Wolf et al. 1949).

6.4 Pollination

Avocado flowers are bisexual, they have a unique flowering behavior and all cultivars and wild species irrespective of race, fall into of two categories. The female and male flower parts function at different times of the day. Varieties are classified into A and B types according to the time of day when the female and male flower parts become reproductively functional (Peterson 1956). Self-pollination occurs during the second flower opening when pollen from the anthers is transferred to the stigma of the female flower parts. Cross-pollination may occur when female and male flowers from A and B type varieties open simultaneously. Self-pollination appears to be primarily caused by wind, whereas cross-pollination is caused by large flying insects such as bees and wasps.

Varieties vary in the degree of self- or cross-pollination necessary for fruit set. Some varieties, such as ‘Waldin’, ‘Lula’, and ‘Taylor’ fruit well when planted alone. Others, such as ‘Pollock’ and ‘Booth 8’ (both B types) do not and it is probably advantageous to plant them with other varieties (A types) which bloom simultaneously to facilitate adequate pollination and fruit set (Campbell and Malo 1976; Morton 1987; Knight 1999; Ospina 2002; Janick and Paul 2008; Crane et al. 2013).

7 Cultivars

A set of morphological and ecological characteristics distinguishes each of the three botanical races of Avocado. The centers of origin for these three races are distinct (Popenoe 1934; Kopp 1966; Bergh and Ellstrand 1986; Knight 2002), and prior to the arrival of the Europeans to the Americas, it is thought that the genetic purity of each race was mostly conserved. This is attributable to the minimal social interchange between the Amerindian tribes that inhabited Mexico and Central America and by significant geographical barriers that exist between the centers of varieties origin (Ashworth et al. 2011; Galindo-Tovar et al. 2007; Landon 2009; Galindo-Tovar et al. 2008). Cultivars grown in tropical and subtropical environments are from the Mexican, Guatemalan and West Indian races and are more adapted to temperatures that exist in these areas. Exploration of Mexico, Guatemala, Honduras, El Salvador, Nicaragua and other countries of Central and Northern South America during early nineteenth century by horticulturists from the USA, provided superior seedlings to the states in California (CA) and Florida (FL) for commercial exploitation, laid the foundations for genetic improvement of avocado for production in these states (Bender 2012). This was somewhat supported by collecting material from already established orchards in Mexico and Nicaragua (Popenoe 1919, 1947, 1951, 1952, 1957; Schroder 1947; Bergh 1957). Avocado cultivars are selected and named because of particularly desirable fruit and tree characteristics. Every avocado tree grown from seed is a potential candidate for selection as a cultivar, because cross-pollination in avocado's reproduction process ensures genetic variability. Once selected, cultivars are propagated by vegetative methods, such as grafting, to produce genetically identical trees (Wolfe et al. 1949; Campbell and Malo 1976; Knight 2002).

7.1 Cultivar Selection Criteria

Important criteria in selecting avocado cultivars can be grouped into (1) production and (2) fruit quality considerations. For home gardens, production characteristics may not be as important as good fruit quality (Bender 2012; Crane et al. 2013). Whereas for commercial growers, production characteristics could be extremely important, but consumer preferences for fruit appearance and quality are also important in determining whether or not a selection is appropriate (Bergh 1969; Campbell and Malo 1976; Bender 2012).

7.2 Cultivars

'Bacon' Mexican X Guatemalan (MXG) hybrid; originated 1928 in Bueno Park, California; trees tall with pointed crowns, leaves have aniseed smell when crushed, red flecking on wood of new shoots; fruit ovate, medium to large size weighing 170–510 g; skin thin, green and glossy with leathery texture; seed size is large (Fig. 3); early maturing with very pale yellow-green flesh; flower Group B; precocious with consistent production and higher yields than 'Fuerte' in colder areas. Cold tolerance is widely reported from California, Australia, Italy and Corsica; frost tolerance is down to 4.4 °C, thus production is suited to colder regions. Susceptible

Fig. 3 'Bacon' (MXG) originated as a seedling tree on the ranch of James E. Bacon in Buena Park, California. The fruit is *dark green*, oval in shape of medium quality and 7–14 ounces in weight. Flower Group B, thin skin, early maturing with very *pale yellow* skin. Considered the most cold-hardy of the commercial varieties

to insect attack, extremely susceptible to anthracnose, unsuitable for humid subtropical areas; skin is susceptible to wind scarring, in severe cases fruit splits exposing seed. 'Bacon' has been used as a pollinator for 'Hass'.

'Beta' Guatemalan X West Indian hybrid (GXW); a 'Waldin' seedling selected at the home orchard of W.H. Krome, Homestead, Florida; fruit elliptical, medium to large size weighing 453–680 g, 84–89 mm diameter; skin is green, smooth; seed is medium sized, tight in cavity; harvested mid-season with fair quality flesh; oil content unknown; moderate cold tolerance; flower Group B; recommended post-harvest storage temperature 4–10 °C. Defects include overbearing and limb breakage (Wolfe et al. 1949; Campbell and Malo 1979; Crane et al. 2013).

'Choquette' (G X WI) Guatemalan X West Indian hybrid; seedling of unknown origin selected at the property of R.D. Choquette, Miami, Florida, and first fruited in 1934; flower Group A; fruit elliptical, flattened obliquely toward apex on one side, central pedicel insertion, medium to large size weighing 510–1133 g, 95–111 mm diameter; skin is light to dark green, nearly smooth with some undulations, glossy, somewhat leathery; seed is medium large, fairly tight in cavity (Fig. 4); harvested

Fig. 4 ‘Choquette’ (G X WI) Guatemalan X West Indian hybrid; seedling of unknown origin; first fruited in 1934; flower Group A; fruit elliptical, medium to large size weighing 510–1133 g, 95–111 mm diameter; skin is *light* to *dark green*, glossy, somewhat leathery; seed is medium large, good to excellent quality flesh; oil content is 8–13 %; moderately high cold tolerance

mid-to-late season with good to excellent quality flesh; oil content is 8–13 %; moderately high cold tolerance; recommended postharvest storage temperature 4–10 °C. Defects include some susceptibility to Cercospora spot (Wolfe et al. 1949; Campbell and Malo 1976; Crane et al. 2013).

‘Dickinson’ (G) Guatemalan hybrid; a California selection, first propagated in 1912; fruit oval to obovate; small to medium; skin dark-purple with large maroon dots, rough, very thick, granular, brittle; flesh of good quality; seed small to medium, tight (Fig. 5); flower Group A; %Ratio Seed/Skin/Flesh: 13:21:66. Season: June-October in CA; February and March in FL; January and February in PR. Tree is a moderate but regular bearer; in Israel ‘Dickinson’ is described as round, small to

Fig. 5 'Dickinson' Guatemalan hybrid; oval to obovate; small to medium; skin *dark-purple* with large *maroon dots*, rough, very thick, granular, brittle; flesh of good quality; seed small to medium, tight; flower Group A; %Ratio Seed/Skin/Flesh:13:21:66

large, very thick-skinned with very large seed; of poor quality, not worth growing. It is no longer grown as a commercial cultivar in Florida or California.

'Duke' Mexican (M) Tree originated in 1912 from seed planted at Sunny-slope Nursery, Bangor, California. Color green, weight 227–340 g; shape pyriform; skin nearly smooth; quality excellent; oil content 21 %. Seed medium, sometimes loose. Flower group A. Season: September to November in CA; late July or mid-August to mid-September in Israel. Tree is large, symmetrical and wind and cold-resistant, and also highly resistant to root rot, especially when grown from cuttings. Vigorous, very hardy to cold, wind resistant, productive. Fine for home planting in cold

Fig. 6 Fuchsia (WI)—seed of unknown origin planted in Homestead, FL, around 1910; propagated commercially in 1926; pear shaped to oblong, sometimes with a neck; of medium size; skin smooth; flesh *pale greenish-yellow*; 4–6 % oil. Tree not very prolific in Florida; no longer popular in commercial groves

interior districts. It is a poor bearer in some areas of CA; however, has borne 168 lbs (78 kg) annually from the 6th to the 15th year in Israel.

'Fuchsia' (Fuchs) West Indian (WI). Originated on the place of C.T. Fuchs Sr., near Homestead, FL, around 1910; first fruited in 1916. Propagated commercially in 1926; pear shaped to oblong, sometimes with a neck; of medium size; skin smooth; flesh pale greenish-yellow (Fig. 6); oil content 4–6 %; good flavor; seed loose in the large cavity. Flower group A; this cultivar is thrifty, prolific and precocious. Season: early June-August; sensitive to damage during shipping. Tree not very prolific in FL; no longer popular in commercial groves.

'Gottfried' Seed of a seedling on Key Largo planted at USDA, Miami, in 1906; distributed in (1918); pear shaped; medium size; skin smooth, purple; flesh of excellent quality, 9–3 % oil; seed medium. Flower group A; Season: August to October.

Tree prolific in CA; a poor bearer in southern FL and subject to anthracnose, but hardy and desirable for home gardens on west coast of FL.

'Hass' (G) Cultivar, predominantly Guatemalan but with some Mexican genes. A chance seedling of unidentified parenting, selected by Mr. Ruddolph Hass in 1935 in California. Hass makes up more than 85 % of all avocados grown and sold worldwide. Hass avocado is more oval than other varieties and has distinctive pebbly skin which turns a rich purple when ripe. On average, this type has a small seed, weighs about 140–340 g and contains a good amount of edible flesh. %Ratio Seed/Skin/Flesh:16:12:72. Flower Group A. Hass avocados grow almost all year round in different regions of California. Hass is also recognized to have several shortcomings, including poor fruit set in some locations, sensitivity to saline irrigation water, intolerance to cold temperature below 30°F (Bergh 1984), and susceptibility to Persea mites and avocado thrips (Wolfe et al. 1949; Campbell and Malo 1979; Crane et al. 2013).

'Lula' Guatemalan X West Indian (GXWI) hybrid; believe to be a seedling of 'Taft'. Originated at the property of G.B. Cellon (Miami, Florida) and named for his wife, first fruited in 1919; flower Group A; fruit pyriform, fruit apex rounded, level pedicel insertion, medium to large size weighing 397–680 g, 81–105 mm diameter; skin is green to dark green, nearly smooth, slightly rough; seed is large, tight in cavity (Fig. 7); harvested late-season with good to excellent quality (slightly sweet) flesh, 65 % edible pulp, oil content is 6.0–15 %; high cold tolerance. Flaws include fruit highly vulnerable to scab and difficult to control tree size (Wolfe et al. 1949; Campbell and Malo 1979; Crane et al. 2013).

'Mexicola' Mexican (M) Originated brought about 1910 at Pasadena, California and propagated about 1912; very small; skin black; flesh of excellent flavor; seed large. Flower Group A. %Ratio Seed/Skin/Flesh:27:12:61, Season: August to October; grown only in home gardens in California and maintained in germplasm collections for breeding purposes. Producing early and regularly; very heat- and cold-resistant; much used as a parent in CA breeding programs.

'**Monroe'** Guatemalan (G)—West Indian hybrid; seedling of unknown parentage originating at the orchard of J.J.L. Phillips, Homestead, Florida, first fruited in 1935; flower Group B; fruit elliptical, flattened obliquely toward apex on one side, asymmetrical pedicel insertion, medium to large size weighing 453–1133 g; 92–111 mm diameter; skin is dark green, glossy, slightly rough; seed is medium large, tight in cavity; harvested late-season with good to excellent quality flesh (Fig. 8), oil content is 6.1–14 %; Flower group A; moderate cold tolerance; safest low storage temperature 4–10 °C. Defects include fruit moderately susceptible to scab, Cercospora spot and anthracnose, fruit drop, and limb breakage (Wolfe et al. 1949; Campbell and Malo 1979; Crane et al. 2013).

'Nabal' (G) Introduced from Guatemala by Wilson Popenoe in 1917. Propagated commercially in CA since 1927 but in FL only since 1937. Fruit almost round, of medium size, 400–680 g. Skin nearly smooth, dark green. Flesh yellow, of good flavor. Seed medium small, tight in cavity (Fig. 9). Oil content 10–15 %. Flower Group B. %Ratio Seed/Skin/Flesh:10:10:80. Season January and February in CA,

Fig. 7 'Lula' (GXWI) Guatemalan West Indian hybrid; flower Group A; fruit pyriform, medium to large size weighing 397–680 g, 81–105 mm diameter; skin is *green* to *dark green*, nearly smooth, slightly rough; seed is large, tight in cavity; harvested (slightly sweet) flesh, 65 % edible pulp, oil content is 6.0–15 %; high

November–December FL. In CA has fruited heavily but in FL restricted to some areas in Dade County.

'Semil 34' (GXW) A Guatemalan X West Indian hybrid from a seedling selected at Finca El Semil, Villalba, Puerto Rico in 1947. Fruit (Fig. 10) is obovate/pyriform and flattened, weight 396–700 g and typically 84–92 mm in diameter, but could be larger; the peel is green, slightly bumpy to smooth and glossy (Fig. 10). In flower Group A; the seed (Fig. 10) is medium size and tight with good to excellent quality edible pulp (78 %). Fruit are harvested mid-season, fruit oil content is 7.5–15 %. Considered one of the major cultivars grown in Dominican Republic (Wolfe et al. 1949; Campbell and Malo 1979).

Fig. 8 'Monroe' West Indian hybrid; seedling of unknown; flower Group B; fruit elliptical, medium to large size weighing 453–1133 g; 92–111 mm diameter; skin is *dark green*, glossy, slightly rough; seed is medium large, tight in cavity

'Sharwil' (GXM) Predominantly Guatemalan with some Mexican genes; selected in 1951 by Sir Frank Sharpe at Redland Bay, Queensland, parentage unknown, the name 'Sharwil' being an mixture of Sharpe and Wilson (J.C. Wilson being the first propagator); trees are large and rounded in shape, broad crown, extremely vigorous, forming a large dome, more upright than 'Fuerte'; new leaves (Fig. 11) distinctively red but changing to green when fully grown, red flecking on wood of new shoots; fruit are pyriform to ovate, medium size weighing 245–475 g; skin is medium to thick, green, medium gloss, corky with wrinkled surface; seed size is small, conical; mid-season maturity with buttery to golden-yellow flesh (Fig. 11), excellent quality with rich nutty flavor, and high palatability over the full maturity

Fig. 9 'Nabal' Budwood brought from Guatemala in 1917; propagated in CA since 1927, in FL from 1937 an in Israel since 1934, nearly round; medium to large; skin nearly smooth, thick, granular; flesh of high quality, *green* near skin; 10–15 % oil in Florida, 18–22 % in Queensland

range (21–30 % dry matter); flower Group B; fruit stores well both on tree and post-harvest. Has potential to set heavy crops but flowering and fruit set are susceptible to cool temperatures, thus reliable production only occurs in warm subtropical climates; has poor tolerance to sub-zero temperatures. Good tolerance to anthracnose and insect pests due to medium to thick skin. One of the most vulnerable cultivars to boron deficiency. Growth is vigorous but large limbs are brittle with protection from strong winds required (Wolfe et al. 1949; Campbell and Malo 1979).

'Simmonds' West Indian (WI); a seedling of 'Pollock' selected at the United States Department of Agriculture (USDA) Subtropical Horticulture Research Station in Miami, Florida; first fruited in 1913. Flower Group A; fruit obovate, flattened obliquely toward apex on one side, asymmetrical pedicel insertion, medium to large size weighing 453–963 g, 78–98 mm diameter; skin is light green to green, smooth, glossy; seed medium sized, tight in cavity; harvested early season with good to excellent quality flesh, 76 % edible pulp, oil content is 3.3–5.0 %; tree has low cold tolerance; recommended postharvest storage temperature 13 °C. Defects

Fig. 10 ‘Semil 34’ (GXWI)- A Guatemalan X West Indian hybrid from a seedling selected at Finca El Semil, Villalba, Puerto Rico in 1947. In flower Group A. Fruit is obovate/pyriform, weight 396–700 g with good to excellent quality edible pulp

include low cold tolerance, lack of vigor and excessive fruit drop (Wolfe et al. 1949; Campbell and Malo 1979; Crane et al. 2013).

‘Taylor’ Guatemalan (G); originated of the California Guatemalan cultivar ‘Royal’ donated to the USDA Subtropical Horticulture Research Station (formerly the United States Plant Introduction Garden), Miami, Florida, named after Dr. Taylor of the USDA, first fruited in 1913; propagated commercially in 1914; flower Group A; fruit obovate to pyriform with rounded base (Fig. 12), pedicel insertion is central, small to medium size weighing 340–510 g, 79–86 mm diameter; skin is dark green, rough-pebbled; seed medium sized, tight in cavity; with excellent quality flesh (Fig. 12), 60–69 % edible pulp, oil content is 12–17 %; flower Group A; harvested mid-to-late-season high cold tolerance; recommended postharvest storage

Fig. 11 'Sharwil' Predominantly Guatemalan with some Mexican genes; selected in 1951 by Sir Frank Sharpe at Redland Bay, Queensland; trees are large and rounded in shape, broad crown, extremely vigorous, forming a large dome, *buttery* to *golden-yellow* flesh, excellent quality with rich nutty flavor

temperature 4 °C. One of the first Guatemalan varieties to be planted commercially, still popular in some places (Chile).

'Tonnage' Guatemalan (G) Seedling of 'Taylor' selected at the orchard of D.M. Roberts, Homestead, Florida, and first fruited in 1921; fruit (Fig. 13) pyriform with rounded base, pedicel insertion very asymmetrical, small to medium size weighing 340–567 g, 76–90 mm diameter; skin (Fig. 13) is pebbled, dark green, glossy, thick; seed (Fig. 13) medium sized, fairly tight in cavity; harvested mid-season with fair quality flesh, oil content is 8–10 %; flower Group B; high cold tolerance; recommended postharvest storage temperature 4–10 °C. Defects include only fair fruit quality, upright growth habit and fruit is moderately vulnerable to scab (Wolfe et al. 1949; Campbell and Malo 1979; Crane et al. 2013).

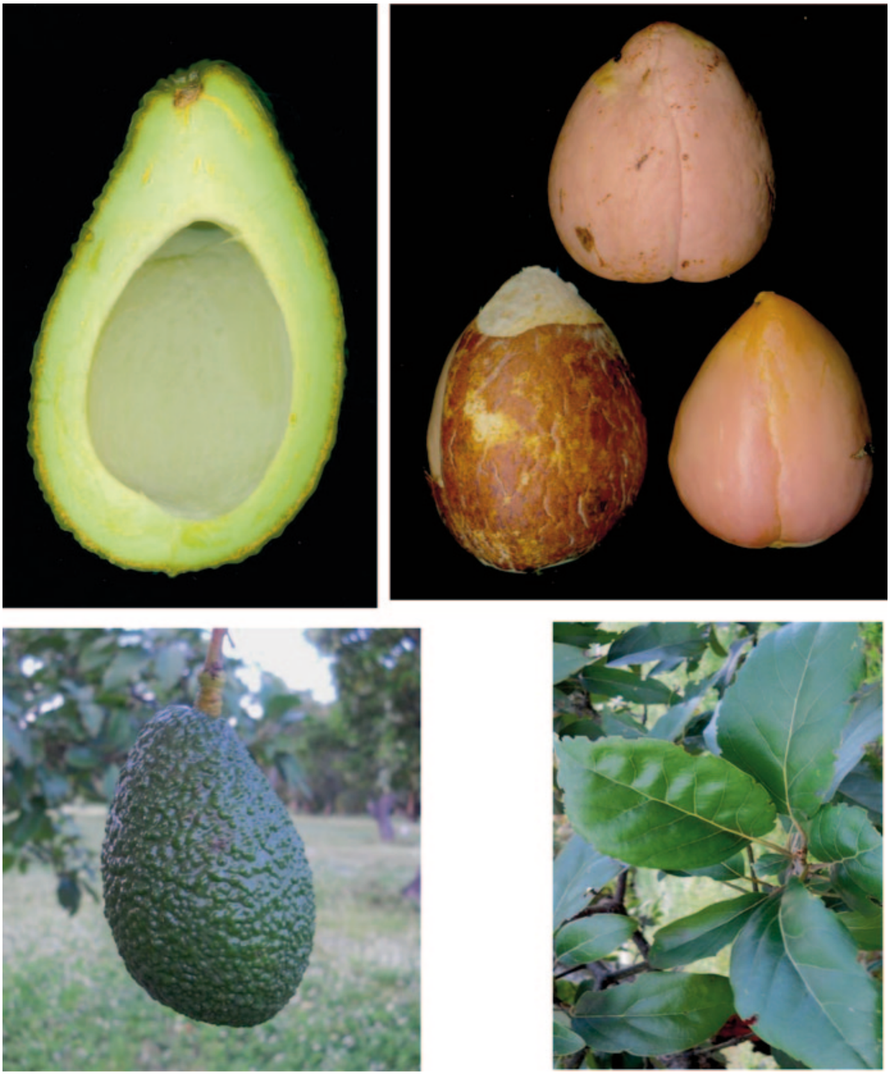

Fig. 12 'Taylor' (G) Guatemalan; seedling of the California Guatemalan cultivar 'Challenge' or 'Royal'; named after Dr. Taylor of the USDA, flower Group A; fruit obovate to pyriform, excellent quality flesh, 60–69 % edible, oil content is 12–17 %; high cold tolerance

'Waldin' West Indian (WI); seedling of unknown parentage selected at the property of B.A. Waldin, Homestead, Florida, and first fruited in 1913; flower Group A; fruit ellipsoid-spheroid (Fig. 14), flattened obliquely toward apex on one side, central pedicel insertion, medium to large size weighing 397–680 g, 87–102 mm diameter; skin is pale green to greenish-yellow, smooth, leathery (Fig. 14); seed is medium to large, fairly tight in cavity (Fig. 14), seed used for rootstock; harvested mid-season with good to excellent quality flesh, 64 % edible pulp, oil content is

Fig. 13 'Tonnage' (G) Guatemalan seedling of 'Taylor'; flower Group B; fruit pyriform with rounded base, fruit small to medium size weighing 340–567 g, skin is pebbled, *dark green*, glossy, thick; seed medium sized, fairly tight in cavity; with fair quality flesh, oil content is 8–10%; high cold tolerance

6–12%; tree has low cold tolerance; recommended postharvest storage temperature 13 °C (Table 1).

8 Production

Some of the main avocado producing countries (Mexico, Chile, USA, Australia, South Africa, Israel,) production is discussed in detail. Mexico is the world's largest producer of avocados, representing over one-third of global production (FAO 2013).

Fig. 14 'Waldin' (WI) West Indian; seedling of unknown parent; flower Group A; fruit ellipsoid-spheroid, fruit medium to large size weighing 397–680 g, 87–102 mm diameter; skin is *pale green* to *greenish-yellow*, smooth, leathery; seed is medium to large, fairly tight in cavity

Chile was the second largest producer in 2011 (330,000 t) accounting for nearly 6.5 % followed by Dominican Republic and Indonesia with about 6.0 % each (FAO 2013) Table 2. World production of avocados is expected to rise in the 2013/2014 period owing to improved production by the major avocado exporting countries, improvement in phytosanitary conditions, border restrictions lifted, reductions in trade barriers and advances in transportation and post-harvest technologies. As a result, Mexico and Chile will continue to dominate the export trade, while the United States could remain the number one importer of avocados. The main avocado producing countries (Mexico, Chile and Dominican Republic) as well as the other main producing countries is discussed in detail (Table 2).

Table 1 Comparison of selected characteristics of the three species (races) of *Persea americana* Mill. (Source: Berg and Lahav 1996; Bergh and Ellstrand 1986; Ayala-Silva et al. 2002)

		Race		
Traits		Mexican	Guatemalan	West Indian
Tree				
General	Origin	Subtropical	Subtropical	Tropical
	Climate	Most	Intermediate	Least
	Cold tolerance	Least	Intermediate	Most
	Salt tolerance	Intermediate	Least	Most
	Alternate bearing	Less	More	Less
Form	Internodes	Longest	Long	Shortest
	Twig lenticels	Pronounced	Absent	Absent
	Bark roughness	Less	Less	More
	Stem pubescence	More	Less	Less
Leaf	Size	Smallest	Large	Largest
	Colour	Green	Green	Pale green
	Flush colour	Greenest	Reddest	Yellowish-green
	Anise	Present (usually)	Absent	Absent
	Underside waxiness	More	Less	Less
Fruit				
Flower	Season	Early	Late	Early-Intermediate
	Bloom to maturity	5–7 months	10–18 months	6–8 months
	Perianth persistence	Greater	Less	Less
Stem	Length	Short	Long	Short
	Thickness	Medium	Thick	Thin
	Shape	Cylindrical	Conical	Nailhead
Fruit	Size	Tiny–Medium	Small–Large	Medium–Very large
	Shape	Mostly elongate	Mostly round	Variable
Pulp	Flavour	Anise-like, spicy	Often rich	Sweet, mild
	Oil content	Highest	High	Low
	Distinct fibers	Common	Less common	Intermediate
Skin	Color	Usually purple	Black or green	Pale green/maroon
	Surface	Waxy coating	Variably rough	Shiny
	Thickness	Very thin	Thick	Medium
	Stone cells	Absent	Present	Slight
	Pliability	Membranous	Stiff	Leathery
	Peeling	No	Variable	Yes
Seed	Seed/Fruit ratio	Large	Often small	Large
	Coats	Thin	Usually thin	Thick
	Tightness in cavity	Often loose	Tight	Often loose
	Surface	Smooth	Smooth	Rough
Oil content		Highest	High	Lowest

Table 2 World avocado production by country from 2008 to 2011. (FAOSTAT Database 2012)

Country	2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011
	Area harvested (Ha)				Yield (Hg/Ha)				Production (t)			
Australia	9827	10,249	9800	9500	45,792	37,543	38,061	38,237	45,000	38,478	37,300	36,325
Bolivia	497	880	871	870	66,519	63,273	63,054	63,253	3306	5568	5492	5503
Brazil	9453	8411	11,111	10,753	155,733	165,366	137,871	149,145	147,214	139,089	153,189	160,376
Cameroon	14,000	13,800	14,200	13,999	39,286	39,130	39,437	49,669	55,000	54,000	56,000	69,532
Chile	33,800	33,500	34,057	36,388	97,929	97,910	96,896	101,288	331,000	328,000	330,000	368,568
China	14,000	15,000	15,000	16,000	67,857	66,667	68,000	67,813	95,000	100,000	102,000	108,500
Colombia	18,470	19,255	21,592	24,514	99,604	98,171	95,148	87,744	183,968	189,029	205,443	215,095
Costa Rica	5117	5431	5810	5615	40,934	40,447	43,453	48,012	20,946	21,967	25,246	26,959
Côte d'Ivoire	4700	4600	5300	5200	58,936	58,913	59,811	59,615	27,700	27,100	31,700	31,000
Democratic Republic congo	8766	8886	9008	8881	74,401	74,400	74,396	93,694	65,220	66,112	67,016	83,210
Dominican republic	5832	7183	10,558	10,649	322,598	256,644	273,430	277,109	188,139	184,357	288,684	295,081
Ecuador	2900	2950	2957	2776	95,472	94,915	98,025	98,667	27,687	28,000	28,986	27,390
El Salvador	1450	1481	440	639	14,724	14,733	42,759	45,180	2135	2182	1880	2887
Ethiopia	6473	5067	5694	7212	40,331	64,046	66,124	79,450	26,106	32,452	37,651	57,299
Ghana	1685	1754	1770	1817	47,478	48,683	47,458	46,780	8000	8539	8400	8500
Guatemala	9293	9363	9435	9246	103,304	105,350	99,932	98,915	96,000	98,639	94,286	91,457
Haiti	8568	9692	10,595	9731	52,521	45,448	46,282	53,105	45,000	44,048	49,036	51,676
Honduras	380	390	413	414	43,421	43,590	43,535	48,502	1650	1700	1798	2008
Indonesia	19,802	19,979	20,507	21,653	123,328	128,956	109,367	127,443	244,215	257,642	224,278	275,953
Israel	6270	6480	6565	6780	84,737	131,124	105,933	111,043	53,130	84,968	69,545	75,287
Jamaica	307	338	354	364	60,293	68,195	64,633	67,335	1851	2305	2288	2451
Kenya	7900	10,053	10,320	11,246	131,042	144,438	196,021	179,155	103,523	145,204	202,294	201,478
Madagascar	3026	2639	2938	3202	79,313	97,620	88,768	80,050	24,000	25,762	26,080	25,632
Mexico	112,479	121,491	123,403	126,598	103,346	101,322	89,717	99,855	1,162,429	1,230,973	1,107,135	1,264,141
Morocco	1972	1863	1868	2539	97,632	139,560	180,112	132,017	19,253	26,000	33,645	33,519

Table 2 (continued)

Country	2008	2009	2010	2011	2008	2009	2010	2011	2008	2009	2010	2011
	Area harvested (Ha)				Yield (Hg/Ha)				Production (t)			
New Zealand	4000	4117	4000	3976	42,500	49,794	49,740	48,250	17,000	20,500	19,896	19,184
Panama	960	1001	1094	1098	41,771	41,039	38,464	93,980	4010	4108	4208	10,319
Paraguay	2411	2400	2691	2446	55,006	58,333	55,622	58,418	13,262	14,000	14,968	14,289
Peru	14,370	16,292	17,750	19,314	94,852	96,621	103,870	110,209	136,303	157,415	184,370	212,857
Portugal	11,600	11,067	11,000	10,981	14,009	14,457	15,311	14,659	16,250	16,000	16,842	16,097
Puerto Rico	811	918	1004	922	24,661	21,329	21,713	24,913	2000	1958	2180	2297
Réunion	69	72	80	87	79,710	80,139	75,000	68,736	550	577	600	598
South Africa	16,000	14,500	15,000	16,346	52,209	52,914	55,469	46,028	83,534	76,726	83,204	75,237
Spain	10,023	10,016	10,434	10,558	73,416	71,816	72,508	79,017	73,585	71,931	75,655	83,426
United States of America	29,473	26,819	24,253	24,261	35,704	100,978	65,208	98,324	105,230	270,813	158,150	238,544
Venezuela	6396	7000	7647	7673	112,212	107,143	95,530	106,334	71,771	75,000	73,052	81,590

Not in ranking order

8.1 Mexico

The avocado production forecast for MY 2012/13 (July/June) is 1.3 million metric t (MMT). The forecasted increase over MY 2011/2012 is based on expected good weather and a mild winter. Implementation of phytosanitary pest control programs has also helped boost production. Production estimates for MY 2011/2012 are 1.26 MMT, higher than previously expected due to a mild winter and good weather conditions (FAS 2013). Total area planted for MY 2012/2013 is forecast at 150,000 ha, an increase of more than 5% over MY 2011/2012, as growers in different states in Mexico are interested in increasing area due to good domestic and international demand for Mexican Hass avocados. The area planted and harvested for MY 2011/2012 increased compared to MY 2010/2011 (FAS 2013). Growers forecast avocado exports higher for MY 2012/2013 compared to MY 2011/2012 or about 500,000 MT. Exports have been increasing due to a good international demand and year-round market access to all 50 U.S. states. According to the Global Trade Atlas, exports for MY 2011/2012 are estimated at 409,761 MT, however, the industry estimates exports at about 460,000 MT. U.S. imports are estimated at about 360,923 MT according to the Census Bureau. According to the Global Trade Atlas, avocado exports for MY 2010/2011 were estimated at 318,462 MT, however the industry estimates exports at about 360,000 MT. U.S. imports were estimated at 281,671 MT according to the Census Bureau (FAS 2012). The Unites States is the top export market for Mexico, consuming 75% of total exports. Japan and Canada are strategic market niches where Japan has about 10% of the market and Canada about 7%. Currently, 34 packers in Michoacan are eligible to export Mexican avocados to the United States (FAS 2012).

8.2 Chile

Chilean avocado production is expected to increase during the current 2013/2014 production season compared to last season. Normal weather conditions are responsible for the increase in production and subsequently exports for this season. For the 2014/2015 season, output is forecasted to increase, as an abundant blooming in most production areas forecasts strong production if weather conditions remain normal. A little over 98% of all Chilean commercial avocado trees are planted in the central area of the country from Region IV through Region VI. Almost all the planting expansion has been of the Hass variety in the last decade, and there are over 20 other varieties planted in Chile. Of the total planted area in Chile, around 30,000 ha are planted as e Hass avocado variety, which represents almost 100% of total exports (99.8%) (FAS 2013). Although declining in importance, the United States is still largest export market for Chilean avocados, followed by the Europe. The US market received 45% of Chile's total avocado exports in 2012, down from over 66% in the previous year. Exports to the EU have increased over the last few years as a result of a big industry effort made to diversify their markets (FAS 2013).

8.3 Dominican Republic

The Government's support to avocado producers of the Dominican Republic has generated a substantial increase in exports of fruit to international markets, with a volume of 20,000 t per year and a foreign exchange contribution that exceeds 30 million dollars. A report from the Department of Fruit of the Ministry of Agriculture indicates that the Dominican Republic has a stable production of avocado with a tendency to increase since, in 2012, 1000 containers of 35,000 units each were exported while, this year, more than 800 containers were exported. The average production per year is 250,000 t of avocado, close to 20 % of which is exported, especially the Semil-34, Jass, Carla and Pollock varieties. The support of the Ministry of Agriculture to avocado growers consists of the delivery of supplies, training, certification of good agricultural practices, market management and the repair and maintenance of roads. Besides, the Special Fund for Agricultural Development (FEDA), through the Agricultural Bank, has funded avocado growers from Cambita, Garabito, in San Cristóbal, with 90 million pesos. The largest fruit production areas are located in San José de Ocoa, Cambita, in San Cristobal; Villa Trina, in Espaillat; Altamira and Mamey, of Puerto Plata; Amina, in Valverde; The Calimetes, in Elías Piña; Padre Las Casas, in Azua; Los Arroyos, in Pedernales; in Peravia and in Neyba.

8.4 United States of America

The value of U.S. avocado production increased from $ 479.1 million in 2010 to $ 492.1 million in 2011. The total volume amounted to 226,450 t, an increase of more than 52,120 t from 2010. According to NASS (2012), the California avocado crop jumped to 195,000 t, while the Florida crop rose to 31,100 t. The number of acres under production stabilized at 59,950 and the yield per acre dramatically increased to 3.8 t. The value of avocado imports into the United States has increased substantially over the past two decades, reaching nearly $ 913 million in 2011. Of that amount, more than $ 17.2 million was for imported organic avocados. Once again, Mexico supplied most of the avocados imported into the United States in 2011, followed by Chile (FAS 2011).

Conclusion

Avocado has been the favored fruit of many people in Mesoamerica dating back to 10,000 BC. It is unique amongst the fruits and it is neither sweet nor bitter. Some superior cultivars have anise or nutty flavor. Today avocado brings pleasure to hundreds of millions of people worldwide. At the beginning of the twentieth century, the Avocado made its first steps on the United States (CA and FL) market, and total consumption on last year was close to 600,000 t. Now a day's quality enhancement of the fruit allows for long distance shipping in shorter periods of time. Avocado is consume now worldwide and the forecast is for consumption to increase. The increase in productivity has increased in the last decades and work including new biotechnology such as molecular markers, preservation in tissue culture and cryopreservation will assist with the breeding and improvement of the fruit. The nutritional importance of the avocado and its worth on promoting good health and the increasing use of its oils and secondary products for cosmetics will benefit the prospects for a significant increase in avocado consumption.

The outlook of the avocado breeding as a whole is increasing with new development of techniques and its full prospective have not yet been exploited given all genetic resources and new technology available.

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References

Abraham JD, Takrama JF (2013) Morphological and genetic diversity of *Persea americana* mill. (Avocado) in two regions of Ghana. Tropentag 2013, Stuttgart, Germany, 17–19 Sept 2013

Acosta Jose [1590] (1985) Historia Natural y Moral de las Indias. 2nd ed. Fondo de Cultura Económica. México

Ai P, Luo Z (2005) Cryopreservation of dormant vegetative buds and genetic stability of regenerated plantlets in persimmon. Acta Horticult 685:85–92

Altieri MA, Merrick LC (1987) In situ conservation of crop genetic resources through maintenance of traditional farming systems. Econ Bot 41:86–96

Arora RK, Rao VR (eds) (1998) Tropical fruits in Asia: diversity, maintenance, conservation and use. Proceedings of the IPGRI-ICAR-UTFANET regional training course on the conservation and use of germplasm of tropical fruits in Asia held at Indian Institute of Horticultural Research, Bangalore, India, 18–31 May 1997

Arpaia ML (1997) Avocado germplasm preservation. California Avocado Society, avocado research project plan and grant requirement. University of California, Riverside

Arpaia ML, Harley S (2012) 2011–12 Production research report California avocado plant improvement planning meeting: taking advantage of what we learned from avocado brainstorming 2011

Ashworth VETM, Clegg MT (2003) Microsatellite markers in avocado (*Persea americana* Mill.): genealogical relationships among cultivated avocado genotypes. J Hered 94:407–415

Ayala-Silva T, Schnell II RJ, Meerow AW, Goenaga RJ, Zee FT (2004) Current status of the subtropical and tropical germplasm repositories of the national plant germplasm system. Proceedings of Florida State Horticultural Society 117:182–187

Ayala-Silva T, Schnell II RJ, Goenaga RJ, Zee FT, Irish BM (2013) The national plant germplasm system: the subtropical and tropical fruit genebanks. Acta Horticult 975:43–54

Ayala-Silva T, Schnell II RJ, Meerow AW, Winterstein MC (2007) Phenotypic characterization of fifteen commercial and rootstock avocado varieties. Proceedings VI World Avocado Congress, Viña del Mar, Chile, 12–16 Nov 2007

Baranski M (2013) Seed collection and plant genetic diversity, 1900–1979. *Embryo Project Encyclopedia* (2013-11-01). ISSN: 1940-5030. http://embryo.asu.edu/handle/10776/6468

Barceló-Muñoz A, Pliego-Alfaro F (2003) Micropropagation of avocado. In: Jain SM, Ishii K (eds) Micropropagation of woody trees and fruits. Kluwer Academic, Dordrecht, pp 519–542
Benavente FT Mde [1536] (2003) Historia de los Indios de la Nueva España Special edDastin. S.L. España
Bender GS (2012) Avocado production in California. A cultural handbook for growers, 2nd edn. Univ Calif Exp Program, Ch. 2 pp 1–32
Benson E (2008) Cryopreservation of phytodiversity: a critical appraisal of theory & practice. Crit Rev Plant Sci 27(3):141–219
Ben-Ya'acov A, Solis-Molina A, Bufler G (2003) The mountain avocado of Costa-Rica. Persea americana var. costaricensis, a new sub-species. In: Proceedings V world avocado congress 27–33, Consejeria de Agricultura y Pesca. Malaga, España, 19–24 Oct 2003
Ben-Ya'acov A (1998) The taxonomy of the avocado: A proposed new classification of the Persea, subgenus Persea, In: Proceedings of the Third World Avocado Congress, Tel Aviv, Israel, p 75
Ben-Ya'acov A, Bufler G, Barrientos A, De La Cruz Torres E, Lopez L, Degani H, Solis Molina A (1990) A study of the avocado genetic resources. GIARA Project 1–15
Ben-Ya'acov A, Bufler G, Barrientos-Priego A (1992) A study of the avocado germplasm resources (1988–1990) I, General description of the international project and its findings. In: Lovatt C, Holthe PA, Arpaia ML (eds) Proceedings of the Second World Avocado Congress, vol 2. University of California, Riverside, pp 535–541
Ben-Ya'acov, Solis A, Peri E (1995) Progress of the study on the avocado genetic resources, II, The avocado genetic resources in Costa Rica, Abstracts 3, ABY–10
Bergh B (1969) Avocado. In: Ferwerda FP, Wit F (eds) Outlines of perennial crop breeding in the tropics. Institute of plant breeding, Landbouwhogeschool, Wageningen, pp 23–51
Bergh B (1975) Avocados. In: Janick J, Moore JN (eds) Advances in fruit breeding. Purdue University Press, West Lafayette, pp 541–567
Bergh B (1992) The origin, nature, and genetic improvement of the avocado. Calif Avocado Soc Yearb 76:61–75
Bergh B (1993) Avocado Persea americana (Lauraceae) In: Smart J (ed) Evolution of crop plants. Longman, New York, p 531
Bergh B, Ellstrand N (1986) Taxonomy of the avocado. Calif Avocado Soc Yearb 70:135–145
Bergh B, Lahav E (1996) Avocados. In: Janick J, Moore JN (eds) Fruit breeding, vol I: tree and tropical fruits. Wiley, West Lafayette, pp 113–166
Blake SF (1920) A preliminary revision of the North American and West Indian avocados (Persea spp.). J Wash Acad Sci 10:9–21
Borokoni TI (2013) The state of ex-situ conservation in Nigeria. Conservation Science, vol 4. Issue 2, p 197
Brooks CI (1929) Avocados. Proc Flo State Horticult Soc 42:123–129
Campbell CW, Malo SE (1976) A survey of avocado cultivars. In: Sauls JW, Phillips RL, Jackson LK (eds) The avocado. Proc. 1st Sub-Tropical Fruit Short Course, Univ Florida Coop Ext Serv, pp 20–24
CGIAR (2013) 1971–1996 database: 25 years of food and agriculture improvement in developing countries. http://www.worldbank.org/html/cgiar/25years/25cover.html. Accessed: Sept 2013
Chen H, Morrell PL, de la Cruz M, Clegg MT (2009) Tracing the geographic origins of major avocado cultivars. J Hered 100:56–65
Cobo Bde [1653] (1956) Historia del Nuevo Mundo. Biblioteca de Autores Españoles. España
Condit IJ (1916) History of the avocado in California. Report of the Calif Avocado Soc Yearb 2:105–106
Convention on Biological Diversity (1992) http://biodiv.org/convention/articles.asp
Cooper HD, Spillane C, Hodgkin T (2001) Broadening the genetic base of crops: an overview. In: Cooper HD, Spillane C, Hodgkin T (eds) Broadening the genetic base of crop production. CABI Publishing, CAB International, Wallingford, pp 1–23
Cooper PA (1987) Advances in the micropropagation of avocado (*Persea americana* Mill.). Acta Horticult 212:571–575

Crane JH, Balerdi CF, Maguire I (2013) Avocado growing in the Florida home landscape. http://edis.ifas.ufl.edu/MG213. Accessed 15 Oct 2013
Crisosto CH, Ferguson L, Thompson M, Byers P, Zee F (2012) Emerging fruit crops. In: Badenes, ML, Byrne D (eds) Fruit breeding. Springer, New York, pp 97–147
Cruz-Cruz CA, González-Arnao MT, Engelmann F (2013) Biotechnology and conservation of plant biodiversity. Resources 2(2):73–95
Diario Libre (2013) Dominican republic: avocado exports generate more than US$ 30 million. http://www.freshplaza.com/article/107278/Dominican-Republic-Avocado-exports-generate-more-than-US-30-million#SlideFrame_1
Drew R, Ashmore S, Somsri S, Noor N, Thi Hoa T, Damasco O, Rao R (2007) Advanced technologies for germplasm conservation of tropical fruit species. Acta Horticult 760:91–98. http://www.actahort.org/books/760/760_10.htm
Efendi D (2003) Transformation and cryopreservation of embryogenic avocado (Persea americana Mill.) cultures. Dissertation, University of Florida
Efendi D, Litz R (2003) Cryopreservation of avocado. Proceedings V World Avocado Congress (Actas V Congreso Mundial del Aguacate), pp 111–114
Ellis D, Skogerboe D, Andre C, Hellier B, Volk G (2006) Implementation of garlic cryopreservation techniques in the National Plant Germplasm System. CryoLetters 27:99–106
FAO (2013) Chile Production Forecast for Marketing Year 2013/114 Avocado Annual Report. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Avocado%20AnnualSantiago-Chile11-27-2013.pdf
FAS (2012) Mexico Production Forecast for Marketing Year 2012/13 Avocado annual report. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Avocado%20Annual_Mexico%20City_Mexico_11–26-2012.pdf
Fiedler J, Bufler G, Bangerth F (1998) Genetic relationships of avocado (*Persea americana* mill) using RAPD markers. Euphytica 101:249–255
Forsline PL, Towill LE, Waddell JW, Stushnoff C, Lamboy WF, McFerson JR (1998) Recovery and longevity of cryopreserved dormant apple buds. J Am Soc Horticult Sci 123:365–370
Galindo-Tovar ME, Arzate-fernandez AM, Ogata-Aguilar N, Landero-Torres I (2007) The avocado (Persea americana, Lauraceae) crop in Mesoamerica: 10,000 years of history. Harv Papers Bot 12(2):325–334
Galindo-Tovar ME, Ogata-Aguilar N, Arzate-Fernandez AM (2008) Some aspects of avocado (Persea americana Mill.) diversity and domestication in Mesoamerica. Genet Resour Crop Evol 55:441–450
Gómez-López VM (1999) Characterization of avocado (*Persea americana* Mill.) varieties of low oil content. J Agric Food Chem 47:2707–2710
Gomez-Lopez VM (2002) Fruit characterization of high oil content avocado varieties. Sci Agric (Piracicaba, Braz.) 59(2):403–406. ISSN 0103-9016. http://dx.doi.org/10.1590/S0103–90162002000200030
Gross BL, Olsen KM (2009) Genetic perspectives on crop domestication. Trends Plant Sci 15:529–537
Guillén H, Rodríguez A, Pedraza M, Vidales I, Morales JL, Tapia M (2011) Morphological characterization of avocados (Persea americana MILL) native to Tacambaro, Michoacan, Mexico. VII World Avocado Congress, Cairns, Queensland Australia, 5–9 Sept 2011
Guzmán-García E, Bradaï F, Sánchez-Romero C (2012) Cryopreservation of avocado embryogenic cultures using the droplet-vitrification method. Acta Physiol Plant. doi:10.1007/s11738-012-1062-3
Hoisington D, Khairallah M, Reeves T, Ribaut JM, Skovmand B, Taba S, Warburton M (1999) Plant genetic resources: what can they contribute toward increased crop productivity? PNAS 96(11):5937–5943. doi:10.1073/pnas.96.11.5937
Hummer KE, Pomper KW, Postman J, Graham CJ, Stover E, Mercure EW, Aradhya M, Hung CD, Trueman SJ (2011) Encapsulation technology for short term preservation and germplasm distribution of the African mahogany *Khaya senegalensis*. Plant Cell Tissue Organ Cult 107:397–405. doi:10.1007/s11240-011-9990

Hung CD, Trueman SJ (2011) In vitro propagation of the African mahogany Khaya senegalensis. New Forestry 42:117–130
Janick J (2005) The origins of fruits, fruit growing and fruit breeding. Plant Breed Rev 25:255–321
Janick J, Paul RE (2008) Persea americana—Avocado. The encyclopedia of fruits & nuts. CABI CAB International, Cambridge, pp 439–449
Kaczmarczyk A, Funnekotter, B, Menon A, Phang PY, Al-Hanbali A, Mancera RL, Bunn E (2012) Curr Issues Plant Cryo, Curr Front Cryobiol, Prof. Igor Katkov (ed.), ISBN: 978-953-51-0191–8
Kapai VY, Kapoor P, Rao IU (2010) In vitro propagation for conservation of rare and threatened plants of India—a review. Int J Biol Tech 1(2):1–14
Kaviani B (2011) Conservation of plant genetic resources by cryopreservation. Aust J Crop Sci 6(5):778–800
Knight Jr RJ (1999) Genetic diversity in avocado. In: Arpaia ML, Hofshi R (eds) Proc avocado brainstorming 99, University of Florida, Homestead, 27–29 Oct 1999
Knight Jr RJ (2002) History, distribution and uses. In: Whiley AW, Schaffer B, Wolstenholme BN (eds) The avocado: botany, production and uses. CAB International, Wallingford, pp 1–14
Kopp LE (1966) A taxonomic revision of the genus Persea in the Western hemisphere (Persea-Lauraceae). Mem NY Bot Gard 14:1–117
Labat JB (1964) The avocado—in 1694. Calif Avocado Soc 1964 Yearbk 64:48–50
Lahav E (1994) Israeli avocado industry. Calif Avocado Soc Yearb 78:51–52
Lahav E, Gazit S (1994) World listing of avocado cultivars according to flowering type. Fruits 49:299–313
Lahav E, Lavi U (2002) Genetics and classical breeding. In A. Wiley, B. Schaffer., and B. Wolstenholome (eds.). The avocado: Botany, Production, and uses. CABI, New York, pp 39–69
Landon AJ (2009) Domestication and Significance of Persea americana, the avocado, in Mesoamerica. Nebraska Anthropologist 47. http://digitalcommons.unl.edu/nebanthro/47
Lavi U, Sa'ada D, Ragev I, Lahav E (2003) Avocado genetics and breeding-present and future. World Avocado Congr VA 42:134–135
López LL, Barrientos-Priego AF, Ben-Ya'acov A (1999) Variabilidad genética de los bancos de germoplasma de aguacate preservados en el Estado de México. Rev Chapingo Sci Horticult 5:19–23
Merrick LC (1990) Crop genetic diversity and its conservation in traditional agroecosystems. In: Altieri MA, Hecht SB (eds) Agroecology and small farm development. CRC, Boca Raton
Mhameed S, Sharon D, Kaufman D, Lahav E, Hillel J, Degani C, Lavi U (2011) Genetic relationships within avocado (*Persea americana* Mill) cultivars and between *Persea* species. Theor Appl Genet 94:279–286
Mijares P, López L (1998) Variedades de aguacate y su producción en México Memoria Fundación Salvador Sánchez Colín CICTAMEX S.C. México
Miller A, Gross BL (2011) From forest to field: perennial fruit crop domestication. Am J Bot 98:1389–1414
Miller AJ, Schaal B (2006) Domestication and the distribution of genetic variation in wild and cultivated populations of the Mesoamerican fruit tree *Spondias purpurea* L. (Anacardiaceae) Mol Ecol 15(6):1467–1480
Mohamed-Yasseen Y (1993) In vitro propagation of Avocado (*Persea americana* Mill.). Calif Avocado Soc Yearb 77:107–111
Morton JF (1987) Fruits of warm climates. Florida Fair Books, Miami, p 505
Muriel P, Pitman N (2004) Persea conferta. 2006 IUCN Red List of Threatened Species
Nakasone HY, Paull RE (1998) Tropical fruits. CAB International, New York, pp 76–102
NASS (2011) Noncitrus Fruits and Nuts 2011 Summary, National Ag Statistics Service (NASS), USDA
Normah MN, Clyde MM, Cho EG, Rao VR, Drew R (2002) Ex situ conservation of tropical rare fruit species. Proc. IS on Trop. & Subtrop. Fruits Acta Horticult 575:221–230
Oduro G, Kwabena N, Ofosu-Budu G, Williams A (2013) Genetic diversity among local and introduced avocado germplasm based on morpho-agronomic traits. Int J Plant Breed Genet 7:76–91

Olsen KM, Wendel JF (2013) A bountiful harvest: genomic insights into crop domestication phenotypes. Annu Rev Plant Biol 64:47–70
Ospina JA (2002) Persea americana Mill. Lauraceae (Laurel Family). In: Vozzo JA (ed) Tropical tree seed manual. USDA, Forest Service, South For Exp Stat Bot Gard 14:1–120
Padulosi S, Bergamini N, Lawrence T (2012) On-farm conservation of neglected and underutilized species: status, trends and novel approaches to cope with climate change: Proc Int Conf. Friedrichsdorf, Frankfurt, 14–16 June 2011. Bioversity International, Rome, Italy
Peterson PA (1955) Dual cycle of avocado flowers. Calif Agric 9:6–7
Peterson PA (1956) Flowering types in the avocado with relation to fruit production. Calif Avocado Soc Yearb 40:174–179
Pliego-Alfaro F (1988) Development of an *in vitro* rooting bioassay using juvenile-phase steam cutting of *Persea americana*. J Horticult Sci 63:295–301
Pliego-Alfaro F, Encina CL, Barceló-Muñoz A (1987) Propagation of avocado rootstocks by tissue culture. South African Avocado Growers' Assoc Yearb 10:36–39
Popenoe W (1919) The avocado in Guatemala USDA Bulletin 743
Popenoe W (1920) Manual of tropical and subtropical fruits, excluding the banana, coconut, pineapple, citrus fruits, olive and fig. Macmillan, New York
Popenoe W (1924) Manual of tropical and subtropical fruits. MacMillan, New York
Popenoe W (1926) The parent 'Fuerte' tree. Annual report. Calif Avocado Assoc 1925–26:24–33
Popenoe W (1927) Wild avocado. Calif Avocado Soc Yearb 1927:51–54
Popenoe W (1934) Early history of the avocado. Calif Avocado Soc Yearb 1934:106–110
Popenoe W (1935) Origin of the cultivated races of avocados. Calif Avocado Soc Yearb 1935:184–193
Popenoe W (1941) The avocado: a horticultural problem. Trop Agric 18:3–7
Popenoe W (1951) 'Toltec', another new horticultural variety of avocado. Ceiba 1:225–227
Popenoe W (1952) The avocado. Ceiba 1:269–367
Popenoe W (1963) Early history of avocado. Calif Avocado Soc 1963 Yearb 47:19–24
Popenoe W, Williams LO (1947) The expedition to Mexico of October 1947. Calif Avocado Soc Yearb 1947:22–28
Popenoe W, Zentmyer GA, Schieber E (1997) The avocado has many names. Calif Avocado Soc 1997 Yearb 81:155–162
Postman JD, Hummer KE, Stover EW, Krueger R, Forsline PL, Grauke LJ, Zee FT, Ayala-Silva T, Irish BM (2006) Fruit and nut genebanks in the us national plant germplasm system. HortSci 41(5):1188–1194
Prance G, Nesbit M (2005) The cultural hstory of plants. Routledge, London
Rai MK, Jaiswal VS, Jaiswal U (2008) Encapsulation of shoot tips of guava (*Psidium guajava* L.) for short-term storage and germplasm exchange. Sci Horticult 118:33–38. doi:10.1016/j.scienta.2008.05.017
Reed BM (1990) Survival of *in vitro*-grown apical meristems of *Pyrus* following cryopreservation. HortScience 25:111–113
Reed BM (2001) Implementing cryogenic storage of clonally propagated plants. Cryo Letters 22:97–104
Reed BM (2002) Implementing cryopreservation for long-term germplasm preservation in vegetatively propagated species. In: Towill LE, Bajaj YPS (eds) Biotechnology in agriculture and forestry: cryopreservation of plant germplasm II, vol 50. Springer, Berlin, pp 22–36
Reed BM (2008) Plant cryopreservation: a practical guide. Springer, New York, ISBN 978-0-387–72275–7
Reed BM, Engelmann F, Dulloo ME, Engels JMM (2004) Technical guidelines for the management of field and *in vitro* germplasm collections. Handbook for genebanks, no 7. IPGRI/SGRP, Rome
Reed BM, Schumacher L, Dumet D, Benson EE (2005) Evaluation of a modified encapsulation-dehydration procedure in corporating sucrose pretreatments for the cryopreservation of *Ribes* germplasm. *In Vitro*. Cell Dev Biol Plant 41:431–436

Reed BM, Tanprasert P (1995) Detection and control of bacterial contaminants of plant tissue cultures. A review of recent literature. Plant Tissue Cult Biotech 1:137–142

Sahagún FB [1570] (2002) Historia general de las Cosas de la Nueva España Cien de México. México

Sahijram L, Rajasekharan PE (1996) Tissue culture strategies applicable to *in vitro* conservation of tropical fruit crops. In: Tropical Fruits in Asia: Conservation and Use; IBPGR Progress Report. International Board for Plant Genetic Resources, Rome, pp 113–111

Sandoval JA, Villalobos AVM (2002) Avocado. IPGRI Tech Bull 7:61–64. Background and methods for in vitro collection of avocado germplasm

Schalls S (1987) Propagation of avocado (*Persea americana* Mill. cv. Fuerte) by microcutting in vitro. Fruits 42(3):171–176

Schieber E, Bergh B (1987) *Persea zentmyerii*: a new species from Guatemala. Calif Avocado Soc Yearb 71:199–203

Schieber E, Zentmyer GA (1973) Collecting Persea in Central America and Mexico. Calif Avocado Soc Yearb 56:94–101

Schieber E, Zentmyer GA (1975) Exploring for Persea in Matagalpa, Nicaragua. Calif Avocado Soc Yearb 59:118–120

Schieber E, Zentmyer GA (1978) Hunting for *Persea steyermarkii* in the mountains of Guatemala. Calif Avocado Soc Yearb 62:67–71

Schieber E, Zentmyer GA, Johnson ELV (1974) Collecting Perseas in the highlands of Guatemala. Calif Avocado Soc Yearb 57:128–134

Schnell RJ, Brown JS, Olano CT, Power EJ, Krol CA (2003) Evaluation of avocado germplasm using microsatellites markers. J Am Soc Horticult Sci 128:881–889

Schroeder CA (1955) Proliferation of mature fruit pericarp tissue slices in vitro. Science 122:601

Schroeder CA (1968) The longevity of avocado tissue in vitro. Calif Avocado Soc Yearb 52:128–130

Schroeder CA (1980) Avocado tissue culture *in vitro*. Calif Avocado Soc Yearb 64:139–141

Scora RW, Bergh B (1990) The origins and taxonomy of avocado (*Persea americana*) Mill. Lauraceae. Acta Horticult 275:387–394

Scora RW, Bergh B (1992) Origin and taxonomic relationships within the genus Persea. In: Lovatt C, Holthe PA, Arpaia ML (eds) Proceedings of the Second World Avocado Congress, vol 2. University of California, Riverside, pp 505–574

Scora RW, Bergh BO, Storey WB, Kumamoto J (1970) Three-factor analysis of essential leaf oils in selected Persea species. Phytochemistry 9:2503–2507

Shibli RA, Mohamad A, Shatnawi MA, Subaih S, Mohammed M, Ajlouni MM (2006) In vitro conservation and cryopreservation of plant genetic resources: a review. World J Agric Sci 2(4):372–382

Smith Jr CE (1966) Archaeological evidence for selection in avocado. Econ Bot 20:169–175

Smith Jr CE (1966) Archeological evidence for selection in avocado. Econ Bot 20:169–175

Smith Jr CE (1969) Additional notes on pre-conquest avocados in Mexico. Econ Bot 23:135–140

Solorzano D (1989) Propagation *in vitro* of rootstocks of avocado. Calif Avocado Soc Yearb 73:149–151

Storey WB, Bergh BO, Zentmyer GA (1986) The origin, indigenous range and dissemination of the avocado. Calif Avocado Soc Yearb 70:127–133

Storey WB, Bergh B, Zentmyer GA (1987) The origin, indigenous range and dissemination of the avocado. Calif Avocado Soc Yearb 70:127–133

Stushnoff C (1991) Cryopreservation of fruit crop genetic resources. Implications for maintenance and diversity during conservation. HortScience 26:518–522

Towill LE, Roos EE (1989) Techniques for preservation of plant germplasm. In: Knutson L, Stoner AK (eds) Biotic diversity and germplasm preservation. Global imperatives. Kluwer Academic, Dordrecht, pp 379–403

Tuxill J, Nabhan GP (2001) People, plants and protected area. Earthscan. London

Vaughan DA, Balazs E, Heslop-Harrison JS (2007) From crop domestication to super-domestication. Ann Bot 100(5):893–901. doi:10.1093/aob/mcm224

Volk GM (2012) Use of cryotherapy to eradicate pathogens from horticultural crops. Meeting Abstract. http://ashs.org/abstracts/m/abstracts12/abstract_id_12207.html
Volk GM et al (2005) Ex situ conservation of vegetatively propagated species: development of a seed-based core collection for Malus sieversii. J Am Soc HorticultSci 130(2):203–210
Walters CT, Berjak P, Pammenter N, Kennedy K, Raven P (2013) Preservation of recalcitrant seeds. Science 339:915–916
Williams LO (1950) Two new Perseas from Central America. Ceiba 1:55
Williams LO (1976) The botany of the avocado and its relatives. In: Sauls JW (ed) Proceedings of the First International Tropical Fruit Short Course, Miami Beach, FL, pp 9–15
Williams LO (1977) The avocado, a synopsis of the genus *Persea*, subg. *Persea*. Econ Bot 31:315–320
Witjaksono, Litz RE, Pliego Alfaro F, Efendi D (2004) *Persea americana* Avocado. In: Litz RE (ed) Biotechnology of fruit and nut crops. CAB International, Wallingford, pp 326–349
Wolfe HS, Toy LR, Stahl AL, Ruehle GD (1949) Avocado production in Florida. Bulletin 141. Agricultural Ext Service, Gainesville, p 124
Zentmyer GA, Schieber E (1990) Persea tolimanensis: a new species for Central America. Acta Horticult 275:383–386
Zentmyer GA, Schieber E, Popenoe W (1987) Early history of the avocado during the time of the Conquistadores. South African Avocado Growers' Assoc Yearb 10:11–12
Zulfiqar B, Akhtar N, Abbasi NA, Touqeer A, Ahmad T, Hafiz IA (2009) Effect of explant sources and different concentrations of plant growth regulators on in vitro shoot proliferation and rooting of avocado (Persea americana Mill.) CV. "FUERTE". Pak J Bot 41(5):2333–2346