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REVIEW ARTICLE

ORIGIN, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY, BREEDING AND CULTIVATION OF AVOCADO

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ABSTRACT

Avocados, Alligator pear and butter fruit belongs to Family: Lauraceae, Genus: Persea, Species: *Persea americana*. Aztecs in Mexico and from there derived the term 'avocado', aguacate (in Spanish), avocat (in French) and abacate (in Portuguese). The Aztecs considered avocados an aphrodisiac and called it huacatl, meaning testicles, reflecting the fruit shape. The fruit is also called palta in Chile, Ecuador and Peru, and has been referred to by a number of other terms such as alligator pear, vegetable butter, butter pear and midshipman's butter. Characteristics of alligator pear and butter fruit are; **Hardiness and Adaptability**: *Persea americana* var. *drymifolia* is more tolerant to cold temperatures compared to other avocado varieties, making it suitable for cultivation in regions with cooler winters. **Growth Habit**: This variety tends to grow into a larger tree than some other avocado types, with a more vigorous root system that allows it to thrive in a variety of soil conditions. **Fruit**: The avocados produced by *Persea americana* var. *drymifolia* are often smaller and have a thicker skin than those from other varieties. They are prized for their rich, creamy flavor and high oil content. A stoneless avocado, marketed as a "cocktail avocado", which does not contain a pit, is available on a limited basis. They are five to eight centimetres long; the whole fruit may be eaten, including the skin. It is produced from an unpollinated blossom in which the seed does not develop. Seedless avocados regularly appear on trees. Known in the avocado industry as "cukes", they are usually discarded commercially due to their small size. Avocados were first domesticated in tropical America, where they were cultivated as individual seedling trees before the Spanish conquest. The plants did not receive serious horticultural attention until about 1900, when horticulturists found that production of grafted trees was simple and allowed perpetuation of superior seedlings and the establishment of orchards. Flourishing avocado industries have since developed around the world in suitable climates. Mexico, the Dominican Republic, Peru, Indonesia, and Colombia were the top producers worldwide in 2020. The fruits are also grown commercially in Florida, California, Hawaii, Kenya, Haiti, Chile, South Africa, Brazil, and Australia, as well as on some Pacific islands and in several Mediterranean countries, including Israel. Horticulturally, avocados are divided into the Mexican (*Persea americana*, variety *drymifolia*), West Indian (*P. americana*, variety *americana*), and Guatemalan (*P. americana*, variety *guatemalensis*) races, with more than 1,000 cultivars between them. The Mexican race is native to Mexico and is characterized by the anise-like odour of the leaves and by small (weighing 90–240 g , thin-skinned fruits of rich flavour and excellent quality. Mexican avocados are the hardiest, growing in regions too cold for other types. The Guatemalan race, native to the highlands of Central America, is slightly less frost-resistant than the Mexican and produces fruits of medium to large size (240–1,000 g), characterized by thick woody skins and a ripening season different from that of the others. Cultivation of the West Indian race, the most tropical in character, is limited in the United States to southern Florida. Hass avocado, the most popular cultivar in the United States, is a Mexican-Guatemalan hybrid.

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INTRODUCTION

Avocados, Alligator pear and butter fruit belongs to Family: Lauraceae, Genus: Persea, Species: *Persea americana* (Bergh and Ellstrand, 1986; Google, 2025; Wikipedia, 2025). The fruit is called *Ahuacatl* by the Aztecs in Mexico and from there derived the term 'avocado', *aguacate* (in Spanish), *avocat* (in French) and *abacate* (in Portuguese). The Aztecs considered avocados an aphrodisiac and called it *huacatl*, meaning testicles, reflecting the fruit shape. The fruit is also called *palta* in Chile, Ecuador and Peru, and has been referred to by a number of other terms such as alligator pear, vegetable butter, butter pear and midshipman's butter (Yahia, 2011). The word *avocado* comes from the Spanish *aguacate*,

which derives from the Nahuatl (Mexican) word *āhuacatl* [aːˈwakat͡l], which goes back to the proto-Aztecan **paːwa*. In Molina's Nahuatl dictionary "auacatl" is given also as the translation for *compañón* "testicle", and this has been taken up in popular culture where a frequent claim is that testicle was the word's original meaning. This is not the case, as the original meaning can be reconstructed as "avocado" – rather the word seems to have been used in Nahuatl as a euphemism for "testicle". The modern English name comes from a rendering of the Spanish *aguacate* as *avogato*. The earliest known written use in English is attested from 1697 as *avogato pear*, later *avocado pear* (due to its shape), a term sometimes corrupted to *alligator pear* (Wikipedia, 2025). In Central American, Caribbean Spanish-speaking countries, and Spain it is known by the Mexican Spanish name *aguacate*, while South American Spanish-speaking countries Argentina, Chile, Perú and Uruguay use a Quechua-derived word, *palta*. In Portuguese, it is *abacate*. The Nahuatl *āhuacatl* can be compounded with other words, as in *ahuacamolli*, meaning avocado soup or sauce, from which the Spanish word *guacamole* derives. In the United Kingdom the term *avocado pear*, applied when avocados first became commonly available in the 1960s, is sometimes used. Originating as a diminutive in Australian English, a clipped form, *avo*, has since become a common colloquialism in South Africa and the United Kingdom. It is known as "butter fruit" in parts of India and Hong Kong (Wikipedia, 2025).

Characteristics of alligator pear and butter fruit are (Subba *et al*., 2023): **Hardiness and Adaptability**: Persea americana var. drymifolia is more tolerant to cold temperatures compared to other avocado varieties, making it suitable for cultivation in regions with cooler winters. **Growth Habit**: This variety tends to grow into a larger tree than some other avocado types, with a more vigorous root system that allows it to thrive in a variety of soil conditions. **Fruit**: The avocados produced by *Persea americana* var. *drymifolia* are often smaller and have a thicker skin than those from other varieties. They are prized for their rich, creamy flavor and high oil content.

A stoneless avocado, marketed as a "cocktail avocado", which does not contain a pit, is available on a limited basis. They are five to eight centimetres long; the whole fruit may be eaten, including the skin. It is produced from an unpollinated blossom in which the seed does not develop. Seedless avocados regularly appear on trees. Known in the avocado industry as "cukes", they are usually discarded commercially due to their small size. (Wikipedia, 2025).

Avocados can be grown on a wide range of soils, but they are extremely sensitive to poor drainage and cannot withstand water-logging. They are intolerant to saline conditions. Optimum range of pH is from 5 to 7. Depending on the race and varieties, avocados can thrive and perform well in climatic conditions ranging from true tropical to warmer parts of the temperate zone. In India, avocado is not a commercial fruit crop. It was introduced from Sri Lanka in the early part of the twentieth century. In a very limited scale and in a scattered way it is grown in Tamil Nadu, Kerala, Maharashtra, Karnataka in the south-central India and in the eastern Himalayan state of Sikkim. It cannot tolerate the hot dry winds and frosts of northern India. Climatically, it is grown in tropical or semitropical areas experiencing some rainfall in summer, and in humid, subtropical summer rainfall areas (Ghosh, 2025). The avocado tree can be grown domestically and used as a decorative houseplant. The pit germinates in normal soil conditions or partially submerged in a small glass (or container) of water. In the latter method, the pit sprouts in four to six weeks, at which time it is planted in standard houseplant potting soil. The plant normally grows large enough to be prunable; it does not bear fruit unless it has ample sunlight. Home gardeners can graft a branch from a fruit-bearing plant to speed maturity, which typically takes four to six years to bear fruit. (Wikipedia, 2025).

About 349 000 ha are dedicated to the production of avocado in about 60 countries, producing more than 2.6 million tonnes annually with average yield of about 7.40 tonnes per ha. Mexico is the leading producer, accounting for about 34% of the total production, with other important producing countries including Chile (7.6%), Indonesia (6.1%), USA (5.7%), Colombia (4.8%), the Dominican Republic (5.1%), Brazil (4.7%), and Peru (3.7%; FAO statistics) (Rajeevan, 2011). Avocado production 2023, millions of tonnes in Mexico 2.97, Colombia 1.09, Dominican Republic 1.02, Peru 0.98, Indonesia 0.87, Kenya 0.54 and World 10.47 (Wikipedia, 2025). Southern California Hass Avocado groves produce natural and delicious avocados. The soil is ideal; there is proper drainage, abundant sunshine and cool ocean breezes all year round. These exceptional conditions supply us with an abundance of mouthwatering, velvety, creamy avocados. Thank goodness! There are hundreds of types of avocados, but seven avocado varieties are grown commercially in California. The Hass variety accounts for approximately 95 percent of the total crop each year – which runs from Spring to Fall. Many varieties are available as certified organic fruit (California, 2025). **The Most Popular Variety:** Hass avocados account for over 80% of avocado- consumed worldwide. **Year-Round Availability:** Unlike some varieties, Hass avocados grow in multiple seasons, making them available all year. **Better When Ripe:** Unlike many other fruits, Avocado Hass ripens after being harvested, ensuring freshness when consumed. **The Accidental Discovery:** The Hass avocado was discovered by chance in the 1920s by a California mail carrier named Rudolph Hass, whose single tree led to the global avocado industry **(**Pluck, 2025**).**

= One triploid (2*n* = 36) and one tetraploid (2*n*48) = individual were found in *P. americana*. Based on stomatal size, their maternal plants were considered to be triploid and diploid, respectively (Armando Garcia, 1975). This is the first karyotype study in *Persea* and also in the family Lauraceae. The karyotype in *Persea* is µm to 6.1 µm. asymmetric (Armando Garcia, 1975). The chromosomes range in size from 2.3 *Persea americana* has one pair of satellited chromosomes, which is the largest pair, two metacentric pairs and nine submetacentric pairs (Armando Garcia, 1975). Two of the submetacentric pairs are highly heterochromatic and both are attached to the nucleolus. All the other species have karyotypes very similar to *P. Americana* (Armando Garcia, 1975). Avocado (*Persea americana*) is botanically classified as a fruit, specifically a large berry, and it belongs to the Lauraceae family (Bergh and Ellstrand, 1986). Within the Lauraceae family, it is categorized under the genus Persea. While often used like a vegetable in culinary contexts, its biological classification is rooted in its development from the flower's ovary and containing seeds (Bergh and Ellstrand, 1986). Anyone familiar with avocados knows that there are many different kinds. They differ in such significant ways as length of time from bloom to fruit maturity, thickness of skin, tolerance of cold (Bergh and Ellstrand, 1986). The genus *Persea* is of African-Laurasian origin, with the subgenus *Eriodaphne* originating in Africa and with the subgenus *Persea* probably also originating in Africa, entering south-west Laurasia, and then rafting to its present position with tropical North America (Rainer and Bergh, 1990). Contrary to classification suggestions that identify either the Mexican or the Guatemalan horticultural race as botanically distinct from the other race plus the Lowland (West Indian) jointly, the preponderant evidence favors classifying all three races as equidistant botanical varieties (Rainer and Bergh, 1990). These three varieties then become *Persea americana* var. *americana* Lowland ("West Indian"), var. *drymifolia* (Mexican) and var. *guatemalensis* (Guatemalan) (Rainer and Bergh, 1990). The Lowland (West Indian) variety appears to be the most distinct of these three races (Rainer and Bergh, 1990).

Avocado is highly heterozygous resulting in unpredictable progeny. Single gene mutations are unknown except for DNA markers (Lahav and Lavi, 2009). Avocado has only one seed per fruit and is characterised by heavy fruit drop, a long juvenile phase and a large tree size resulting in a substantial area required for a reliable assessment of hybrids (Lahav and Lavi, 2009). The advantages for the breeder are the wide genetic variation and the ease to vegetatively propagate the selected seedlings (Lahav and Lavi, 2009). Avocado breeding programmes have been

reported in California, Australia, South Africa, Mexico and Israel (Lahav and Lavi, 2009). Two steps are usually involved in fruit tree improvement: selection of improved genotypes and their fixation by vegetative propagation (Lahav and Lavi, 2009). Avocado produces only sexual seeds and flowering dichogamy somewhat favours cross-pollination. Seedlings produced by a single tree (or cultivar) are extremely variable and in most instances have a prolonged juvenile period (Lahav and Lavi, 2009). The few selected seedlings, resulting from breeding projects that produce high yield of high fruit quality, must be vegetatively propagated as their sexual progeny have significant variation in fruit and tree characteristics (Lahav and Lavi, 2009). The first known grafting of avocado took place in Florida before 1900 (Lahav and Lavi, 2009). Selection of horticultural improved avocados occurred long before they were asexually propagated (Lahav and Lavi, 2009). Avocado seeds of varying antiquity (beginning about 7000 B.C.), excavated in Mexico (Smith 1966), indicated that selection for large fruit could have begun about 4000 B.C. (Lahav and Lavi, 2009). The number of seeds present was greater in the later deposits and sample size was strongly correlated with the largest individual seed size (Lahav and Lavi, 2009). It seems reasonable that selection would also have occurred for a smaller proportional seed size as well as a larger fruit size (Lahav and Lavi, 2009). Avocado (*Persea americana* Mill.) is a tree of economic importance mostly grown for its fruit in home gardens and farms all over Cameroon (Lahav and Lavi, 2009). Plant germplasm resources are the basis for crop improvement. Analysis of complex traits and research on diversity on those resources is the first step leading to the exploration and creation of new plant varieties (Lahav and Lavi, 2009). The objective of this study was to assess the phenotypic variation of 206 avocado genotypes collected in ten villages across four altitude ranges in the Bamboutos highlands in western Cameroon (Lahav and Lavi, 2009). Cross tabulation and Chi-square tests revealed differential distribution of traits variants among villages and altitude ranges. Various phenotypic features were observed among trees, pointing out the existence of several avocado races in Cameroon. For all the 46 qualitative traits, 162 phenotypic classes were detected, giving an average of 3.52 phenotypic classes per trait. The diversity index varied significantly between traits, populations and altitude ranges with a mean value of H'= 0.90 for qualitative traits and H'=1.31 for quantitative traits. The top five traits with higher diversity indices were fruit shape (H'=2.04), ripe fruit skin colour (H'=1.75), seed shape (H'=1.75), Tree shape (H'=1.74) and colour of flesh next to seed (H'=1.47) (Lahav and Lavi, 2009). The lowest altitude range, 1100–1300 m above sea level (MASL) displayed smallest diversity when comparing altitude ranges (Lahav and Lavi, 2009). The partitioning of the diversity revealed more variation within population and within altitude ranges (Lahav and Lavi, 2009). Dendrogram revealed that avocado trees from the same village and even from the same altitude ranges differ substantially (Lahav and Lavi, 2009). Altitude was negatively associated seed length, time from ripeness to deterioration and time from maturity to deterioration of fruits (Lahav and Lavi, 2009). Seventeen traits were significantly associated with the two main principal components of the PCA. Cluster analysis revealed four distinct clusters, associated to the existing avocado races (Lahav and Lavi, 2009).

The avocado (*Persea americana*) originated in Mexico, Central or South America, and was first cultivated in Mexico as early as 500 BC. (Dreher and Davenport, 2013). The first English language mention of avocado was in 1696. In 1871, avocados were first introduced to the United States in Santa Barbara, California, with trees from Mexico (Dreher and Davenport, 2013). By the 1950s, there were over 25 avocado varieties commercially packed and shipped in California, with Fuerte accounting for about two-thirds of the production. As the large-scale expansion of the avocado industry occurred in the 1970s, the Hass avocado cultivar replaced Fuerte as the leading California variety and subsequently became the primary global variety (Dreher and Davenport, 2013). The Hass avocado contains about 136 g of pleasant, creamy, smooth texture edible fruit covered by a thick dark green, purplish black, and bumpy skin. The avocado seed and skin comprise about 33% of the total whole fruit weight (Dreher and Davenport, 2013). Avocados are a farm-to-market food; they require no processing, preservatives or taste enhancers. The avocado's natural skin eliminates the need for packaging and offers some disease and insect resistance, which allows them to be grown in environmentally sustainable ways (Dreher and Davenport, 2013).

Discovering a genome-wide set of avocado (*Persea americana* Mill.) single nucleotide polymorphisms and characterizing the diversity of germplasm collection is a powerful tool for breeding (Rubinstein *et al*., 2019). However, discovery is a costly process, due to loss of loci that are proven to be non-informative when genotyping the germplasm (Rubinstein *et al.,* 2019). Our study on a collection of 100 accessions comprised the three race types, Guatemalan, Mexican, and West Indian. To increase the chances of discovering polymorphic loci, three pools of genomic DNA, one from each race, were sequenced and the reads were aligned to a reference transcriptome (Rubinstein *et al.,* 2019). In total, 507,917 polymorphic loci were identified in the entire collection. Of these, 345,617 were observed in all three pools, 117,692 in two pools, 44,552 in one of the pools, and only 56 (0.0001%) were homozygous in the three pools but for different alleles (Rubinstein *et al.,* 2019). The polymorphic loci were validated using 192 randomly selected SNPs by genotyping the accessions within each pool. The sensitivity of polymorphic locus prediction ranged from 0.77 to 0.94 (Rubinstein *et al*., 2019). The correlation between the allele frequency estimated from the pooled sequences and actual allele frequency from genotype calling of individual accessions was r = 0.8 (Rubinstein *et al.,* 2019). The three races were distinctly clustered by projecting the genetic variation on a PCA plot (Rubinstein *et al.,* .2019). As expected, by estimating the kinship coefficient for all the accessions, many of the cultivars from the California breeding program were closely related to each other, especially, the Hass-like ones. The green-skin avocados, *e.g*., 'Bacon', 'Zutano', 'Ettinger' and 'Fuerte' were also closely related to each other (Rubinstein *et al*., 2019).

Criollo avocado of Mexican race (CAMR) (Persea americana var**.** drymifolia) is native to Mexico. It is a species with great genetic variability due to open pollination and a high degree of polymorphism, which contributes to the unpredictable and highly variable phenotypic characteristics of its progeny (Joel and Sergio, 2020). The fruits have been consumed in an ancestral way and are part of the culture and ethnobotanical knowledge of the Mexican peoples. CAMR's fruits have great nutraceutical and agro-industrial potential; however, they are currently underutilized and their main use is as rootstock for commercial varieties, mainly 'Hass' and 'Fuerte' (Joel and Sergio, 2020). In addition, the thin peel and high perishability of the fruits are a limitation for their commercialization outside the production regions and a worrying fact is that with the introduction of other varieties, a large number of unexplored genotypes is being lost.In the above context, it is necessary to disseminate the horticultural, nutraceutical and agro-industrial potential of the CAMR among producers, marketers and consumers with the purpose of revaluation and conservation (Joel and Sergio, 2020).

Criollo avocado of the Mexican race (CAMR) (Persea americana var. Drymifolia) is native to the high parts of central and southern Mexico, and from there it was dispersed towards the north of Mexico and part of Central America,[1] belongs to the Lauraceae Family and is part of the genetic base of commercial varieties that are currently marketed throughout the world as 'Hass', 'Fuerte' and their genetic variants.[2] (Joel and Sergio, 2020). The CAMR is considered a hyper variable species because it presents a high degree of genetic polymorphism, in addition, its form of reproduction is by open pollination and its genome size is very large compared to other species (920 million base pairs), which contributes to the fact that the phenotypic characteristics of its progeny are unpredictable and with a high degree of morphological polymorphism (Joel and Sergio, 2020). However, CAMR presents morphological and chemical characteristics of the species, which allows it to be differentiated from other races Persea americana var. guatemalensis and Persea americana var. americana.[5] In this context, the objective of this review is to describe the horticultural attributes and the main uses of CAMR, through the consultation and analysis of information available in articles and other sources published under strict scientific rigor (Joel and Sergio, 2020). The production of CAMR from pre-Hispanic times to the present day has been

carried out in nature and in the backyard, with minimal agronomic work and without the application of agrochemicals, often subjected to high degrees of stress by biotic and abiotic factors,[5] this has allowed it to thrive in a large number of microclimates, thus contributing to the dispersal, hybridization and genetic variability of the species (Joel and Sergio, 2020). CAMR stands out from other avocado breeds for presenting agronomic characteristics desirable in horticulture, including resistance to cold and good adaptation to different types of soils (Joel and Sergio, 2020). It is worth mentioning that although some CAMR genotypes are susceptible to damage caused by insects (e.g., Trioza anceps**,** Heilipus lauri, and Thysanoptera: Thripidae) and pathogenic fungi (*e.g.,* Phytophthora cinnamomi**,** Colletotrichum gloeosporioides, and Sphaceloma perseae) that cause damage to avocado crops, the damage is less than in commercial varieties such as'Hass' and 'Fuerte' (Joel and Sergio, 2020). In addition, there are resistant genotypes, Sánchez-Gonzales *et al*.[8] reported the resistance of CAMR rootstocks to *Phytophthora cinnamomi;* main pathogen that affect avocado production worldwide, causing root rot and secondary symptoms in the upper part of the plant, including dieback of branches, yellowing and wilting leaves, complete defoliation and death of the tree (Joel and Sergio, 2020).

However, the characteristics of resistance and adaptation have led to the fact that currently the main use of CAMR is as rootstock for hybrid varieties that are marketed throughout the world, reducing the use of the fruit as a horticultural product for human consumption (Joel and Sergio, 2020). In addition, the mechanical characteristics of the fruit and its high perishability prevent it from being marketed outside the production regions. This has caused producers to opt for the introduction of cultivars of higher value in the market such as 'Hass' and 'Fuerte' in orchards where CAMR was previously produced, thus causing a rapid disappearance of genotypes that have not been explored from a horticultural and nutritional point of view that could be of interest in the selection, improvement and creation of new varieties (Joel and Sergio, 2020). The CAMR is an important part of the culture and identity of the communities where it is produced. The tree is used in an integral way: the wood is used in the manufacture of furniture and crafts and the leaves are used as a condiment in traditional dishes and as infusions against pain and inflammation; however, there was no scientific evidence to support the benefits of consumption (Joel and Sergio, 2020). CAMR leaves have a characteristic smell similar to anise and it is reported that they contain some compounds such as β-pinene, caryophyllene, estragole, hexadecanoic acid, heptacosane and α- tocopherol, some of them with antifungal, larvicidal, insecticidal and genotoxic activity. In addition, they are a great source of phenolic compounds with antioxidant, anti-inflammatory and antimicrobial activity (Joel and Sergio, 2020). On the other hand, CAMR fruits have been consumed since ancient times and represent a source of income for regional merchants (Joel and Sergio, 2020). They are botanically classified as berries and have a weight ranging from 188.14 to 1042.93 g, an average length and diameter of 11.77 of 8.43 cm respectively, the most common fruit shapes are pyriform, oval and rounded (Joel and Sergio, 2020). The pulp has a very characteristic consistency of avocado fruits, similar to butter due to its high lipid content (up to 23% of the total weight of the pulp) and the color presents yellowish tones in the center and green in the part (Joel and Sergio, 2020). It has been reported to contain phenolic compounds and flavonoids in amounts comparable to those of the cultivar 'Hass', which have antioxidant, anti-inflammatory and antimicrobial activity. The lipophilic portion of the pulp contains carotenoids (up to 7.83 mg eq. of β-carotene 100 g^{-1}f. w.) of which are known to have photoprotective activity and against chronic diseases such as prostate, liver and breast cancer. In the same context, Méndez-Zúñiga *et al*. reported a high content of monounsaturated and polyunsaturated fatty acids (up to 75.96 and 19.34%), commonly related to the proper functioning of the cardiovascular system (Joel and Sergio, 2020). The seed generally takes the shape of the fruit and can weigh up to 35 % of the total fruit and has anticancer and antimicrobial properties. In this context, Guzmán-Rodríguez *et al*. and Flores-Álvarez *et al*. reported the discovery of genes that code for the synthesis of defense peptides in the CAMR seed, which cause cell death by apoptosis in cancer cells that cause degenerative diseases such as breast cancer, colon cancer, and chronic myeloid leukemia (Joel and Sergio, 2020). The peel is thin (4 to 11% of the total weight of the fruit) with a characteristic smell and flavor of the species, which resembles anise, generally they present colors with shades that go from purple to dark due to the presence of anthocyanins, pigments with high antioxidant activity (Joel and Sergio, 2020). It should be noted that, unlike other varieties, this type of fruit is traditionally consumed with the shell, taking advantage of the antioxidants it contains (Joel and Sergio, 2020). In the above context, the CAMR presents great nutraceutical and agro-industrial potential that could be used by producers, food and pharmaceutical industries for different uses in which little has been done (Joel and Sergio, 2020).

Avocados first came into notice in Mexico in 291 B.C. However, this buttery and delicious fruit underwent domestication in 6400 B.C. This domestication is technically genetic modification as human desires lead to genetic selection and breeding. Ancient avocados are not the glorious fruit as modern avocados (Tripodis, 2021). Their seeds were large with a measly portion of fleshly goodness. Today, there are three main types of avocados: Mexican, Guatemalan, and West Indian dominate the current industry. The two dominant cultivars found around the world are the 'Fuerte' and 'Hass' (Tripodis, 2021). The market demand for avocados is growing. Between 1990 and 2020 avocado consumption in the USA saw an increase of over 600%! This correlates to an annual increase of 20% during this period (Tripodis, 2021). For instance, in Australia, the price of avocados dropped as the supply and demand have shifted during the COVID-19 lockdown of 2020 (Tripodis, 2021). The demand for avocado decreased while the supply increased, resulting in a lower market price. Consequently, the Australian avocado market is favoring higher quality. Smaller avocado farms growing higher quality rather than quantity, potentially could increase their profit margins (Tripodis, 2021). With a massive surplus stock of avocados, Australian farmers are turning their excess stock into avocado oil. In some regions of the world, wooden utensils are being created using seed pulp (Tripodis, 2021). While others are drying out the seeds to create powders that are rich in antioxidants. The seed also creates a pink-hued dye for cosmetic and fabric use. So, there are a lot of options available to make sure avocado waste is at a minimum while making a profit (Tripodis, 2021). There exist several other major challenges in avocado production. Genetic variability is one. The offspring of an avocado tree may grow differently from its parents (Tripodis, 2021). This could result in different fruit quality. Additionally, there is an exceptionally long juvenile period. From seedlings, avocados take around 10 years to provide fruit. It is for this reason that propagation techniques have been used in the avocado industry. Conventional propagation techniques are laborious, time consuming, as well as expensive (Tripodis, 2021). A propagation method known as the 'Frolich and Platt double grafting' method, is frequently used in avocado agriculture worldwide (Tripodis, 2021). This method is over 40 years old, contains many steps and requires a wide range of conditions and hormones (Tripodis, 2021). The basis of this method is to use etiolation (growing in the dark) to create long thin stems. Followed by grafting (joining) of cuttings from desired trees to rootstock via a scion (a young stem). Then a rooting hormone is added just below the scion and is placed in the dark. This induces rooting above the rootstock. The method has been useful in producing avocados we know and love. However, now it is time for innovation (Tripodis, 2021). Avocado (*Persea americana* Mill.) is a tree native from central and eastern México that belongs to the Lauraceae family (Ochoa-Zarzosa *et al*., 2021). Avocado has three botanical varieties known as Mexican (*P. americana* var. *drymifolia*), West Indian (*P. americana* var. *americana*), and Guatemalan (*P. americana* var. *guatemalensis*) (Ochoa-Zarzosa *et al.,* 2021). It is an oil-rich fruit appreciated worldwide because of its nutritional value and the content of bioactive molecules (Ochoa-Zarzosa *et al*., 2021). Several avocado molecules show attractive activities of interest in medicine (Ochoa-Zarzosa *et al*., 2021). Avocado fatty acids have beneficial effects on cardiovascular disease risk factors (Ochoa-Zarzosa *et al*., 2021). Besides, this fruit possesses a high content of carotenoids and phenolic compounds with possible antifungal, anti-cancer and antioxidant activities (Ochoa-Zarzosa *et al*., 2021). Moreover, several metabolites have been reported with anti-inflammatory effects. Also, an unsaponifiable fraction of avocado in combination with soybean oil is used for the

treatment of osteoarthritis (Ochoa-Zarzosa *et al.,* 2021). The Mexican variety is native from México and is characterized by the anise aroma in leaves and by small thin-skinned fruits of rich flavor and excellent quality (Ochoa-Zarzosa *et al*., 2021).

Avocado is a significant cash crop in Vietnam, while little is known about its genetic diversification (Ninh *et al*., 2022). Random amplified polymorphic DNA (RAPD) and inter-simple sequence repeat (ISSR) markers were performed to investigate the genetic diversity of twenty-eight imported and domestic avocado cultivars being maintained at Western Highlands Agriculture and Forestry Science Institute, Dak Lak, Vietnam (Ninh *et al*., 2022). 18 RAPD and 15 ISSR primers produced 3183 and 2807 scorable bands, of which 83.92% and 71.72% were polymorphic, respectively. The RAPD markers exhibited an average PIC of 0.27 and Rp index of 12.63 whereas the mean PIC and Rp values of ISSR primers were 0.21 and 13.37, respectively. The correlation between RAPD and ISSR markers was low (r = 0.338), suggesting that the ability to resolve genetic variation among varieties may relate to the number of detected polymorphisms rather than the marker employed (Ninh *et al.*, 2022). Nevertheless, the correlation between ISSR and combined data was high (r = 0.791) and the correlation between RAPD and combined matrices was even higher (r = 0.897). This indicates that RAPD markers have slightly higher efficiency over ISSR to resolve genetic variation among 28 avocado cultivars (Ninh *et al*., 2022). High genetic diversity among 28 avocado cultivars was revealed with the Jaccard's similarity coefficient ranging from 0.623 to 0.913 based on combined data analysis. The UPGMA dendrogram generated from combined RAPD and ISSR data grouped Vietnamese domestic and imported avocado cultivars into three different groups at 72% similarity. These results could be applied to the avocado conservation and breeding programs (Ninh *et al.,* 2022). Avocado (*Persea americana* Mill.) is a nutritious fruit plant grown both in tropical and subtropical regions of many countries (Ninh *et al.,* 2022). Avocado is a polymorphic species with three botanic varieties including *P. americana* var. *Americana, P. americana* var. *guatemalensis* and *P. americana* var. *drymifolia* known as the West Indian, Guatemalan and Mexican, respectively. These avocado races are distinguishable ecologically. However, they are cross-compatible and hybridization could take place between two races (Ninh *et al.,* 2022). Genetic diversity plays a paramount role in plant conservation and breeding programs. Several techniques have been used to analyze the genetic diversity in plant germplasm including morphological, biochemical and DNA makers (Ninh *et al*., 2022). In Vietnam, avocado was first introduced to Lam Dong province by the French in the 1940s. The plant has been propagated mainly through seed propagation for more than 80 years and has adapted to a broad range of climates, topography, and vegetation (Ninh *et al*., 2022). Consequently, high genetic diversity has been accumulated in this germplasm. To date, analyses of genetic diversity based on DNA polymorphisms in avocados grown in Vietnam (Ninh *et al.,* 2022).

Persea americana var. *drymifolia*, commonly referred to as the Mexican avocado or Mexican variety of avocado, is a subtype of the avocado tree (*Persea americana*). This variation is native to the dry forests of Mexico and Central America. It is known for its distinctive characteristics and adaptability to certain environmental conditions (Subba *et al*., 2023).

Diversity studies were carried out among 52 avocado accessions using Mahalanobis D2 statistics and principal component analysis. Based on D2 analysis avocado accessions were grouped into six clusters. Cluster I consisted of 2 accessions, cluster II had 18 accessions, cluster III had 17 accessions while cluster IV, V and VI consisted of three, eight and four accessions respectively. The study showed 13 principal components that account for 77% of the total diversity in qualitative characteristics across accessions. Crop improvement is likely to result from choosing genotypes from divergent clusters and using them in hybridization programmes (Vaka *et al.,* 2023). Avocado (*Persea americana*) is a member of the Lauraceae family, with chromosomal number 2n = 2x = 24 and a genomic size of 800 Mbp (Vaka *et al.,* 2023). Avocado is divided into three botanical races: Mexican *(P. americana* var. *drymifolia*), Guatemalan (*P. americana* var. *guatemalensis*) and West Indian (*P. americana* var. *americana*) (Vaka *et al*., 2023). West Indian avocados originated in the tropical lowlands of southern Mexico and Central America, but Guatemalan and Mexican avocados originated in their respective countries' mid altitude highlands (Vaka *et al.,* 2023). Because of its nutritional importance, the avocado plant has spread around the world. It includes mono-unsaturated fatty acids, which effectively lower the levels of low density lipoproteins in the blood, so aiding in the prevention of heart disease (Vaka *et al*., 2023). Avocado being a cross pollinated species and predominance of propagation via seed provides ample opportunities for the selection of outstanding types with desirable horticultural characteristics (Vaka *et al.,* 2023). Genetic divergence aids in the selection of genetically different parents for use in hybridization programmes. Several methods have been developed for measuring divergence between populations using multivariate analysis (Vaka *et al.,* 2023). The multivariate analysis is an effective means of understanding genetic similarities and dissimilarities among the genotypes, where the several different traits are examined simultaneously to understand the clustering mechanism for their utility breeding, commercialization and conservation of plant genetic resourcesn (Vaka *et al.,* 2023). A morphological technique utilising both cluster and principal component analysis was used to acquire phenomenal insight into the diversity among avocado accessions (Vaka *et al*., 2023).

Avocados were first domesticated in tropical America, where they were cultivated as individual seedling trees before the Spanish conquest (Encyclopaedia, 2025). The plants did not receive serious horticultural attention until about 1900, when horticulturists found that production of grafted trees was simple and allowed perpetuation of superior seedlings and the establishment of orchards (Encyclopaedia, 2025). Flourishing avocado industries have since developed around the world in suitable climates (Encyclopaedia, 2025). Mexico, the Dominican Republic, Peru, Indonesia, and Colombia were the top producers worldwide in 2020 (Encyclopaedia, 2025). The fruits are also grown commercially in Florida, California, Hawaii, Kenya, Haiti, Chile, South Africa, Brazil, and Australia, as well as on some Pacific islands and in several Mediterranean countries, including Israel (Encyclopaedia, 2025). Horticulturally, avocados are divided into the Mexican (*Persea americana*, variety *drymifolia*), West Indian (*P. americana*, variety *americana*), and Guatemalan (*P. americana*, variety *guatemalensis*) races, with more than 1,000 cultivars between them (Encyclopaedia, 2025). The Mexican race is native to Mexico and is characterized by the anise-like odour of the leaves and by small (weighing 90–240 g, thin-skinned fruits of rich flavour and excellent quality. Mexican avocados are the hardiest, growing in regions too cold for other types (Encyclopaedia, 2025). The Guatemalan race, native to the highlands of Central America, is slightly less frost-resistant than the Mexican and produces fruits of medium to large size (240–1,000 g), characterized by thick woody skins and a ripening season different from that of the others (Encyclopaedia, 2025). Cultivation of the West Indian race, the most tropical in character, is limited in the United States to southern Florida. Hass avocado, the most popular cultivar in the United States, is a Mexican-Guatemalan hybrid (Encyclopaedia, 2025).

Avocado genetic diversity is substantial, stemming from its classification into three primary botanical races: Mexican, Guatemalan, and West Indian, according to research published in the journal Hereditas (AI, 2025). These races, adapted to different climates and altitudes, exhibit a high degree of cross-compatibility, leading to significant hybridization and the development of diverse cultivars (AI, 2025). Microsatellite markers, with their high mutation rates, have been instrumental in revealing the extent of this genetic variation (AI, 2025). Avocado's cross-pollinating nature, combined with the cross-compatibility of the races, fuels a high level of genetic mixing, resulting in a wide array of hybrid varieties (AI, 2025). These DNA sequences with high mutation rates are valuable tools for assessing genetic diversity, revealing a high number of alleles per locus and heterozygosity levels (AI, 2025). While the three races have distinct origins, their introduction to various regions and subsequent hybridization have led to a complex pattern of genetic diversity across different avocado-growing areas (AI, 2025). Understanding

avocado's genetic diversity is crucial for breeding programs aiming to develop new cultivars with desirable traits, such as disease resistance, improved fruit quality, and adaptation to specific environments (AI, 2025). Studies in Ethiopia revealed distinct genetic groups among avocado landraces, with the Wondo Genet population showing high diversity and unique alleles (AI, 2025). Research in northwestern Mexico demonstrated a high level of genetic diversity in local avocado genotypes, suggesting a rich reservoir of potential breeding material (AI, 2025). A comprehensive study using microsatellite markers characterized the genetic diversity of Indian avocado accessions, providing insights into population structure and relationships (AI, 2025). Analysis of Florida avocado germplasm revealed three distinct populations corresponding to the three races, with some races showing closer genetic relationships (AI, 2025).

Avocado is a dicotyledon of the genus Persea of the Lauraceae family (KRMS, 2025). More than 200 varieties are divided between three races (KRMS, 2025). The Mexican race is of little commercial interest as most of the fruits are too small. However, its agronomic qualities mean that it is widely used as rootstock or as a parent (KRMS, 2025). Practically all sales of fruits of the West Indian race are on domestic markets (KRMS, 2025). International trade handles mainly varieties belonging to the Guatemalan race or crosses between the Guatemalan and Mexican races (KRMS, 2025). Avocado (*Persea americana* Mill.) is a tree of economic importance mostly grown for its fruit in home gardens and farms all over Cameroon (Kouam *et al.,* 2025). Plant germplasm resources are the basis for crop improvement (Kouam *et al.,* 2025). Analysis of complex traits and research on diversity on those resources is the first step leading to the exploration and creation of new plant varieties (Kouam *et al.,* 2025). The objective of this study was to assess the phenotypic variation of 206 avocado genotypes collected in ten villages across four altitude ranges in the Bamboutos highlands in western Cameroon (Kouam *et al.,* 2025). Cross tabulation and Chi-square tests revealed differential distribution of traits variants among villages and altitude ranges (Kouam *et al.,* 2025). Various phenotypic features were observed among trees, pointing out the existence of several avocado races in Cameroon (Kouam *et al.,* 2025). The Hass avocado is a variety of avocado with dark green, bumpy skin. It was first grown and sold by Southern California mail carrier and amateur horticulturist Rudolph Hass, who also gave it his name (Wikipedia, 2025a). The Hass avocado is a large-sized fruit weighing 200 to 300 g. When ripe, the skin becomes a dark purplish-black and yields to gentle pressure. When ripe, the flesh is pale green near the skin and becomes a deeper yellow-green towards the Center (Wikipedia, 2025a). Owing to its taste, size, shelf-life, high growing yield and in some areas, year-round harvesting, the Hass cultivar is the most commercially popular avocado worldwide. In the United States it accounts for more than 80% of the avocado crop and 95% of the California crop, and it is the most widely grown avocado in New Zealand (Wikipedia, 2025a). All commercial, fruit-bearing Hass avocado trees have been grown from grafted seedlings propagated from a single tree that was grown from a seed bought by Rudolph Hass in 1926 from A. R. Rideout of Whittier, California (Wikipedia, 2025a). At the time, Rideout was getting seeds from any source he could find, even restaurant food scraps. The cultivar this seed came from is not known. In 2019, the National Academy of Sciences published a genetic study concluding that the Hass avocado is a cross between Mexican (61%) and Guatemalan (39%) avocado varieties (Wikipedia, 2025a). In 1926, at his 1.5-acre grove at 430 West Road, La Habra Heights, California, Hass planted three seeds he had bought from A. R. Rideout, which yielded one strong seedling (Wikipedia, 2025a).

After trying and failing at least twice to graft the seedling with branches from Fuerte avocado trees (the leading commercial cultivar at the time), Hass thought of cutting it down but a professional grafter named Caulkins told him the young tree was sound and strong, so he let it be (Wikipedia, 2025a). When the tree began bearing odd, bumpy fruit, his children liked the taste. As the tree's yields grew bigger, Hass easily sold what his family did not eat to co-workers at the post office (Wikipedia, 2025a). The Hass avocado had one of its first commercial successes at the Model Grocery Store on Colorado Street in Pasadena, California, where chefs working for some of the town's wealthy residents bought the new cultivar's big, nutty-tasting fruit for $1 each, a very high price at the time (equivalent to $18 in 2024) (Wikipedia, 2025a). Hass patented the tree in 1935 and made a contract with Whittier nurseryman Harold Brokaw to grow and sell grafted seedlings propagated from its cuttings, with Brokaw getting 75% of the proceeds (Wikipedia, 2025a). Brokaw then specialized in the Hass and often sold out of grafted seedlings since, unlike the Fuerte, Hass yields are year-round and also more plentiful, with bigger fruit, a longer shelf life and richer flavor owing to higher oil content (Wikipedia, 2025a). By the early 21st century the US avocado industry took in over $1 billion a year from the heavy-bearing, high quality Hass cultivar, which accounted for around 80% of all avocados grown worldwide (Wikipedia, 2025a). The name "Hass" (rhymes with "pass") is sometimes confused with the name "Haas" in the United States due to the habit of some supermarkets using that spelling in the produce department to advertise the fruit (Wikipedia, 2025a).

The Hass avocado is one of the most delicious varieties of avocado around, with a rich creamy flesh and superior taste (MC, 2025). Hass avocados make up 95% of all the avocados eaten in the USA but you may be surprised to learn that the humble Hass is one of the newest varieties of avocado and didn't even exist before the 1920's (MC, 2025). Avocados have, of course, been around for thousands of years. Avocados are native to Central America and Mexico, where they were cultivated by early humans as far back as 500 B.C. (MC, 2025). The original name for the avocado was "Ahuacatl" which refers to a certain part of the male anatomy that the shape of avocados happens to resemble since they tend to grow in pairs (MC, 2025). The word became "ahuacate" after the Spanish conquest of Mexico and was renamed to "avocado" by American farmers since it was easier to pronounce (MC, 2025). Fast forward to 1926 when the story of the Hass avocado grove began in California. A postal worker named Rudolph Hass purchased some avocado seeds from a local nursery owned by A. R. Rideout (MC, 2025). Rideout was sourcing avocado seeds from several different locations, including restaurant scraps and neighbors' yards (MC, 2025). During this time, there were several different varieties of avocado being grown and sold in California. Hass planted the seeds on his property in La Habra Heights, CA, which already had a few mature Fuerte avocado trees (MC, 2025). After the seeds he had planted grew into immature trees, Hass used cuttings from the Fuerte trees to perform a grafting of the newly planted avocado trees with the Fuerte avocado (MC, 2025). Grafting is a horticultural process often used on fruit trees to ensure that the desired variety of fruit continues to grow on the new tree (MC, 2025). In this case, Hass was trying to grow Fuerte avocados (which at the time were considered to be one of the superior varieties) from the avocado seeds of unknown origin. Hass avocado trees have high yields compared to other varieties and a mature tree can produce over a million blooms (MC, 2025). Most Hass trees bloom twice a year and occasionally there is a third bloom. Hass trees start bearing fruit in three to five years and grow from 15 to 30 feet tall (MC, 2025). The lifespan of an average tree is several decades. 95% of avocados consumed in the UNITED STATES are Hass. Unlike other avocados, which have smooth green skin, the Hass avocado fruit has dark green bumpy skin that darkens as it ripens, eventually reaching a very dark shade that is almost black. Like all avocados, Hass avocados ripen only once they are picked from the tree and they can be left on the tree for several months after the fruit has matured (MC, 2025). When it comes to nutritional content, Hass avocados are higher in fat than other varieties, which gives them a richer taste and smoother, creamier texture (MC, 2025). 80% of avocados consumed in the world are Hass avocados, meaning all other varieties make up only a small proportion of the remaining 20%. In the US, this number rises to 95% (MC, 2025). Learn about the health benefits of avocados, how to prepare the fruits in a way that maximizes these, and how to prevent guacamole from turning brown (Britannica, 2025a). Avocados were first domesticated in tropical America, where they were cultivated as individual seedling trees before the Spanish conquest (Britannica, 2025a). The plants did not receive serious horticultural attention until about 1900, when horticulturists found that production of grafted trees was simple and allowed perpetuation of superior seedlings and the establishment of orchards

(Britannica, 2025a). Flourishing avocado industries have since developed around the world in suitable climates. Mexico, the Dominican Republic, Peru, Indonesia, and Colombia were the top producers worldwide in 2020 (Britannica, 2025a). The fruits are also grown commercially in Florida, California, Hawaii, Kenya, Haiti, Chile, South Africa, Brazil, and Australia, as well as on some Pacific islands and in several Mediterranean countries, including Israel. (Britannica, 2025a).

Avocado is a native of tropical America. It originated in Mexico and Central America, possibly from more than one wild species (Ghosh, 2025). The early Spanish explorers recorded its cultivation from Mexico to Peru but it was not in the West Indies at that time (Ghosh, 2025). It was introduced into Jamaica in 1650 and to Southern Spain in 1601. It was reported in Zanzibar in 1892. It was first recorded in Florida in 1833 and in California in 1856 (Ghosh, 2025). Avocado is the most nutritive among fruits and is regarded as the most important contribution of the New World to human diet. The fruit is relished by some people, but not by others. The pulp is rich in proteins (up to 4%) and fat (up to 30%), but low in carbohydrates. The fat is similar to olive oil in composition and is widely used in the preparation of cosmetics. Avocados have the highest energy value (245 cal/100 g) of any fruit besides being a reservoir of several vitamins and minerals (Ghosh, 2025). Avocado is mainly used fresh, in sandwich filling or in salads. It can also be used in ice creams and milk shakes and the pulp may be preserved by freezing. Three antifungal compounds have been isolated from the peel extracts of immature fruits of the Green cultivar (Ghosh, 2025).

The avocado, alligator pear or avocado pear (*Persea americana*) is an evergreen tree in the laurel family (Lauraceae) (Wikipedia, 2025). It is native to the Americas and was first domesticated in Mesoamerica more than 5,000 years ago (Wikipedia, 2025). It was prized for its large and unusually oily fruit (Wikipedia, 2025). The tree likely originated in the highlands bridging south-central Mexico and Guatemala.[4][5][6] Avocado trees have a native growth range from Mexico to Costa Rica (Wikipedia, 2025). Its fruit, sometimes also referred to as an alligator pear or avocado pear, is botanically a large berry containing a single large seed (Wikipedia, 2025). Sequencing of its genome showed that the evolution of avocados was shaped by polyploidy events and that commercial varieties have a hybrid origin (Wikipedia, 2025). Avocado trees are partly self-pollinating, and are often propagated through grafting to maintain consistent fruit output (Wikipedia, 2025). Avocados are presently cultivated in the tropical and Mediterranean climates of many countries.[4] As of 2023, Mexico is the world's leading producer of avocados, supplying 29% of the global harvest of 10.5 million tonnes (Wikipedia, 2025). The fruit of domestic varieties have smooth, buttery, golden-green flesh when ripe (Wikipedia, 2025). Depending on the cultivar, avocados have green, brown, purplish, or black skin, and may be pear-shaped, egg-shaped, or spherical (Wikipedia, 2025). For commercial purposes, the fruits are picked while unripe and ripened after harvesting (Wikipedia, 2025). The nutrient density and high fat content of avocado flesh are advantages for various cuisines, including vegetarian diets (Wikipedia, 2025). In major production regions like Chile, Mexico and California, the water demands of avocado farms place strain on local resources (Wikipedia, 2025). Avocado production is implicated in other externalities, including deforestation and human rights concerns associated with the partial control of their production in Mexico by organized crime (Wikipedia, 2025). Global warming is expected to result in significant changes to the suitable growing zones for avocados, and place additional pressures on the locales in which they are produced due to heat waves and drought (Wikipedia, 2025). The earliest known written account of the avocado in Europe is that of Martín Fernández de Enciso (c. 1470 – 1528) in 1519 in his book, *Suma De Geographia Que Trata De Todas Las Partidas Y Provincias Del Mundo*, while describing the native settlement of Yaharo (present-day Dibulla, Colombia) (Wikipedia, 2025). The first detailed account that unequivocally describes the avocado was given by Gonzalo Fernández de Oviedo y Valdés in his work *Sumario de la natural historia de las Indias* in 1526, while holding administrative Spanish colonial duties in Santo Domingo and visiting Castilla de Oro (Wikipedia, 2025). The first written record in English of the use of the word 'avocado' was by Hans Sloane, who coined the term,[39] in a 1696 index of Jamaican plants (Wikipedia, 2025).

Domestication, leading to genetically distinct cultivars, possibly originated in the Tehuacan Valley in the state of Puebla, Mexico (Wikipedia, 2025). There is evidence for three possible separate domestications of the avocado, resulting in the currently recognized Guatemalan (*quilaoacatl*), Mexican (*aoacatl*) and West Indian (*tlacacolaocatl*) landraces (Wikipedia, 2025). Guatemalan and Mexican landraces originated in the highlands of those countries, while the West Indian landrace is a lowland variety that ranges from Guatemala, Costa Rica, Colombia, Ecuador to Peru, achieving a wide range through human agency before the arrival of the Europeans (Wikipedia, 2025). The three separate landraces were most likely to have already intermingled in pre-Columbian America and were described in the Florentine Codex (Wikipedia, 2025). As a result of artificial selection, the fruit and correspondingly the seeds of cultivated avocados became considerably larger relative to their earlier wild forebears millennia before the Columbian exchange (Wikipedia, 2025). The earliest residents of northern coastal Peru were living in temporary camps in an ancient wetland and eating avocados, along with chilies, mollusks, sharks, birds, and sea lions (Wikipedia, 2025). The oldest discovery of an avocado pit comes from Coxcatlan Cave, dating from around 9,000 to 10,000 years ago (Wikipedia, 2025). Other caves in the Tehuacan Valley from around the same time period also show early evidence for the presence and consumption of avocado (Wikipedia, 2025). There is evidence for avocado use at Norte Chico civilization sites in Peru by at least 3,200 years ago and at Caballo Muerto in Peru from around 3,800 to 4,500 years ago (Wikipedia, 2025). The avocado tree also has a long history of cultivation in Central and South America, likely beginning as early as 5,000 BC (Wikipedia, 2025). A water jar shaped like an avocado, dating to AD 900, was discovered in the pre-Inca city of Chan Chan (Wikipedia, 2025). The plant was introduced to Spain in 1601, Indonesia around 1750, Mauritius in 1780, Brazil in 1809, the United States mainland in 1825, South Africa and Australia in the late 19th century, and the Ottoman Empire in 1908. In the United States, the avocado was introduced to Florida and Hawaii in 1833 and in California in 1856 (Wikipedia, 2025). The name *avocado* has been used in English since at least 1764, with minor spelling variants such as *avogato* attested even earlier (Wikipedia, 2025). The avocado was commonly referred to in California as *ahuacate* and in Florida as *alligator pear* until 1915, when the California Avocado Association popularized the term *avocado* (Wikipedia, 2025). As a subtropical species, avocados need a climate without frost and with little wind. High winds reduce the humidity, dehydrate the flowers, and affect pollination (Wikipedia, 2025). When even a mild frost occurs, premature fruit drop may occur; although the 'Hass' cultivar can tolerate temperatures down to −1 °C (Wikipedia, 2025). Several cold-hardy varieties are planted in the region of Gainesville, Florida, which survive temperatures as low as −6.5 °C (20 °F) with only minor leaf damage (Wikipedia, 2025). The trees also need well-aerated soils, ideally more than 1 m deep. However, Guatemalan varieties such as "MacArthur", "Rincon", or "Nabal" can withstand temperatures down to −1.6 °C (Wikipedia, 2025). According to information published by the Water Footprint Network, it takes an average of approximately 70 litres (18 US gallons; 15 imperial gallons) of applied fresh ground or surface water, not including rainfall or natural moisture in the soil, to grow one avocado (283 L/kg [33.9 US gal/lb; 28.2 imp gal/lb]) (Wikipedia, 2025). However, the amount of water needed depends on where it is grown; for example, in the main avocado-growing region of Chile, about 320 L (85 US gal; 70 imp gal) of applied water are needed to grow one avocado (1,280 L/kg [153 US gal/lb; 128 imp gal/lb]) (Wikipedia, 2025). Increasing demand and production of avocados may cause water shortages in some avocado production areas, such as the Mexican state of Michoacán (Wikipedia, 2025). Avocados may also cause environmental and socioeconomic impacts in major production areas, illegal deforestation, and water disputes (Wikipedia, 2025). Water requirements for growing avocados are three times higher than for apples, and 18 times higher than for tomatoes (Wikipedia, 2025).

The avocado, alligator pear or avocado pear (*Persea americana*) is an evergreen tree in the laurel family (Lauraceae) (Wikipedia, 2025b). It is native to the Americas and was first domesticated in Mesoamerica more than 5,000 years ago (Wikipedia, 2025b). It was prized for its large and unusually oily fruit (Wikipedia, 2025b). The tree likely originated in the highlands bridging south-central Mexico and Guatemala. Avocado trees have a native growth range from Mexico to Costa Rica (Wikipedia, 2025b). Its fruit, sometimes also referred to as an alligator pear or avocado pear, is botanically a large berry containing a single large seed (Wikipedia, 2025b). Sequencing of its genome showed that the evolution of avocados was shaped by polyploidy events and that commercial varieties have a hybrid origin (Wikipedia, 2025b). Avocado trees are partly self-pollinating, and are often propagated through grafting to maintain consistent fruit output (Wikipedia, 2025b). Avocados are presently cultivated in the tropical and Mediterranean climates of many countries. As of 2023, Mexico is the world's leading producer of avocados, supplying 29% of the global harvest of 10.5 million tonnes (Wikipedia, 2025b). The fruit of domestic varieties have smooth, buttery, golden-green flesh when ripe. Depending on the cultivar, avocados have green, brown, purplish, or black skin, and may be pear-shaped, egg-shaped, or spherical (Wikipedia, 2025b). For commercial purposes, the fruits are picked while unripe and ripened after harvesting (Wikipedia, 2025b). The nutrient density and high fat content of avocado flesh are advantages for various cuisines, including vegetarian diets (Wikipedia, 2025b). In major production regions like Chile, Mexico and California, the water demands of avocado farms place strain on local resources (Wikipedia, 2025b). Avocado production is implicated in other externalities, including deforestation and human rights concerns associated with the partial control of their production in Mexico by organized crime (Wikipedia, 2025b). Global warming is expected to result in significant changes to the suitable growing zones for avocados, and place additional pressures on the locales in which they are produced due to heat waves and drought (Wikipedia, 2025b).

In Mexico and Central America, avocados are served mixed with white rice, in soups, salads, or on the side of chicken and meat. They are also commonly added to *pozole*. In Peru, they are consumed with *tequeños* as mayonnaise, served as a side dish with *parrillas*, used in salads and sandwiches, or as a whole dish when filled with tuna, shrimp, or chicken. In Chile, it is used as a puree-like sauce with chicken, hamburgers, and hot dogs; and in slices for celery or lettuce salads. The Chilean version of Caesar salad contains large slices of mature avocado (Wikipedia, 2025). Avocados in savory dishes, often seen as exotic, are a relative novelty in Portuguese-speaking countries, such as Brazil, where the traditional preparation is mashed with sugar and lime, and eaten as a dessert or snack. This contrasts with Spanish-speaking countries such as Chile, Mexico, or Argentina, where the opposite is true and sweet preparations are rare. With the exception of the Philippines, a former Spanish colony where avocados are traditionally used in sweet preparations and savory uses are seen as exotic (Wikipedia, 2025). In the Philippines (where avocados were introduced from Mexico since before the 1700s), Brazil, Indonesia, Vietnam, and southern India (especially the coastal Kerala, Tamil Nadu and Karnataka region), avocados are frequently used for milkshakes and occasionally added to ice cream and other desserts. In Brazil, the Philippines, Vietnam, and Indonesia, a dessert drink is made with sugar, milk or water, and pureed avocado. Chocolate syrup is sometimes added. In Morocco, a similar chilled avocado and milk drink is sweetened with confectioner's sugar and flavored with a touch of orange flower water. (Wikipedia, 2025). In Ethiopia, avocados are made into juice by mixing them with sugar and milk or water, usually served with Vimto and a slice of lemon. It is also common to serve layered multiple fruit juices in a glass (locally called *Spris*) made of avocados, mangoes, bananas, guavas, and papayas. Avocados are also used to make salads. In Kenya and Nigeria, the avocado is often eaten as a fruit alone or mixed with other fruits in a fruit salad, or as part of a vegetable salad. In Ghana, they are often eaten alone on sliced bread as a sandwich. In Sri Lanka, their well-ripened flesh, thoroughly mashed or pureed with milk and *kitul* treacle (a liquid jaggery made from the sap of the inflorescence of jaggery palms), is a common dessert. In Haiti, they are often consumed with cassava or regular bread for breakfast (Wikipedia, 2025). In the United Kingdom, the avocado became available during the 1960s when introduced by Sainsbury's under the name 'avocado pear'. Much of the success of avocados in the UK is attributed to a long-running promotional campaign initiated by South African growers in 1995. In Australia and New Zealand, avocados are commonly served on sandwiches, sushi, toast, or with chicken (Wikipedia, 2025). In addition to the fruit, the leaves of Mexican avocados (*Persea americana* var. *drymifolia*) are used in some cuisines as a spice, with a flavor somewhat reminiscent of anise. They are sold both dried and fresh, toasted before use, and either crumbled or used whole, commonly in bean dishes (Wikipedia, 2025).

ORIGIN AND DISRTIBUTION

The avocado originated in Central America and southern Mexico. Based on archaeological evidence found in Tehuacán, Puebla (Mexico), it is believed to have appeared approximately 12,000 years ago (Yahia, 2011). It has been determined that the centre of origin of this fruit is the central part of Mexico, passing through Guatemala to Central America. In this region, the natural gene stock can be found, which can be useful for the biotechnological improvement of the species. As evidence for this theory, primitive avocado trees have been found in the 'Oriental Sierra Madre' along from the State of Nuevo León (Mexico) to Costa Rica. From this region, avocado dispersed to the south-eastern part of the USA, the West Indies, and then to a large part of South America (Rajeevan, 2011). The Mexican race, which originated in the mountains of Mexico and Central America, is characterized by relatively small fruit, ranging from 75 to 300 g, with a thin, smooth skin. Mexican race fruit are mostly green skinned (the natural seedling 'criollo' is black skin), and the pulp is green in colour with very high oil content (up to 30% by fresh weight). Mexican cultivars are well adapted to the cool climates of the tropics and subtropics and are the most cold-tolerant of the three races. Mature trees of the Mexican race are capable of withstanding temperatures as low as − 4 °C without damage. The West Indian race is native to the lowlands of Central America and northern South America, and these are best adapted to lowland tropical conditions of high temperature and humidity. They are characterized by intermediate fruit size, with smooth, leathery and sometimes glossy skin. Generally, West Indian avocado trees are the most cold (frost)-sensitive and are damaged by temperatures below − 1.2 °C. While racial ancestry was identified as the most important factor influencing susceptibility to cold, other factors such as tree size, age and vigour, crop load and cultural practices were also shown to influence cold damage. Fruit of the Guatemalan race are native to the highlands of Central America. The Guatemalan cultivars are intermediate between the other two cultivars with respect to climatic adaptation. Guatemalan fruit are large, averaging 500 to 600 g, and characterized by thick brittle peel, high oil content and nutty flavoured pulp (Rajeevan, 2011).

Mexico has a wide variety of types of avocado-there are at least 20 different species related to the avocado.The avocado is part of the Lauraceae family, considered by many botanists to be among the most primitive of the dicotyledonous plant; the centre of origin of the avocado is located in the highlands of central and east-central Mexico and the Guatemalan highlands. In Mexico, three races are recognized: Mexican, Guatemalan and West Indian, which were classified as botanical varieties. *Persea americana* var. *drymifolia*, or the Mexican avocado, is the oldest variety used as food; seeds of avocados were found in cave deposits in the Tehuacan Valley, Puebla in Mexico, the oldest cotyledon from the Coxcotlán cave deposit is dated to at least 7,000 B.C. In 1966, the geographical distribution of the *P. americana* var**.** *drymifolia* in Mexico was determined in the mountain forests of the eastern and south-eastern and in the Pacific zone (Sánchez-González *et al*., 2015). *Avocado*, (*Persea americana*), tree of the family Lauraceae and its edible fruit. Avocados are native to the Western Hemisphere from Mexico south to the Andean regions and are widely grown in warm climates (Hadidi *et al*., 2017). Native to the Americas, specifically Mesoamerica (Google, 2025).

TAXONOMY

Morphological and molecular data indicate that the Lauraceae is a monophyletic family, although classification with the family is less clear. Despite its ecological importance in tropical ecosystems, the Lauraceae is poorly known, since material is difficult to collect, the flowers are inconspicuous, and fruits and flowers are needed for accurate identification of most species. This creates problems for the delimitation of both genera and species, and thus absolute statements about generic distribution are difficult to make, particularly for genera that have widely disjunct distributions (*e.g., Apollonias* between India and the Canary Islands). Traditional Lauraceae classifications have placed the parasitic genus *Cassytha* in its own subfamily (Cassythoideae), and treated the remaining genera as a second subfamily (Lauroideae). Within the Lauroideae, morphological characters (*e.g.,* flower and wood anatomy) have been used to define three tribes: (1) Laureae (*e.g., Laurus*); (2) Perseeae (*e.g*., *Persea*); and (3) Cryptocaryeae (*e.g., Beilschmiedia*). However, molecular analysis of the family suggests that *Cassytha* should be placed with either *Hypodaphnis* or *Neocinnamomum*, and that the Lauroideae tribes, as currently defined, are not monophyletic (Jeffery, 2004).

Lauraceae, the laurel family of flowering plants (order Laurales), comprising some 50 genera and more than 2,500 species of mostly evergreen shrubs and trees. Lauraceae is distributed throughout tropical and subtropical regions; principally Southeast Asia and tropical America, particularly Brazil. The family contains a number of economically important trees, including avocado, cinnamon, bay, and a variety of valuable timber trees, the wood of which sometimes remains fragrant for decades after it is cut (Britannica, 2025a). The vast majority of species of Lauraceae differ from other Laurales members in possessing leaves that are alternately arranged or whorled, although a few have opposite leaves. The leaves of Lauraceae are usually leathery and evergreen with numerous essential oil cavities, which accounts for the aromatic nature of many species. Most of the species also have aromatic oil in the wood and bark (Britannica, 2025a). The generally small green, yellow, or white flowers are usually arranged in clusters, and the floral parts develop in multiples of three. The perianth is not differentiated into sepals and petals. There are between 3 and 12 stamens per flower, and the filament of each stamen often has paired nectar-producing appendages attached near the base. Stamens may have two (Beilschmiedia) or four (Litsea) pollen sacs; the pollen decays readily and thus is seldom found in the fossil record. The fleshy fruits are single-seed drupes or berries, and they often have a smooth cupule surrounding the base akin to the cap of an acorn. Each seed has a large embryo and little to no endosperm at maturity (Britannica, 2025a). **Avocado**, (Persea americana), tree of the family Lauraceae and its edible fruit. Avocados are native to the Western Hemisphere from Mexico south to the Andean regions and are widely grown in warm climates. Avocado fruits have greenish or yellowish flesh with a buttery consistency and a rich nutty flavour. They are often eaten in salads, and in many parts of the world they are eaten as a dessert. Mashed avocado is the principal ingredient of guacamole, a characteristic saucelike condiment in Mexican cuisine. Avocados provide thiamin, riboflavin, and vitamin A, and in some varieties the flesh contains as much as 25 percent unsaturated oil. (Britannica, 2025a). The avocado is a member of the large plant family known as the Lauraceae, or laurels. The family is named for the Grecian laurel tree, or "sweet bay" (Laurus nobilis), whose foliage adorned the brows of the champions in the ancient Pythian contests at Delphi, Greece, every four years; unlike the rival Olympic games, the Pythian competitions included cultural events like music and literature. Most of the laurels have foliage that is fragrant when crushed, for example the Mexican race of avocado — from whose leaves pleasant teas and wines have been made. The only California native is the California laurel (*Umbellularia californica*), also known as the California bay, Oregon myrtle, or pepperwood; its leaves are so powerfully aromatic that they can cause headaches. Both the Grecian and the California laurels grow well in our avocado areas. Both are grown as ornamentals, and the leaves of both are used as flavoring in soups and stews. Most members of the laurel family are tropical or subtropical, including the avocado. But there are two hardy American natives: spicebush, sometimes used as a substitute for allspice; and sassafras, whose powdered bark is still used medicinally and whose bark and leaf flavoring make a pleasantly scented tea, are used in cooking and in carbonated beverages (Bergh and Ellstrand, 1986).

-The great Swedish botanist and taxonomist, Carolus Linnaeus, placed the avocado in the Laurus genus with the Greek laurel. It was apparently taken from Greek mythology and has no known factual connection with the country of Persia. The Persea genus contains some 50 species. One of these is the true avocado, "americana." So, adding the abbreviated name of its describer, the avocado is botanically designated Persea americana Mill. As its name indicates, *P. americana* originated in the New World. So did most of the species, but *P. indica* came from the Canary-Madeira-Azores islands, and several presumed species are native to southeast Asia. The species fall into two groups*: P. americana* and a few closely related species on the one hand, and a large and quite variable group of species on the other. Each of the two groups is a subgenus. The commercial avocado, *P. americana*, is in subg. *Persea* (the same as the genus name), and the larger group of species are placed in subg. Eriodaphne, The two subgenera are sharply distinct. But, at this time, the only Persea species of much economic importance is the avocado itself, *P. Americana* (Bergh and Ellstrand, 1986). Systematic studies have classified more than 500 varieties; however, many are not commercially produced, because of productivity problems (production time, amount of fruit), quality (protein and fat content), and handling problems (such as resistance to damage during transportation). Many of the commercial cultivars are hybrids of the three races. There is great variability in fruit traits not only between races but also between cultivars within a race. One of the most distinct differences between cultivars is the peel colour when ripe. The peel of some cultivars changes from green to black or purple with advanced maturity or ripening. 'Hass', a Guatemalan-Mexican (G-MX) hybrid, is a black-skinned (when ripe), ovate cultivar whose fruit weighs 140 to 300 g. 'Hass' is the most important commercial cultivar worldwide, and the predominant cultivar in the important production countries (Mexico, Chile and the USA) and is also important in other smaller producer countries (*e.g.* Spain, Australia and New Zealand). Some other commercial cultivars include 'Bacon', 'Fuerte', 'Gwen', 'Ryan', 'Lamb Hass', 'Pinkerton', 'Reed', 'Sharwil', 'Edranol' and 'Zutano'. The main Florida cultivars (West Indian and Guatemalan races and hybrids) are 'Simmonds', 'Nadir', 'Booth 8', 'Choquette' and 'Lula'. With the exception of 'Reed', which is believed to be entirely of the G race, the other cultivars are considered primarily G-MX hybrids. 'Sharwil' is a MX-G cross and represents more than 57% of the commercial acreage in Hawaii. Its green-skinned fruit weigh 220 to 560 g, matures in winter and spring, and has small seeds and greenish-yellow flesh with a rich, nutty flavour. The avocado fruit can be round, pear shaped, or oblong, and the skin of the fruit may vary in texture and colour. The skin may be pliable to woody, smooth to rough, and green-yellow, reddish-purple, purple, or black in colour. The flesh of the fruit is greenish-yellow to bright yellow when ripe and buttery in consistency, but inferior varieties may be fibrous. The avocado fruit has one large seed, which makes up to 10 to 25% of the fruit weight. The fruit of different avocado cultivars vary in moisture and oil content, from less than 5% to more than 30% oil (Rajeevan, 2011).

Botanical varieties that lie within *P. americana* include *P. americana* var. *drymifolia*, *P. americana* var. *guatemalensis* and *P. Americana* var. *Americana.* These are commonly known as the Mexican, Guatemalan and West Indian (Lowland or Antillean) horticultural races respectively, based on their presumed centres of origin. Three distinguishable ecological races of avocado have long been recognized. They have ordinarily been termed the Mexican, Guatemalan, and West Indian types or races, named for their presumed respective centers of origin. The races differ in many traits, some of commercial importance (Bergh and Ellstrand, 1986). Commercial avocado (*Persea americana* Mill.) belongs to the sub-genus Persea that also contains two other species, *P. schiedeana* (Nees) and *P. parviflora* (Williams). *P. americana* is a polymorphic species containing several separate taxa that are considered to be botanical varieties more commonly referred to as horticultural races. There are no

sterility barriers among the three races or among any taxa classified under *P. americana*. Hence, hybridisation occurs wherever trees of different races are growing in proximity, whether indigenously or under cultivation. 'Fuerte', the cultivar that long led production in California and most other editerranean/subtropical growing regions, is apparently a natural Mexican×Guatemalan hybrid, although with predominantly Mexican race characteristics. 'Hass', currently the dominant cultivar in most of these regions, is generally regarded as pure Guatemalan, but progeny produced by self-pollination indicate that it contains Mexican genes. Guatemalan × West Indian hybrids are currently the leading cultivars in Florida and look promising for future production in more tropical areas. For a detailed description of avocado taxonomy (Lahav and Lavi, 2009). The avocado is botanically classified into three races, with differences in fruit maturity and oil content between the different races. West Indian (WI), Persea americana Mill. var. *americana* (***P.*** *gratissima* Gaertn.), are tropical with large variably shaped fruit and lower oil content; Mexican (MX), ***P.*** *americana* Mill. var. *drymifolia* Blake (P *drymifolia* Schlecht. & Cham.), are semi-tropical with smaller elongated thin-skinned fruit and higher oil content; and Guatemalan (G), ***P.*** *nubigena* var. *guatemalensis* L. Wms., are subtropical with mostly round thick-skinned fruit and intermediate oil content (Rajeevan, 2011).

Avocado, originally from Mexico and Central America, is part of the Lauraceae family, *i.e*., the genus *Persea*. This genus has two subgenera: *Persea* and *Eriodaphne*. The subgenus with commercial interest is *Persea*, which in turn has three botanical varieties: *P. americana* Mill. var. Drymifolia (Mexican species); *P. americana* Mill. var. *American (*West Indian species); and *Persea nubigena* Mill. var. *Guatemalensis* (Guatemalan species).

The requirements of avocado vary according to the variety. The Antillean variety has a pyriform shape and is adapted to low temperatures. The Guatemalan variety has rounded fruits and is even more resistant to cold. Meanwhile, the Mexican variety has small fruits and is the most resistant to low temperatures (Pleguezuelo *et al*., 2018). Avocado is classified into three ecotypes: Guatemalan (*P. americana* var. *guatemalensis* L. Wms.), Mexican (*P. americana* var. *drymifolia* Schlecht. et Cham. Blake), and West Indian (*Persea americana* var. *americana*). These races originated from distinct geographical regions: West Indian from Mesoamerican coastal lowlands, Guatemalan from Guatemalan highlands, and Mexican from Mexican highlands. Morphologically, Mexican avocados tend to be smaller in size with larger seeds, thin skins, and a waxy bloom texture. In contrast, Guatemalan and West Indian avocados exhibit variable fruit sizes, with Guatemalans having thick and rough skins and smaller seeds. Additionally, Mexican avocados are notably rich in oil content, whereas West Indian fruits generally have lower oil levels. These ecotypes were introduced to the United States in the mid-to-late 19th century. They underwent extensive hybridization, developing interracial hybrids with promising characteristics, which are widely used in commercial avocado cultivation today (Li *et al*., 2024).

BOTANICAL DESCRIPTION

Avocado trees can be tall or spreading, and they have elliptic to egg-shaped leaves that are 10–30 cm (4–12 inches) in length. The small greenish flowers are borne in dense inflorescences and lack true petals. The flowers have nine stamens, arranged in three series, and a one-celled ovary. Interestingly, there are two types of avocado flowers, A and B, depending on the cultivar. These flowers are dichogamous (male and female parts mature separately), and each flower opens only twice. Type A flowers are functionally female in the morning, close at midday, and then reopen as functionally male in the afternoon of the following day. Type B flowers are functionally female in the afternoon, close in the evening, and then reopen the following morning as functionally male. When the two flower types are grown together, this temporal overlap of mature male and female parts encourages cross-pollination and, thus, greater fruit production. The fruit is exceedingly variable in size, no larger than a hen's egg in certain Mexican races and sometimes weighing 1–2 kg in other races. The form varies from round to pear-shaped with a long slender neck, and the colour ranges from green to dark purple. Botanically, the fruit is a berry and features a single large round seed with two cotyledons. The fruit's outer skin is sometimes no thicker than that of an apple and sometimes is coarse and woody in texture (Hadidi *et al.,* 2017).

The tree is evergreen, but normally it is considered as wintergreen since the leaves do not stay on the tree more than 12 months and the entire canopy is changed during the growth that follows the flowering period. Trunk and branches are monopodial and end in a vegetative bud. Leaves reach their final size in approximately 30 days . It has a vegetative preference in its growth pattern, and therefore assimilates preferentially to shoot growth and not to reproductive organs. This behaviour, together with the fast production of leaves and shading areas in the canopy, reduces the number of shoots available for flowering. In subtropical latitudes, flowering begins when shoot growth enters the inactive period. Flowering occurs normally during late winter and spring and anthesis lasts from 3 to 8 weeks. Inflorescences are panicles of cymes. Avocados are protogynous and have synchronous dichogamy with the maturation of anthers and stigmas in different periods—that is, flowers open when the pistil is receptive and afterward close to open again on the second day when the pollen is dispersed and the pistil is no longer receptive. The timing of the opening and closing of the flowers changes according to the variety. A medium-flowering tree can have 1–2 million flowers, but produces only 200–300 fruits. In subtropical latitudes, the fruit load is decreased by leaf shed during approximately the first month after fruit set and then again at the beginning of summer. The fruit is botanically a berry with a thick, fleshy mesocarp surrounding a single large seed. After flowering, a great number of fruits drop; this period is crucial since resources must be shared between fruit growth and new shoot growth (Pleguezuelo *et al*., 2018). Avocado is a fruit, botanically classified as a berry, known for its creamy texture and mild, nutty flavor. It's a popular ingredient in various dishes and is considered a nutrient-rich "superfood". Fruit: A large, pear-shaped berry with a single seed. Skin: Varies in color and texture depending on the variety, ranging from green to dark green and smooth to bumpy. Flesh: Creamy, buttery, and pale to deep green (Google, 2025). *Persea americana* is a tree that grows to 9–20 m with a trunk diameter between 0.3–0.6 m. The leaves are –25 cm long and alternately arranged. Panicles of flowers with deciduous bracts arise from new growth or the axils of leaves. The tree flowers thousands of blossoms every year. Avocado blossoms sprout from racemes near the leaf axils; they are small and inconspicuous 5–10 mm wide. They have no petals but instead two whorls of three pale-green or greenish-yellow downy perianth lobes, each blossom has 9 stamens with 2 basal orange nectar glands (Wikipedia, 2025). The avocado fruit is a climacteric, single-seeded berry, due to the imperceptible endocarp covering the seed, rather than a drupe. The pear-shaped fruit is usually 7–20 cm long, weighs between 100 and 1,000 g, and has a large central seed, 5–6.4 cm long. Early wild avocados prior to domestication had much smaller seeds around 2.1–2.2 centimetres in diameter, likely corresponding to smaller fruit size. The species produces various cultivars with larger, fleshier fruits with a thinner exocarp because of selective breeding by humans (Wikipedia, 2025). Avocado trees can be tall or spreading, and they have elliptic to egg-shaped leaves that are 10–30 cm in length. The small greenish flowers are borne in dense inflorescences and lack true petals. The flowers have nine stamens, arranged in three series, and a one-celled ovary. Interestingly, there are two types of avocado flowers, A and B, depending on the cultivar. These flowers are dichogamous (male and female parts mature separately), and each flower opens only twice. Type A flowers are functionally female in the morning, close at midday, and then reopen as functionally male in the afternoon of the following day. Type B flowers are functionally female in the afternoon, close in the evening, and then reopen the following morning as functionally male. When the two flower types are grown together, this temporal overlap of mature male and female parts encourages cross-pollination and, thus, greater fruit production. The fruit is exceedingly variable in size, no larger than a hen's egg in certain Mexican races and sometimes weighing 1–2 kg in other races. The form varies from round to pear-shaped with a long

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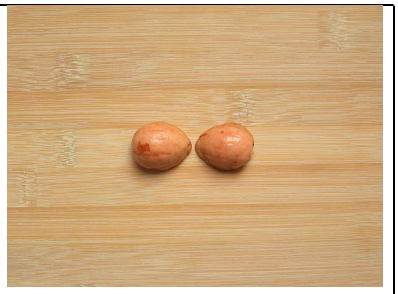
		
Tree	**Seeds**	**Seeds**
		
Seedling	**Seedling**	**Leaves**
		
Stamens	**Perianth**	**Stamens and Carpels**
		
Elliptical-shaped leaves.	**Flowers**	**Young fruits**

Continue …..

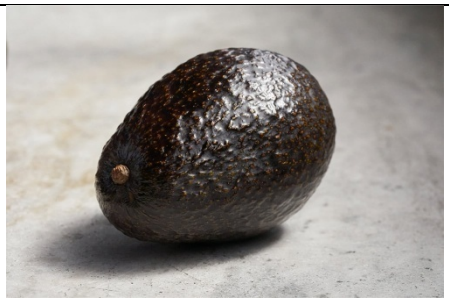
		
Fruits	**Fruits**	**fruit and foliage**
		
Fruit	**Cut Fruit**	**seedless**

Fig. 1: Botanical Description

GENETICS AND CYTOGENETICS

The number of chromosomes in avocado is 2n = 24 (Garcia 1975). Furthermore, a chromosome-scale genome assembly of the most popular avocado cultivar 'Hass' has been published and revealed a diploid genome with a chromosome number of 2n = 24 and an approximate genome size of 920 Mb. This genomic information serves as a valuable reference for identifying genetic foundations underlying desirable avocado traits (Li *et al.,* 2024).

GENETIC DIVERSITY

Despite the considerable significance of fruit quality traits, limited attention has been devoted to improve these characteristics in avocados. There is an urgent need for increased efforts in this area. In previous studies, a set of 5,050 high quality SNP markers was developed using transcriptome data obtained through Illumina sequencing technology. We aligned these markers to the recently published 'Hass' reference genome (GCA_029852735.1) resulting in 4,706 valid SNPs. These makers were used to assess the genetic diversity and population structure of 110 Persea accessions. Concurrently, correlations between these SNPs and nine fruit quality traits, collected from 2017 to 2022, including fruit skin color, fruit shape, fruit taste, and fruit skin texture, were examined. Significant associations between genomic regions and fruit quality traits were detected, leading to the identification of candidate genes through functional inference. These findings hold promise for marker-assisted selection in avocado breeding, potentially reducing the time and financial resources required for the development and release of new avocado varieties (Li *et al.,* 2024).

Avocado (*Persea americana*) is a highly nutritious fruit gaining worldwide popularity. However, its cultivation is currently reliant on a limited number of cultivars with restricted genetic diversity. This study aims to investigate the genetic diversity and population structure of avocado germplasm and identify genetic loci associatedwith key fruit quality traits that influence customer preference. Methods: A diversity panel of 110 avocado accessions was analyzed using 4,706 high-quality single nucleotide polymorphisms (SNPs). Genetic diversity and population structure were analyzed using pairwise FST, AMOVA, admixture analysis, and phylogenetic analysis. Genome-wide association studies (GWAS) were conducted targeting nine fruit quality traits using two models: General Linear Model (GLM) with Principal Component Analysis (PCA) and Mixed Linear Model (MLM) with PCA and kinship (PCA + K) (Li *et al.,* 2024). To address population stratification in the GWAS analyses, Centered Identical by State (IBS) kinship using a maximum of 6 alleles and PCA with the top 5 components were calculated. The association between 4,706 SNPs and fruit quality traits in 110 avocado accessions were assessed using two models: Generalized Linear Models (GLM) with PCA (subjected to 1000 permutations) and Mixed Linear Models (MLA) with PCA + Kinship in TASSEL version 5.0. Additionally, p-values thresholds of 0.0001 and 0.0005 for slightly weaker associations were considered to prevent overlooking functional regions. The GWAS results including QQ-plots (quantile-quantile plots) to mitigate false positives by assessing the distribution of p-values were visualized by the CMplot package. The LD r2 value of 0.2 was utilized as a moderate threshold for linkage with SNPs within 200 kb window commonly exhibiting stronger associations than the threshold. All genes within 200 kb windows centered on markers associated with fruit quality traits were identified. Then, gene ontology (GO) and Kyoto Encyclopedia of Genes and Genomes (KEGG) pathway enrichment analyses were performed on these genes utilizing an annotated gene set from the 'Hass' genome as reference, and the results were compared with the plant database in TBtools 2. The resulting data were filtered, and the top GO terms and KEGG pathways with high enrichment scores and significant p-value were plotted with custom R code with ggplot (Li *et al.,* 2024). Over the years, horticultural characteristics of avocados have exhibited extensive variation, primarily due to cross-pollination and sexual propagation. Understanding genetic diversity is crucial for collecting, preserving, and utilizing

avocado germplasm in crop development. Molecular markers, known for their high polymorphism and heritability, play a pivotal role in characterizing the genetic makeup of germplasm. These markers are particularly advantageous for early identification of accessions and varieties with desirable traits. This accelerates the breeding process for fruit trees such as avocados significantly, which have a lengthy juvenile period of up to 15 years before initial blooming and fruit production. Various molecular markers, including random amplified polymorphic DNA (RAPD), restriction fragment length polymorphism (RFLP) and Simple Sequence Repeats (SSRs) have been widely employed to analyze the genetic diversity of avocado accessions worldwide. However, earlier research on the three ecological races – West Indian, Mexican, and Guatemalan - yielded inconsistent results. While some studies grouped Guatemalan and West Indian races based on morphological traits and early DNA markers like RAPD and RFLP, others suggested a closer relationship between Guatemalan and Mexican races (Li *et al*., 2024).

Conventional molecular markers have encountered challenges in accurately distinguishing among avocado genomes, particularly those with subtle differences resulting from recent interracial hybridization. However, with advancements in high-throughput technologies such as microarray, next-generation sequencing (NGS) and genotypingby-sequencing (GBS), single-nucleotide polymorphisms (SNPs) have emerged as powerful genetic markers. These common genetic variations enable comprehensive genome-wide variability estimation . Meanwhile, molecular biology methodologies, including Quantitative Trait Locus (QTL) mapping and Genome-Wide Association Studies (GWAS), have demonstrated considerable potential in identifying markers and candidate genes associated with important traits such as yield, disease resistance, and stress tolerance (Li *et al.,* 2024).

All the forty-six qualitative traits showed polymorphism, presenting each two or more phenotypic variants (Fig. 2). Cross tabulation and Chi-square tests revealed differential distribution of traits variants among villages and altitude ranges. Various phenotypic features were observed among trees, pointing out the existence of several avocado races in Cameroon. For all the 46 qualitative traits, 162 phenotypic classes were detected, giving an average of 3.52 phenotypic classes per trait. The diversity index varied significantly between traits, populations and altitude ranges with a mean value of H'= 0.90 for qualitative traits and H'=1.31 for quantitative traits. The top five traits with higher diversity indices were fruit shape (H'=2.04), ripe fruit skin colour (H'=1.75), seed shape (H'=1.75), Tree shape (H'=1.74) and colour of flesh next to seed (H'=1.47). Bangang and Batcham populations were found to be more diverse. The lowest altitude range, 1100–1300 m above sea level (MASL) displayed smallest diversity when comparing altitude ranges. The partitioning of the diversity revealed more variation within population and within altitude ranges. Although this study revealed extensive variation between trees at the village and altitude range levels, no clear groupings of genotypes was identified based on geography. Dendrogram revealed that avocado trees from the same village and even from the same altitude ranges differ substantially. Altitude was negatively associated seed length, time from ripeness to deterioration and time from maturity to deterioration of fruits. Seventeen traits were significantly associated with the two main principal components of the PCA. Cluster analysis revealed four distinct clusters, associated to the existing avocado races (Kouam *et al.,* 2025) Fig. 2..

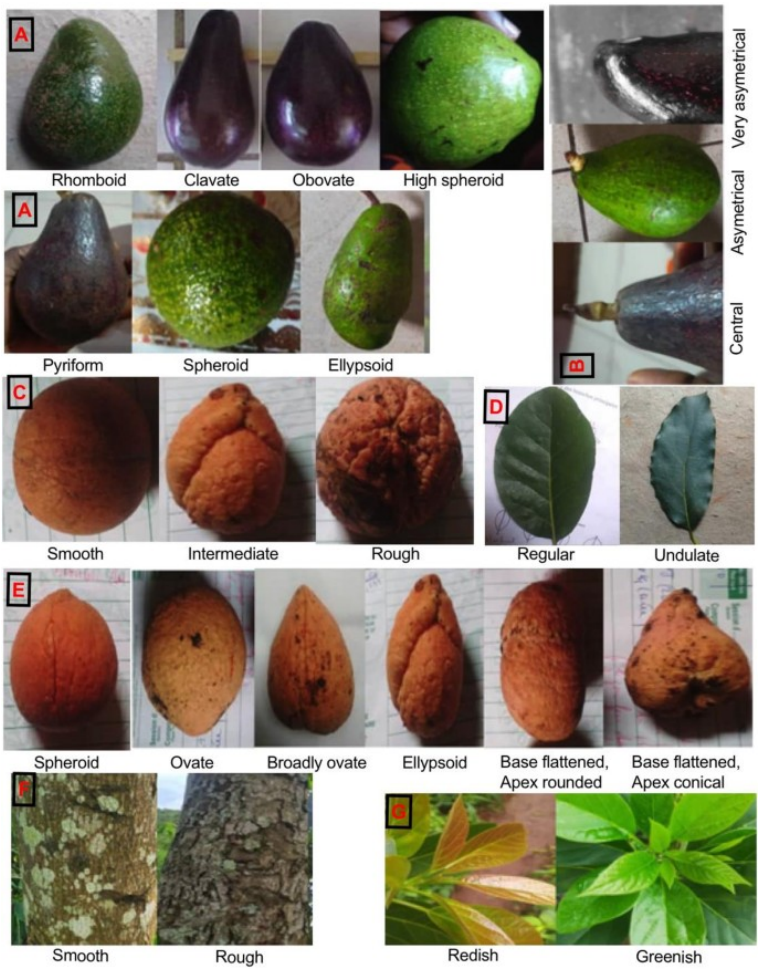


Fig. 2. Main phenotypic variants of some phenotypic qualitative traits in avocado trees from the Bamboutos highlands in Western Cameroon: Fruit shape (A), Pedicel position on fruit (B), Cotyledon surface (C), Leaf margin (D), Seed shape (E), Trunk surface (F), Colour young twig (G)

BREEDING

Propagation: Avocados can be propagated by seed, taking roughly four to six years to bear fruit, although in some cases seedlings can take 10 years to come into bearing.[73] The offspring is unlikely to be identical to the parent cultivar in fruit quality. Prime quality varieties are therefore propagated by grafting to rootstocks that are propagated by seed (seedling rootstocks) or by layering (clonal rootstocks). After about a year of growing in a greenhouse, the young rootstocks are ready to be grafted. Terminal and lateral grafting is normally used. The scion cultivar grows for another 6–12 months before the tree is ready to be sold. Clonal rootstocks are selected for tolerance of specific soil and disease conditions, such as poor soil aeration or resistance to the soil-borne disease (root rot) caused by *Phytophthora cinnamomi*. Advances in cloning techniques that can produce up to 500 new plants from a single millimetre of tree cutting have the potential to increase the availability of rootstocks (Wikipedia, 2025). Commercial avocado production is limited to a small fraction of the vast genetic diversity in the species. Conservation of this genetic diversity has relied largely on field collection, as avocado seeds often do not survive storage in seed banks. This is problematic, as field preservation of living cultivars is expensive, and habitat loss threatens wild cultivars. More recently, an alternate method of conservation has been developed based on cryopreservation of avocado somatic embryos with reliable methods for somatic embryogenesis and reconstitution into living trees (Wikipedia, 2025).

Breeding: The species is only partially able to self-pollinate because of dichogamy in its flowering. This limitation, added to the long juvenile period, makes the species difficult to breed. Most cultivars are propagated by grafting, having originated from random seedling plants or minor mutations derived from cultivars. Modern breeding programs tend to use isolation plots where the chances of cross-pollination are reduced. That is the case for programs at the University of California, Riverside, as well as the Volcani Centre and the Instituto de Investigaciones Agropecuarias in Chile.

Races: Alpha, Ashikawa, Beardsley, Beshore, Daily II, Chris Kelly, Cobain, Cocktail Fuerte, Collin 33, Cooper Late Green, Fuerte, Fujikawa, Fukumitsu, Green Gold, Hall, Hamachi, Hashimoto, Hayes, Hulumanu, Illialu, Infante, Infante 2, Itzamna, Ixtapan - J- 70, Jan Boyc, Jeanette, Johnson, Kakazu, Kampong, Kellum, Kaneko, Kosel, Leal, Little Kado, Masami, Mr.T, MIT 13, Murashige, Nabal, Naranjo, Nishikawa, Ohata, Ota, Pankay, Papaiko, Principe, Reed, Rodrigues, San Miquel, Purple, Schattauer 1, Schattauer 2, Semil 34, Serpa, Shirai, Tamashiro, Thompson, Yamagata, Yamane and Vargas (Rainer and Bergh, 1990).

Horticulturally, avocados are divided into the Mexican (*Persea americana*, variety *drymifolia*), West Indian (*P. americana*, variety *americana*), and Guatemalan (*P. americana*, variety *guatemalensis*) races, with more than 1,000 cultivars between them. The Mexican race is native to Mexico and is characterized by the anise-like odour of the leaves and by small (weighing 90–240 grams [3–8 ounces]), thin-skinned fruits of rich flavour and excellent quality. Mexican avocados are the hardiest, growing in regions too cold for other types. The Guatemalan race, native to the highlands of Central America, is slightly less frost-resistant than the Mexican and produces fruits of medium to large size (240–1,000 grams), characterized by thick woody skins and a ripening season different from that of the others. Cultivation of the West Indian race, the most tropical in character, is limited in the United States to southern Florida. Hass avocado, the most popular cultivar in the United States, is a Mexican-Guatemalan hybrid (Britannica, 2025a).

The Guatemalan race. *Persea nubigena* L. Wins var. *guatemalensis:* This race probably originated not only in the highlands of Guatemala but also in the Chiapas in Mexico. The leaves are large and uniformly dark green on both faces. Although it is not as tolerant to cold as the Mexican race, it is useful for marginal cultivation zones. The fruits are roundish and have thick, very hard warty skin. The size may vary considerably but they are generally larger than fruits of the Mexican race. The seed is fairly small and almost always clings. Pulp oil content is medium at 10 to 20%. Flowering to harvest time is 8 to 10 months. It can be longer in the cold parts of California (12 to 14 months). The race is a good parent for crosses (contributing genes for small seeds). Nearly 40% of avocados belong to this race, including 'Anaheim', 'Corona', 'Sharwil' and the major commercial varieties such as 'Edranol', 'Gwen', 'Hass', 'Nabal' and 'Reed' (KRMS, 2025).

The West Indian race. *Persea americana* Miller var. *Americana:* In spite of its name, this race probably originated in Colombia. It is well suited to humid tropical regions where it is used to supply local markets. The tree has large green leaves. The fruits are elongated, usually large and weigh 400 to 900 g. The epidermis is fairly thin (0.8 to 1.5 mm) and is smooth and shiny, soft green or greenish yellow or reddish when mature. The pulp is watery with a low oil content (< 10%). The seed—often free—is large and has a more or less corrugated surface. All these characteristics make the fruits delicate. They often display pulp browning (caused by chilling injury) at the temperatures generally used for the storage and refrigerated transport of fruits of the other races (+ 6°C, + 8°C). The race is the most sensitive one to cold and aridity but the most tolerant to salinity. The flowering to harvest time is only 5 to 7 months. The West Indian race groups about 15% of avocado varieties and the best known among them are 'Peterson', 'Pollock' and 'Waldin' (KRMS, 2025).

The Mexican race. *Persea americana* Miller var. *drymifolia* Schlecht and Cham.: his fairly hardy race is adapted to low temperatures originated in the Mexican highlands. It differs from the two other races in several botanical characteristics:

•• the leaves are generally small and release a characteristic aniseed odour when crumpled;
•• flowering is earlier than in the other races and the flowering to harvest time is 7 to 9 months;
•• the fruits are small and elongated and rarely weigh more than 250 g. The skin is very thin and smooth.

The pulp is often fibrous and has a high oil content (> 15%). The seed is generally large and sometimes free. This race is very sensitive to salinity. In contrast, it tolerates high temperatures and comparatively low relative humidity. Furthermore, it has greater tolerance to Phytophthora cinnamomi than the other races. It thus forms good rootstock and its genetic potential is well exploited in hybridisation breeding programmes. Finally, its high lipid content is an interesting feature when the fruits are used for oil production. About 20% of varieties belong to this race. The best known include 'Duke', 'Gottfried', 'Mexicolo', 'Topa Topa' and 'Zutano' (KRMS, 2025).

The characteristics of the major avocado races are (Ghosh, 2025)

Mexican race: Small (250 g) fruit type, ripening 6 to 8 months after flowering. Fruits have thin smooth skin with a large seed fitting loosely in the central cavity. Oil content is up to 30 per cent in the fruits. Trees of this race are cold hardy.

Guatemalan race: Fruits fairly large, weighing up to 600 g and borne on long stalks. The fruits ripen 9-12 months after flowering. Fruit skin is thick and often warty. Seeds, held tightly in the hollow of the fruit, are small. The oil content in fruits ranges between 8 and 15 per cent.

West Indian race: Fruit medium in size and the fruit skin smooth, leathery and glossy. Fruits are borne on long stalks and require up to 9 months for ripening from the date of flowering. Its seeds are large, fitting loosely in the cavity. The oil content of the fruit is low (3-10 per cent). This race is suitable for warm tropical climates.

Varieteis

Hybrids: A large proportion of the varieties of interest for international trade are hybrids. These are generally natural crosses and in rarer cases are the result of breeding exploiting the inter-fertility of the three races. The main selection criteria are agronomic (resistance to pests and diseases, especially *Phytophthora*, tolerance to salinity and cold, productivity) and those related to fruit quality (size, high pulp percentage, flavour, absence of fibres, oil content). 'Bacon', 'Ettinger', 'Fuerte' and 'Lula' in particular are natural Mexican x Guatemalan hybrids. Guatemalan x West Indian hybrids, mainly from Florida, include the varieties 'Ajax', 'Booth', 'Choquette', 'Collinson' and 'Simpson'. Mexican x West Indian hybrids such as 'Indian River' are very rare. Other varieties resulting from inter-race crosses are possible (KRMS, 2025).

Hass. Guatemalan race: 'Hass' has replaced 'Fuerte' as the sector standard. It is currently the most commonly planted avocado in the world. It was selected by Rudolph Hass in California in the early 1920s and registered in 1935. The tree is vigorous and highly productive. The fruits vary in shape in some production regions, ranging from pyriform to ovoid. Average fruits size is fairly small in hot regions. Keeps well on the tree. The skin turns from dark green to purplish brown at maturity. It is easy to remove from the pulp. The organoleptic qualities are excellent. Rich flavour (nutty taste) and buttery non-fibrous pulp (KRMS, 2025).

Fuerte. Mexican x Guatemalan hybrid: This variety was long the most commonly planted in the world and originated in Mexico (Atlixco). The tree is vigorous with fairly good frost resistance (to 4°C), but is particularly temperature-sensitive during the flowering period. Productivity is generally good in temperate zones but it displays strong alternate bearing. The fruits are easy to peel and have excellent organoleptic qualities (buttery pulp) (KRMS, 2025).

Ettinger. Mexican x Guatemalan hybrid: This variety was bred from 'Fuerte' in Kefar Malal in Israel, where it is mainly grown. The tree is very fertile and vigorous with an erect habit. The fruits are similar to those of 'Fuerte'. The skin is susceptible to problems of corky areas and tends to adhere to the pulp. The pulp is buttery and fibreless and has good organoleptic qualities (KRMS, 2025).

Pinkerton. Mexican x Guatemalan hybrid: A recent variety bred in California by John Pinkerton and registered in 1975. It is probably the result of a Hass x Rincon cross. The tree is very vigorous and tolerates temperatures of -1/-2°C to 30°C. Production is good and alternate bearing is mild. The fruits may suffer from ring-neck if the tree is under conditions of stress. The organoleptic qualities of this variety are excellent (nutty taste). The pulp is smooth, buttery and fibreless (KRMS, 2025).

Reed. Guatemalan race: This variety of Californian origin was selected by James Reed. Registered in 1960, the patent expired in 1977. It has succeeded in conserving the qualities of its parents 'Nabal' and 'Anaheim' without their negative features. It is fairly productive and alternate bearing is not marked. Its resistance to cold is comparable to that of 'Hass'. The fruits are large and a singular round shape. They keep well on the tree. The organoleptic qualities are excellent and the buttery pulp has a slight nutty taste and does not blacken after slicing. Peeling is also easy (KRMS, 2025). All three horticultural races adapted to tropical and sub-tropical conditions *i.e.* West Indian, Guatemalan and Mexican have been tried in India. The cultivars of West Indian race are grown in localized pockets in Maharashtra, Tamil Nadu and Karnataka. In tropical and near-tropical areas, only West Indian race is well-adapted but its hybrids with Guatemalan (*e.g*. Booth selection) perform well and are considered valuable for extending the harvest season. In less tropical regions, hybrids of Guatemalan with Mexican race predominate since they combine the cold hardiness of the latter with the superior horticultural traits of both and also bridge the two seasons of maturity. In the eastern Himalayan state of Sikkim, avocado has been introduced successfully in hill ranges with an altitude of 800 to 1,600 metres. Both the Mexican and Gautemalan races are grown successfully in Sikkim. In avocado-growing areas of Sikkim, temperatures range from 12 to 30°C with an average annual rainfall of 2,000 millimetres. The Mexican race is cultivated on mid-altitude hills (pH 5-6) (Ghosh, 2025). The avocado is unusual in that the timing of the male and female flower phases differs among cultivars. The two flowering types are A and B. A-cultivar flowers open as female on the morning of the first day and close in late morning or early afternoon. Then they open as male in the afternoon of the second day. B varieties open as female on the afternoon of the first day, close in late afternoon and reopen as male the following morning

A cultivars: 'Hass', 'Gwen', 'Lamb Hass', 'Pinkerton', 'Reed'

B cultivars: 'Fuerte', 'Sharwil', 'Zutano', 'Bacon', 'Ettinger', 'Sir Prize', 'Walter Hole'.
'Choquette': Avocado 'Choquette' grafted A seedling from Miami, Florida. 'Choquette' bore large fruit of good eating quality in large quantities and had good disease resistance, and thus became a major cultivar. Today 'Choquette' is widely propagated in south Florida both for commercial growing and for home growing.

'Gwen': A seedling bred from 'Hass' x 'Thille' in 1982, 'Gwen' is higher yielding and more dwarfing than 'Hass' in California. The fruit has an oval shape, slightly smaller than 'Hass' (100–200 g or 3+1⁄2–7 oz), with a rich, nutty flavor. The skin texture is more finely pebbled than 'Hass', and is dull green when ripe. It is frost-hardy down to −1 °C (30 °F).

'Hass': Two 'Hass' avocados The 'Hass' is the most common cultivar of avocado. It produces fruit year-round and accounts for 80% of cultivated avocados in the world.[38][95] All 'Hass' trees are descended from a single "mother tree" raised by a mail carrier named Rudolph Hass, of La Habra Heights, California.[37][95] Hass patented the productive tree in 1935. The "mother tree", of uncertain subspecies, died of root rot and was cut down in September 2002.

'Lula': A seedling reportedly grown from a 'Taft' avocado planted in Miami on the property of George Cellon, it is named after Cellon's wife, Lula. It was likely a cross between Guatemalan and Mexican types. 'Lula' was recognized for its flavor and high oil content and propagated commercially in Florida.

'Maluma': A relatively new cultivar, it was discovered in South Africa in the early 1990s by Mr. A.G. (Dries) Joubert. It is a chance seedling of unknown parentage.

'Pinkerton': First grown on the Pinkerton Ranch in Saticoy, California, in the early 1970s, 'Pinkerton' is a seedling of 'Hass' x 'Rincon'. The large fruit has a small seed, and its green skin deepens in color as it ripens. The thick flesh has a smooth, creamy texture, pale green color, good flavor, and high oil content. It shows some cold tolerance, to −1 °C (30 °F) and bears consistently heavy crops. A hybrid Guatemalan type, it has excellent peeling characteristics.

'Reed': Developed from a chance seedling found in 1948 by James S. Reed in California, this cultivar has large, round, green fruit with a smooth texture and dark, thick, glossy skin. Smooth and delicate, the flesh has a slightly nutty flavor. The skin ripens green. A Guatemalan type, it is hardy to −1 °C (30 °F). Tree size is about 5 by 4 m (16+1⁄2 by 13 ft).

'Fuerte': Commercialized in the U.S. from budwood imported from Atlixco, Mexico in 1911, Fuerte was the dominant commercial variety in the U.S. for the first half of the 20th century.

Sharwil': Developed by James Cockburn Wilson (died 1990) with Frank Victor Sharpe in Tamborine Mountain, Queensland, Australia, in the 1950s, a portmanteau of Sharpe and Wilson.[99] Wilson also developed the Willard variety (Wilson and Hazzard), imported the Reed variety into Australia, and developed the Shepard variety. Sharpe OBE was later awarded a CMG in 1972 for services to the avocado industry. The variety originated in Guatemala.

Other avocado cultivars include 'Spinks'. Historically attested varieties (which may or may not survive among horticulturists) include the 'Challenge', 'Dickinson', 'Kist', 'Queen', 'Rey', 'Royal', 'Sharpless', and 'Taft'.

Certain cultivars, such as the 'Hass', have a tendency to bear well only in alternate years. After a season with a low yield, due to factors such as cold (which the avocado does not tolerate well), the trees tend to produce abundantly the next season. In addition, due to environmental circumstances during some years, seedless avocados may appear on the trees. Known in the avocado industry as "cukes", they are usually discarded commercially due to their small size (Wikipedia, 2025).

The characteristics of the major avocado varieties

The varieties Fuerte, Bacon, Zutano, Hass, Booth 7, Booth 8, Sharwil and Ettinger are reported to be promising. The varieties Pollock, Waldin, Nabal, Linda, Puebla, Gottfreid, Collins, Booth 8 and Fuerte are recommended for commercial cultivation. The varieties that are cultivated in India go by several names, such as Purple, Green, Fuerte, Pollock, Peradeniya Purple Hybrid, Trapp, Round and Long. Among the several existing varieties, perhaps Fuerte is the most widely grown, but it is regarded as unsuitable for the tropics. The Purple and Green varieties were introduced into India from Ceylon in 1941. The following varieties have been introduced at the Fruit Research Station, Kallar, Tamil Nadu: Long, Round, Fuerte, Pollock, Peradeniya Purple Hybrid, Shambaganur and Trapp (Ghosh, 2025).

The performances of avocado varieties in the Sikkim state are as follows (Ghosh, 2025):

Fuerte: Grown successfully in the mid-altitude hills of Sikkim. Fruits, pyriform, weight between 200 and 400 grams each.

Pinkerton: An established variety from California, USA, having pyriform green fruits. The fruit weight varies from 200 to 400 grams.

Green: A successfully grown variety of Guatemalan race with oval-shaped, greenish or light green fruits. Fruit size is similar to Fuerte or Pinkerton.

Hass: Also suitable for Sikkim, with fruit at maturity being purple in colour and medium in size.

Use

Avocado consumption is concentrated in the major producing areas. US per capita consumption of fresh avocados increased from 0.18 kg in 1970 to 0.68 to 1.0 kg in the late 1980s, and in 2000 ~1.4 kg. This is equivalent to consumption of nectarines and comparable to that of pineapples (0.77 kg), but considerably less than bananas (11 kg), apples (8.7 kg) and oranges (6.6 kg) (Rajeevan, 2011). Avocado fruits have greenish or yellowish flesh with a buttery consistency and a rich nutty flavour. They are often eaten in salads, and in many parts of the world they are eaten as a dessert. Mashed avocado is the principal ingredient of guacamole, a characteristic saucelike condiment in Mexican cuisine (Hadidi *et al*., 2017).

Persea americana var. *drymifolia* is cultivated not only for its fruit but also as an ornamental tree and for its timber. The tree's hardiness and adaptability make it a valuable resource for reforestation efforts and for farmers looking to diversify their crops.

Ornamental Value: The tree's attractive foliage and ability to thrive in a range of environments make it a popular choice for landscaping.

Economic Importance: In regions where it is cultivated, Persea americana var. drymifolia contributes to local economies through the sale of its fruit, both domestically and internationally (Subba *et al.,* 2023).

The fruit of horticultural cultivars has a markedly higher fat content than most other fruit, mostly monounsaturated fat, and as such serves as an important staple in the diet of consumers who have limited access to other fatty foods (high-fat meats and fish, dairy products). Having a high smoke point, avocado oil is expensive compared to common salad and cooking oils, and is mostly used for salads or dips (Wikipedia, 2025). A ripe avocado yields to gentle pressure when held in the palm of the hand and squeezed. The flesh is prone to enzymatic browning, quickly turning brown after exposure to air. To prevent this, lime or lemon juice can be added to avocados after peeling (Wikipedia, 2025). The fruit is not sweet, but distinctly and subtly flavored, with smooth texture. It is used in both savory and sweet dishes, though in many countries not for both. The avocado is common in vegetarian cuisine as a substitute for meats in sandwiches and salads because of its high fat content (Wikipedia,

2025). Generally, avocado is served raw, though some cultivars, including the common 'Hass', can be cooked for a short time without becoming bitter. The flesh of some avocados may be rendered inedible by heat. Prolonged cooking induces this chemical reaction in all cultivars (Wikipedia, 2025). It is used as the base for the Mexican dip known as guacamole, as well as a spread on corn tortillas or toast, served with spices. Avocado is a primary ingredient in avocado soup. Avocado slices are frequently added to hamburgers and *tortas* and is a key ingredient in California rolls and other *makizushi* ("maki", or rolled sushi)
(Wikipedia, 2025).

Guacamole: A staple in Mexican cuisine, made from mashed avocado.

Salads, sandwiches, and wraps: Adds a creamy texture and flavor.

Smoothies and desserts: Versatile for both savory and sweet dishes.

Toast topping: Popular for breakfast and snacks. (Google, 2025).

Nutritional Value: Avocado is consumed as a fresh fruit, besides its use in the oil, cosmetic, soap, and shampoo industries. Unlike many fruits that typically have a sweet or acidic taste, avocados have a smooth, buttery consistency and a rich flavour. A popular use is as a salad fruit, but avocados are also processed into guacamole and can be used in sandwich spreads. Oil extracted from avocados can be used for cooking and preparation of salads, sauces and marinades. Cold-pressed avocado oil (using extraction technologies similar to those for olive oil) for culinary use is a relatively new processed product, compared with olive oil. Avocado oil (typically refined after extraction) is used for skin care products such as sunscreen lotions, cleansing creams, and moisturizers, or for hair conditioners and makeup bases. Several more uses have been added around the world. For example, in Mexico and Brazil, it is added to ice creams and sorbets; in Japan it is eaten in sushi rolls; in Cuba the pulp is mixed with capers, green olives, lemon juice and olive oil to make a sauce that is served with steamed fish; and in Nicaragua it is stuffed with cheese, fried and baked. In Taiwan, it is eaten with milk and sugar; in Korea it is mixed with milk and used as a facial cream and body lotion; in Indonesia it is mixed with coffee, rum and milk to make a refreshing beverage; in the Caribbean it is mixed with salt, garlic, and coconut and served as an entrée; and in the Philippines the avocado purée is mixed with sugar and milk to make a beverage that is served as a dessert (Rajeevan, 2011). Avocados provide thiamin, riboflavin, and vitamin A, and in some varieties the flesh contains as much as 25 percent unsaturated oil (Hadidi *et al.,* 2017).

Chemical Composition of Avocado Fruit (per 100g of edible portion)

I. General Composition		III. Minerals (mg)	
Energy value (cal.)	245.0	Calcium	10.00
Protein (g)	1.7	Chlorine	11.00
Fat (g)	26.4	Copper	0.45
Total carbohydrates (g)	5.1	Iron	0.60
Crude fibre (g)	1.8	Magnesium	35.00
		Manganese	4.21
II. Vitamins (mg)		Phosphorus	38.00
Vitamin A as carotene	0.17	Sodium	368.00
Ascorbic acid	16.00	Sulphur	28.50
Niacin	1.10		
Riboflavin	0.13		
Thiamine	0.06		

(Ghosh, 2025).

Nutritional Value (Per 100 g)
Nutrition Facts for 100g of Raw Avocado Hass:

1. Calories: 160
2. Carbohydrates: 8.5g
3. Dietary Fiber: 6.7g
4. Protein: 2g
5. Fat: 14.7g
6. Water: 73.2g

Vitamins in Avocado Hass

- Vitamin A: 146 IU
- Vitamin C: 10mg
- Vitamin K: 21µg
- Vitamin B6: 0.3mg
- Folate: 81µg
- Thiamin: 0.07mg
- Riboflavin: 0.13mg
- Niacin: 1.7mg

Minerals in Avocado Hass

- Calcium: 12mg
- Iron: 0.6mg
- Magnesium: 29mg

- Phosphorus: 52mg
- Potassium: 485mg
- Sodium: 7mg
- Zinc: 0.6mg

(Pluck, 2025).

(Avocados, raw)	
Nutritional value per 100 g	
Energy	670 kJ (160 kcal)
Carbohydrates	8.53 g
Sugars	0.66 g
Dietary fiber	6.7 g
Fat	14.66 g
Saturated	2.13 g
Monounsaturated	9.80 g
Polyunsaturated	1.82 g
	(Wikipedia, 2025).

Raw avocado flesh is 73% water, 15% fat, 9% carbohydrates, and 2% protein. In a 100-gram reference amount, avocado supplies 670 kilojoules (160 kilocalories), and is a rich source (20% or more of the Daily Value, DV) of several B vitamins (such as 28% DV in pantothenic acid) and vitamin K (20% DV), with moderate contents (10–19% DV) of vitamin C, vitamin E, and potassium. Avocados also contain phytosterols and carotenoids, such as lutein and zeaxanthin.[116] (Wikipedia, 2025). Avocados have diverse fats. For a typical one: About 75% of an avocado's energy comes from fat, most of which (67% of total fat) is monounsaturated fat as oleic acid. Other predominant fats include palmitic acid and linoleic acid. The saturated fat content amounts to 14% of the total fat. Typical total fat composition is roughly: 1% ω-3, 14% ω-6, 71% ω-9 (65% oleic and 6% palmitoleic), and 14% saturated fat (palmitic acid). Although costly to produce, nutrient-rich avocado oil has a multitude of uses for salads or cooking and in cosmetics and soap products (Wikipedia, 2025).

Healthy fats: Rich in monounsaturated fats, which are beneficial for heart health.

Vitamins and minerals: Contains vitamins C, K, E, B5, B6, potassium, folate, and fiber.

Antioxidants and anti-inflammatory compounds: May help protect against certain diseases.

Low in fructose: Less likely to cause gas compared to some other fruits. (Google, 2025).

Health Benefits of Avocado Hass: Consumers have a mixed perception of avocados, some considering them healthy, while others who are aiming to lose weight believe avocados are fattening because of their high fat content (25 to 30% w/w FW). It was found in a study with 55 subjects who were on an energy-vrestricted diet, that the consumption of 200 g day^{-1} of avocado instead of 30 g of mixed dietary fat did not reduce weight loss compared with a control group. They also found no effect on serum lipid concentrations. *Mono-unsaturation of the lipids:* The lipid content of avocados is made up of approximately 15 to 20% saturated fats, 60 to 80% monounsaturates and 10% polyunsaturates. A diet high in monounsaturated fatty acids (MUFAs) is recommended on healthy grounds. This diet has shown favourable effects on lipoprotein measurements, endothelieum vasodilation, insulin resistance, metabolic syndrome, antioxidant capacity, and myocardial and cardiovascular mortality. The healthy Mediterranean diet recommends abundant plant foods and olive oil as the principal source of dietary lipids. Avocados and avocado oil have a very similar lipid profile to olives and olive oil, and hence can be included as a healthy addition to the Mediterranean diet (Rajeevan, 2011). In 2022, a prospective cohort study following 110,487 people for 30 years found that eating two servings of avocado per week reduced the risk of developing cardiovascular diseases by 16–22%. The study involved replacing half a daily serving of saturated fat sources, including margarine, butter, egg, yogurt, cheese, or processed meats, with an equivalent amount of avocado (Wikipedia, 2025).

1. **Heart Health Booster:** Rich in monounsaturated fats, Avocado Hass helps lower bad cholesterol and supports cardiovascular health.
2. **Gut-Friendly Superfood:** High fiber content promotes digestion and gut health.
3. **Weight Management Aid:** Despite being calorie-dense, Avocado Hass keeps you full longer, reducing overall calorie intake.
4. **Brain Function Enhancer:** Loaded with healthy fats and folate, it supports cognitive function and mental clarity.
5. **Skin and Hair Nourisher:** Vitamin E and antioxidants help maintain youthful skin and shiny hair.
6. **Eye Health Protector:** Lutein and zeaxanthin in Avocado Hass help prevent age-related vision problems.
7. **Natural Anti-Inflammatory:** Contains powerful anti-inflammatory compounds that may help reduce joint pain.
8. **Bone Strength Promoter:** High in vitamin K, Avocado Hass contributes to strong bones and improved calcium absorption.
9. **Blood Sugar Stabilizer:** Low in carbohydrates but high in fiber and healthy fats, Avocado Hass helps regulate blood sugar levels.
10. **Immune System Booster:** Packed with vitamins and antioxidants, it strengthens the immune system and helps fight infections **(**Pluck, 2025**).**

CULTIVATION

Production of Planting Material: In India, avocado is commonly propagated through seeds. The viability of seeds of avocado is quite short (2 to 3 weeks) but this can be improved by storing the seed in dry peat or sand at 5(C. Removal of seed coat before sowing hastens germination. In Sikkim, all the trees grown are seedlings in origin. The seeds taken from mature fruits are sown directly in the nursery or in polyethylene bags.

When 6-8 months old, the seedlings are ready for transplanting. Such seedling trees at 10-15 years produce 300 to 400 fruits. Vegetative propagation by means of budding or grafting has resulted in establishment of selected varietal clones. Mexican race is reported to provide almost all of the rootstock requirements in California. Generally, it is used also in Israel and South Africa. The Gautemalan race is more sensitive to cold and has also proved more susceptible to high pH chlorosis and to *Verticillium* wilt. West Indian stocks are preferred in warmer regions or where salinity is a problem. Need of *Phytophthora*-resistant rootstocks is recognized as the most important factor for the success of its cultivation. At the Fruit Research Station, kallar, in the Nilgiri Hills of Tamil Nadu, layering as well as inarching gave up to 75 per cent success, while in West Bengal chip-budding is reported to be successful. In India, presently, there is no commercial nursery engaged in vegetative propagation of avocado, nor is there any initiative either at governmental or private level to undertake nursery production of avocado planting material (Ghosh, 2025):

Establishment of Orchards: If an avocado plantation is to be established in a relatively new area, the varieties to be selected for planting should belong to both A and B groups and their flowering must overlap. The proportion of A and B group varieties can be 1:1 or 2:1. Avocado is planted out to a distance of 6 to 12 metres depending on the vigour of variety and its growth habit. For varieties having a spreading type of growth, like Fuerte, a wider spacing should be given. In areas prone to excess water, they should be planted on mounds as avocados cannot withstand waterlogging. In Sikkim, a planting distance of 10 x 10 metres on hills slopes (on half-moon terraces) is preferred and planting is done in June-July. Pits of 90 x 90 centimetres are dug during February-March, and filled with farmyard manure and top soil (1:1 ratio) before planting. In Coorg, a region of Karnataka state, they have been planted also as one of the mixed crops in a primarily coffee-based cropping system (Ghosh, 2025):

Care and Management of Orchards: Pruning is rarely practised except with upright varieties such as Pollock. In spreading varieties like Fuerte, branches are thinned and shortened. Heavy pruning has been found to promote excessive vegetative growth, consequently reducing the yield. Sprinkler irrigation has been reported to improve the fruit size and oil percentage; also, it advances harvesting time. Irrigation at intervals of three to four weeks during the dry months is beneficial to avocado. To avoid moisture stress during winter season, mulching with dry grass/dry leaves is desirable. Flooding is undesirable as it promotes root rot incidence. Avocados need heavy manuring, and application of nitrogen has been found to be most essential. In general, young avocado trees should receive N, P_2O_5 and K_2O in a proportion of 1:1:1 and older trees in the proportion of 2:1:2. At a pH of above 7, iron deficiency symptoms may appear, which may be corrected by applying iron chelate at the rate of 35 g/tree. Various micronutrients (Fe, Zn, B) have profound influences on tree growth, nutrient uptake and yield of avocado. Integrated nutrient management with inorganic fertilizer, supplemented by organic manuring, is advocated for avocado (Ghosh, 2025):

In Sikkim, the soil is deficient in nitrogen, zinc and boron. Application of urea in two split doses, in March/April and September/October (just before and after the onset of the monsoon) is recommended. Foliar application of zinc sulphate (0.5 per cent) may be undertaken in April-May, and other fertilizers applied in soil during March-April. Among insect pests, scales, mealy bugs and mites are the important ones, and may be controlled by suitable insecticides. Fruit spot disease caused by *Colletotrichum gleosporioides* results in shedding of young fruits. Fruits often become deformed. The infection may remain latent in some fruits. Another strain of the same fungus causes leaf spot. Accelerated softening of fruits caused by *Fusarium solani* and *F. sambucinum* has been reported. The Fuerte cultivar is reported to be more susceptible to anthracnose (*Glomerella cingulata* var. minor) and stem-end rot (*Dothiorella aromatica*) from fruit set till harvest. The time of infection has been found to vary with the seasons and is related to rainfall. In addition, Cercospora sport (*Cercospora purpurea*) and scab (*Sphaceloma perseae*) have been found to attack both leaves and fruits also. The most serious disease of avocado is the root rot caused by *Phytophthora cinnamoni*, leading to death of plant. The disease situation is aggravated by ill drained and waterlogged conditions. Metalaxyl (Ridomil) mixed with soil before planting or applied as a soil drench controls root rot at least for four months after treatment (Ghosh, 2025).

Potential for Avocado Production Development: The agro-climatic conditions prevailing in various parts of the country appear to be favourable for bringing more areas under avocado. Presently, plantations are not well organized and they are scattered. Also, quite a good number of improved varieties are now available with higher yield potential. Vegetative propagation techniques have also been standardized. Multiplication of a large number of high-quality nursery plants of selected varieties and their systematic planting, both in tropical southern India and humid semi-tropical areas of the northeastern region of India, could help to place avocado properly on the fruit map of India. The research support for the crop is still very poor, but the available research information from Tamil Nadu and Sikkim amply demonstrate that size, colour and quality of fruits attained in India are comparable with those of avocado fruits grown elsewhere. Avocado is grown successfully in neighbouring Sri Lanka, where good-quality fruits are harvested during May to August and December to January at different regions. Similar agro-climatic conditions to Sri Lanka are available in the Andamans and Nicobar Islands and in the tropical southern India. With proper varietal selection it should be possible to exploit also the possibility of out-of-season production, thus enhancing the availability of fruits for a longer period during the year. Avocado fruits produced in the country can be marketed without much difficulty, particularly to meet the requirement of the growing tourist industry. The mainland India and the Andaman and Nicobar Islands are attracting foreign tourists in a large number of places, where avocado could find a good market access. Avocado has also a good export potential (Ghosh, 2025):

Fruit Harvesting and Yields: Avocado plants raised from seeds start bearing five to six years after planting. Mature fruits of purple varieties change their colour from purple to maroon, whereas fruits of green varieties become greenish-yellow. Fruits are ready for harvest when the colour of seed coat within the fruit changes from yellowish white to dark brown. Mature fruits ripen six to ten days after harvesting. The fruits remain hard as long as they stay on the trees, softening only after harvest. The yield ranges from about 100 to 500 fruits per tree. In Sikkim, specifically, on average 300-400 fruits can be harvested from 10-15 years old trees. In Sikkim, fruits of Purple variety are harvested during July, and for Green variety September-October is the usual harvesting time. In Tamil Nadu, July-August is the peak harvest time. The yield performance of avocado, both in tropical southern India and humid sub-tropical northeastern India is highly satisfactory (Ghosh, 2025)

Constraints in Avocado Production Development: One of the important constraints appears to be due to the consumer preference. In the domestic market the avocado may not be liked by the common people due to the nature of its taste and also due to availability of many other tropical fruits throughout the year which are more palatable than avocado. Nevertheless, due to increasing health consciousness among the educated population and the high nutritive value of avocado, it is expected to find its rightful place in the Indian market in due course. The successful introduction of avocado and its wide acceptance among the tribal population of the hilly state of Sikkim indicate that for household nutrition security avocado should be a potential fruit crop in India (Ghosh, 2025).

Post-Harvest Handling, Storage and Marketing: Avocados do not ripen on the tree, and fruits soften only after they are picked. Fruits need to be picked carefully. They should be harvested at the correct stage of maturity, when they are still hard and have a minimum oil content of 12 per

cent. In India, fruits of 250 to 300 grams in size are preferred. Most popular varieties are Hass, Fuerte and Green. Hard, mature fruits are harvested and allowed to ripen during transport and distribution. Up to 14 days transport time is considered satisfactory, though unripe avocados can be stored for up to four weeks if the temperature is kept between 5.5 and 8°C. Presently, there is no organized marketing system for avocado as the production is small and production areas are scattered (Ghosh, 2025):

International market: A 2024 market analysis indicated that avocado exports will increase over the next five years with as many as 30 countries producing avocados, possibly becoming the world's most traded fruit by 2030 (Wikipedia, 2025).

Storage Tips for Avocado Hass

Ripening: If unripe, store at room temperature until it softens to the touch. To speed up ripening, place the avocado in a paper bag with a banana or apple.

Refrigeration: Once ripe, store in the refrigerator to slow down ripening and maintain freshness.

Cut Avocados: To prevent browning, store cut avocados with the seed intact, brush with lemon juice, and wrap tightly before refrigerating.

Freezing: For long-term storage, mash ripe avocados with a little lemon juice and freeze in an airtight container for later use in smoothies and spreads. (Pluck, 2025).

Allergies: Some people have allergic reactions to avocado. There are two main forms of allergy: those with a tree-pollen allergy develop local symptoms in the mouth and throat shortly after eating avocado; the second, known as latex-fruit syndrome, is related to latex allergy and symptoms include generalised urticaria, abdominal pain, and vomiting and can sometimes be life-threatening (Wikipedia, 2025).

Toxicity to animals: Avocado leaves, bark, skin, or pit are documented to be harmful to animals; cats, dogs, cattle, goats, rabbits, rats, guinea pigs, birds, fish, and horses can be severely harmed or even killed when they consume them. The avocado fruit is poisonous to some birds, and the American Society for the Prevention of Cruelty to Animals (ASPCA) lists it as toxic to horses. Avocado leaves contain a toxic fatty acid derivative, persin, which in sufficient quantity can cause colic in horses and without veterinary treatment, death. The symptoms include gastrointestinal irritation, vomiting, diarrhea, respiratory distress, congestion, fluid accumulation around the tissues of the heart, and even death. Birds also seem to be particularly sensitive to this toxic compound. The leaves of the Guatemalan variety of *P. americana* are toxic to goats, sheep, and horses (Wikipedia, 2025).

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