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REVIEW ARTICLE

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

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ABSTRACT

Vanilla belongs to the family Orchidaceae, subfamily Vanilloideae, tribe Vanilleae genus *Vanilla,*. and species *V. planifolia.* Scientific name is *Vanilla planifolia* Jacks. ex Andrews. The word vanilla is an adaptation of the Spanish vaynilla, derived from vaina diminutive of the *Latin vagina* (case). The Franciscan Bernhardina de Sahagun perhaps wrote the first publication on vanilla in 1575, where he described the use of vanilla by Indians in Mexico. However Vanilla plani-folia has priority and should be restored. Vanilla has also been called the following: *Lobus aromaticus, Volubilis siliquos mexicana, Vanilla mexicana, Vanilla epidendrum, Vanilla viridiflora, Vanilla sativa, Vanilla sylvestris, and Vanilla fragans* in which authors name were not cited. The word *vanilla* is derived from the Spanish word *vainilla* meaning "little pod", the diminutive of *vaina* derived from the Latin *vagina* (sheath) describing the shape of the pods. The word "vanilla" entered the English language in 1754, when the botanist Philip Miller wrote about the genus in his *Gardener's Dictionary.* It is also known by other names such as *Bourbon Vanilla, Common Vanilla, Madagascar Vanilla, Mexican Vanilla, Réunion Vanilla, Tahitian Vanilla, Tahiti Vanilla, Vainilla, Vanilla planifolia, Vanilla tahitensis, Vanille, Vanille Bourbon, Vanille de Bourbon, Vanille de Madagascar, Vanille du Mexique, Vanille de Tahiti, Vanillin Introduction.* Common names of vanilla in English are *Bourdon vanilla*, *Madagascar-Bourbon vanilla,* and *Mexican vanilla*; French Polynesian: tumuvanira; French: vanille, goussedevanille, vanillier; German: vanille, vanilleschote, ; Italian: vaniglia, baccellodivaniglia, ; Japanese Rōmaji: banira; Portuguese: baunilha, favadabaunilha, ; Spanish: vainilla, mantecado, vainadelavainilla ; Swedish: vanilj. The genus *Vanilla* (Orchidaceae) consists of 140 species, most of which are scientifically and commercially unexplored. This genus, represented by perennial vines, is characterized by a thick and fleshy stem, a monopodial growth habit. aerial hairless roots growing at each node, and underground hairy roots, absence of pseudobulbs, alternate leaves, axillary inflorescence, flowers with lips partially adnate to the column, versatile anther that is generally saddle-shaped, and fruits with encrusted seeds. Certain species of this genus are commercially designated as natural vanilla, a spice made from the fruit of orchid vines, which has a high gastronomic standard. Namely, they are *Vanilla. planifolia* Jacks. ex Andrews and *V. tahithensis* J.W. Moore are among the market's most expensive condiments. Vanilla cultivation is heavily based on the clonal material from a single species (*V. planifolia*). This species' gene pool undergoes one of the most impressive processes of genetic erosion, being limited by, and susceptible to, biotic and abiotic stresses. In addition, the center of species diversity in Mexico is under intense anthropogenic pressure, and renewal of planted varieties is increasingly unlikely. Nevertheless, *V. planifolia*, the main natural source of vanillin, can supply less than 1% of the annual market demand. Other species of the genus, *V. tahitensis* and *V. pompona* Schiede, are also produced for commercial purposes, al- though with minor distribution. *Vanilla* fruits have been used as a flavoring and medicinal beverage since the Preclas- sical period by multiple cultures in Mesoamerica, including the Mayans, Olmecs, Aztecs, and Totonacs (civilizations of present-day Mexican territory), most notably in 'atole', a corn-based drink. Vanilla was considered sacred by the native peoples of these regions and used to perfume their temples. The Mayans also created a drink derived from cocoa and it was probably at this time that vanilla began to be used as a spice to flavor food. Documents have shown that *V. planifolia* Jacks. ex Andrews was chosen from over 100 species and first domesticated by the Aztecs in the Postclassical period because of its flavoring properties. Until recently, it was believed that vanilla was only used in these regions, however, important chemical compounds from natural vanilla were found in ceramic vessels placed in a tomb dated to the Middle Bronze III in Israel. This was the first archaeological evidence of vanilla exploration in the ancient Old World, circa 1650–1550 BC. In the 16th century, after the Spanish conquest of the Aztecs, vanilla was introduced in Europe but was not cultivated outside of its native range until 1832, when Edmond Albius, from Reunion Island, developed a technique for manually pollinating the flowers. Genetic data confirmed that the origin of the vanilla cultivated worldwide was in Mexico, most precisely in the Papantla region. Even though it was considered a flavor valued as a luxury product, vanilla came to have a real commercial value only in the 17th century, as a component of chocolate, which was popular in European capitals. In this review article on Origin, Taxonomy, Botanical Description, Genetic Diversity, Breeding and Cultivation of Vanilla are discussed.

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INTRODUCTION

Vanilla belongs to the family Orchidaceae, subfamily Vanilloideae, tribe Vanilleae genus *Vanilla* and species *V. planifolia* (Menon and Nayeem, 2013; Wikipedia, 2024a; Wikipedia, 2024b; Wikipedia, 2024e; NWE, 2024; Bionity, 2024). Scientific name is *Vanilla planifolia* Jacks. ex Andrews (Growables, 2024; Wikipedia, 2024e). The word vanilla is an adaptation of the Spanish vaynilla, derived from vaina diminutive of the *Latin vagina* (case). The Franciscan Bernhardina de Sahagun perhaps wrote the first publication on vanilla in 1575, where he described the use of vanilla by Indians in Mexico. However Vanilla planifolia has priority and should be restored. Vanilla has also been called the following: *Lobus aromaticus, Volubilis siliquos mexicana, Vanilla mexicana, Vanilla epidendrum, Vanilla viridiflora, Vanilla sativa, Vanilla sylvestris, and Vanilla fragans* in which authors name were not cited) (Fouché and Jouve, 1999). The word *vanilla* is derived from the Spanish word *vainilla* meaning "little pod", the diminutive of *vaina* derived from the Latin *vagina* (sheath) describing the shape of the pods. The word "vanilla" entered the English language in 1754, when the botanist Philip Miller wrote about the genus in his *Gardener's Dictionary* (Wikipedia, 2024). It is also known by other names such as *Bourbon Vanilla, Common Vanilla, Madagascar Vanilla, Mexican Vanilla, Réunion Vanilla, Tahitian Vanilla, Tahiti Vanilla, Vainilla, Vanilla planifolia, Vanilla tahitensis, Vanille, Vanille Bourbon, Vanille de Bourbon, Vanille de Madagascar, Vanille du Mexique, Vanille de Tahiti, VanillinIntroduction* (Webmd, 2024). Common names of vanilla in English are *Bourdon vanilla*, *Madagascar-Bourbon vanilla,* and *Mexican vanilla*; French Polynesian: tumuvanira; French: vanille, goussedevanille, vanillier; German: vanille, vanilleschote, ; Italian: vaniglia, baccellodivaniglia, ; Japanese Rōmaji: banira; Portuguese: baunilha, favadabaunilha, ; Spanish: vainilla, mantecado, vainadelavainilla ; Swedish: vanilj (Growables, 2024). Vanilla is one of America's favorite flavors. Growing and processing vanilla beans takes time, knowledge and patience (Supply, 1996). Thoughts of one of America's favorite flavors, vanilla, evoke feelings of warmth and comfort. Even infants seem soothed by its flavor and aroma. Just taking a whiff from a bottle of pure vanilla extract can send the olfactory system into euphoria. The Aztecs and the Europeans once considered the vanilla bean to be a powerful aphrodisiac (Supply, 1996). Vanilla has many obvious applications in dairy products, baked goods and confections, but have you ever thought of adding just a little bit to your sauces, stews or dressings? (Supply, 1996). Growing and processing vanilla beans takes much time, knowledge and patience. Poorer quality products result from speeding up the process. Both consumers and food product designers would never again refer to this complex flavor as "plain old vanilla" if they realized the steps involved in taking vanilla from the vine to the bottle (Supply, 1996). Vanilla and sweet goods go hand in hand, but have you ever thought of vanilla vinaigrette, vanilla glaze over pork, or vanilla stir-fry? Product developers who are looking for unique flavor profiles in savory applications may try using vanilla to boost or blend flavors. "The potential use of vanilla extract in savory applications is limited only by a developer's creativity," according to Marianne Gillette, market manager for McCormick Flavors, Hunt Valley, MD (Supply, 1996). The food product designers at McCormick have come up with an entire luncheon menu, from appetizers to desserts, that incorporates vanilla extract into the three applications noted above, as well as Tournedos with Mushrooms Madagascar, Vanilla Apricot Fried Rice, Vanilla Baked Beans, and Grilled Shrimp in Vanilla Sauce. According to the description for the shrimp dish, "Pure vanilla extract melds the flavors of garlic and bay leaf in a light sauce." (Supply, 1996). Vanilla is also featured in many non-traditional recipes, such as cream of chicken and vanilla soup, vanilla mayonnaise, and vanilla baked acorn squash, in the Vanilla Cookbook, by Patricia Rain (Supply, 1996). "Vanilla is a wonderful flavor enhancer that boosts the flavor of savory as well as sweet products," says Gillette. "When vanilla is used as a subtle, background note (usage level less than 0.5%), it brings out desirable flavor notes and rounds out flavor profiles." She notes her own home use of vanilla extract in spaghetti and seafood sauces. Other possibilities include dishes with chicken, pot roast, spare ribs, chili, and macaroni and cheese (Supply, 1996). Vanilla is an exotic, complex flavor that is liked throughout the world. Food product designers are continually discovering new uses for all ingredients, so why not add a little vanilla to your barbecue sauce or vinaigrette for something just a little bit different? (Supply, 1996).

Vanilla is a major natural flavor widely used in many industries as food, beverages, sodas, pharmaceutics, cosmetics tobacco and traditional crafts. Vanilla beans originated in Mexico, and in some Central American countries as Costa Rica and Honduras. However, today vanilla beans are cultivated in many areas of the world and the main producing countries are (Fig. 1) Madagascar, Indonesia, China, Comores and in a lesser extent Tonga, Reunion, Turkey and Guadeloupe. In México, the main producing area is located in the Totonacapan, located in the northern part of the state of Veracruz. In recent years the Mexican states of Oaxaca and Puebla have joined Veracruz for production and processing of vanilla beans (Medina et al., 2009). Vanilla with the sobriquet 'Prince of Spices' is the only orchid spice. It is a perennial succulent vine trailed on trees or other standards .Vanilla accounts for about 0.75 percent world import of spices in volume and in terms of value its share is six to seven percent of nearly 1500 million US$ of global spice trade (Sasikumar, 2010). The major vanilla producing countries are India, Indonesia, Madagascar, Mexico, Reunion Islands and the Comoros besides the other countries such as China, Guadeloupe, French Polynesia, Fiji, Malawi, Tonga, Uganda, Zimbave, etc. which grow the crop to a lesser Extent (Sasikumar, 2010). Vanilla yields vanillin from the processed beans (pods), which is used as a food flavourant besides in pharmaceuticals, perfumes and liquors. It is estimated that during 2001 the global trade of natural vanilla accounted for 103.18 million US $. However, currently cheap synthetic vanillin poses a tough competition for the natural vanillin (Sasikumar, 2010). Synthetic vanillin is made from cheap sources like waste sulphate liquor of paper mills or coal tar extracts. During 2000-01 India imported 404.0 tonnes of synthetic vanillin worth Rs.1649.91lakhs(Vanilla Status Paper, Spices Board, Kochi, India, 2003). Vanilla is the onlysource of natural vanillin at present and high yielding varieties of the crop will be a boon in this regard (Sasikumar, 2010). Vanilla, though sets seed, is conventionally propagated using cuttings. The viable sexual reproduction coupled with the vegetative method of propagation can be exploited in the improvement of vanilla. However, a clear understanding of the breeding behaviour of the plant is warranted to adopt an appropriate breeding strategy (Sasikumar, 2010).

Fig.1. Vanilla beans producing areas

Vanilla planifolia, or 'flat-leafed' vanilla, is the scientific name for the plant referred to as the 'vanilla vine', 'vanilla orchid' or simply, and most commonly, as vanilla. The name "vanilla" is derived from the Spanish word "vanilla", which means "little pod". The vanilla beans are also called as pods or "black flower" as the mature bean, shrivels and turns black after it is picked. It is a commercial as well as medicinal orchid which belongs to the family Orchidaceae, which is the largest family of flowering plants with over 700 genera and 20,000 species. Many orchid species are grown for their flowers, but vanilla is the only orchid that produces a commercial fruit (Menon and Nayeem, 2013).

The vanilla orchid is one of the world's most interesting plants. Of the nearly 35,000 species of orchid, the second largest botanical family of plants, vanilla is the only species that produces an edible fruit. True vanilla is a sought after product, usually the second most expensive spice in the world, yet we associate the word vanilla with plain, boring, and commonplace. Native to Mexico and Central America, the vanilla vine is well suited for any tropical homestead. Yet vanilla is a particular plant requiring special care, in particular during pollination where every flower must be hand pollinated (Porvenir, 2018). Hand pollination sounds like a lot of work. However considering the common alternative, synthetic vanilla, which is derived from a combination of wood pulp and coal tar, and is found in a huge amount of processed food;, a little hand pollination is worthwhile (Porvenirdesign, 2018). There is a lot of interest in vanilla at the moment due to apparent global shortages and an extreme jump in crop prices. Like all commodities, the supply and demand of vanilla is subject to many factors outside of simply how much vanilla is produced each year. A powerful contingent of middle men are often accused of driving up prices by hoarding supplies. Keep this in mind if you expect to grow vanilla as a commercial crop (Porvenir, 2018). On the homestead scale, it is much better to have five plants that you give exquisite care than 50 plants that receive marginal care. These five plants will likely out produce the 50 and at less work (Porvenir, 2018). The genus *Vanilla* (Orchidaceae) consists of 140 species, most of which are scientifically and commercially unexplored. This genus, represented by perennial vines, is characterized by a thick and fleshy stem, a monopodial growth habit. aerial hairless roots growing at each node, and underground hairy roots, absence of pseudobulbs, alternate leaves, axillary inflorescence, flowers with lips partially adnate to the column, versatile anther that is generally saddle-shaped, and fruits with encrusted seeds. Certain species of this genus are commercially designated as natural vanilla, a spice made from the fruit of orchid vines, which has a high gastronomic standard. Namely, they are *Vanilla. planifolia* Jacks. ex Andrews and *V. tahithensis* J.W. Moore are among the market's most expensive condiments (de Oliveira *et al*., 2022). Vanilla cultivation is heavilybased on the clonal material from a single species (*V. planifolia*). This species' gene pool undergoes one of the most impressive processes of genetic erosion, being limited by, and susceptible to, biotic and abiotic stresses. In addition, the center of species diversity in Mexico is under intense anthropogenic pressure, and renewal of planted varieties is increasingly unlikely. Nevertheless, *V. planifolia*, the main natural source of vanillin, can supply less than 1% of the annual market demand. Other species of the genus, × *V. tahitensis* and *V. pompona* Schiede, are also produced for commercial purposes, al- though with minor distribution (de Oliveira *et al*., 2022). *Vanilla* fruits have been used as a flavoring and medicinal beverage since the Preclas- sical period by multiple cultures in Mesoamerica, including the Mayans, Olmecs, Aztecs, and Totonacs (civilizations of present-day Mexican territory), most notably in 'atole', a corn-based drink. Vanilla was considered sacred by the native peoples of these regions and used to perfume their temples. The Mayans also created a drink derived from cocoa and it was probably at this time that vanilla began to be used as a spice to flavor food. Documents have shown that *V. planifolia* Jacks. ex Andrews was chosen from over 100 species and first domesticated by the Aztecs in the Postclassical period because of its flavoring properties. Until recently, it was believed that vanilla was only used in these regions, however, important chemical compounds from natural vanilla were found in ceramic vessels placed in a tomb dated to the Middle Bronze III in Israel. This was the first archaeological evidence of vanilla exploration in the ancient Old World, circa 1650–1550 BC. In the 16th century, after the Spanish conquest of the Aztecs, vanilla was introduced in Europe but was not cultivated outside of its native range until 1832, when Edmond Albius, from Reunion Island, developed a technique for manually pollinating the flowers (de Oliveira *et al*., 2022). Genetic data confirmed that the origin of the vanilla cultivated worldwide was in Mexico, most precisely in the

Papantla region. Even though it was considered a flavor valued as a luxury product, vanilla came to have a real commercial value only in the 17th century, as a component of chocolate, which was popular in European capitals (de Oliveira *et al*., 2022).

The wrinkled brown vanilla pods are actually the fruit of a tropical species of climbing orchid that only blooms once a year, when it must be pollinated by hand—a delicate process that requires a special tool akin to a toothpick. This hand-pollination technique, discovered by a 12-year-old boy in 1841, allowed vanilla to be cultivated in places other than its native Mexico and contributed to the spice's global popularity (Waldbieser, 2022). *Vanilla planifolia*, the species used in most commercial vanilla production, is what you may know as Madagascar (or sometimes Bourbon) vanilla, although it's also grown in Mexico, Papua New Guinea and other equatorial countries around the globe. There's also *V. tahitensis* or Tahitian vanilla, and *V. pompona*, often found in Central and South America. They taste similar, with slight variations. The Tahitian kind, for instance, contains fewer vanillins—the compounds responsible for its flavor—giving it a more subtle vanilla taste with sweet floral notes (Waldbieser, 2022). Processing vanilla isn't much easier than growing it. Beans are green when picked and have to be cured, a process than can take up to two months. "It's a long process and difficult to do," "Curing incorrectly can either lead to an unusable bean or a reduction in quality and size that would make it worth significantly less." Even when everything goes well, as little as 10% of the green beans may turn into usable vanilla (Waldbieser, 2022). It's no wonder, then, that pure vanilla carries such a high price tag. But the price can fluctuate widely, influenced by forces of nature and changing demand. In the past decade, tropical storms have battered many of Madagascar's vanilla plantations, at one point causing the price per kilo to increase tenfold. "Because there are very few places that produce it, one natural disaster can have a big impact on the supply chain," (Waldbieser, 2022). Nteresting plants. Of the nearly 35,000 species of orchid, the second largest botanical family of plants, vanilla is the only species that produces an edible fruit (Growables, 2024). Vanilla powder is produced by grinding the whole, dried bean, while vanilla extract is made by macerating chopped beans in a solution to extract the flavor and then aging the mixture (Growables, 2024). Genus name comes from the Spanish name vainilla meaning a small pod with reference to the shape of the fruit (Growables, 2024). In major consuming countries (United States, European Union) vanilla is the only spice which benefits from a 'Standard of Identity' which helps shield vanilla beans from competition from substitutes (Growables, 2024). *Vanilla planifolia* is the most commonly cultivated variety among the three and has achieved greater commercial success than Tahitensis and Pompona due to its higher concentration of vanillin, rendering it a desirable asset in both the culinary and perfumery industry (Scentspiracy, 2024). Its distinctively sweet and floral aroma is often used as a flavoring agent for dessert, baked goods, and confections. It's worth noting that, thanks to its particularly adaptable and unique aroma, this variety of vanilla can also be used in pâtisserie to enhance the flavor of cookies, cakes, custards and also ice cream (Scentspiracy, 2024). In perfumery, Vanilla Planifolia is a popular base note which adds warmth, sweetness, and depth to the fragrances. Its complex and nuanced olfactory profile can vary in intensity and undertones, depending on factors such as growing conditions and extraction methods, making it a highly valued ingredient among perfumers and flavorists. *Vanilla planifolia's* olfactory profile is generally described as possessing creamy, exotic, and slightly floral notes with subtle hints of smokiness. Thanks to its higher concentration of vanillin and flexibility, *Vanilla planifolia* can be used both as a base note or a complementary addition to fragrances, enhancing the sweetness and warmth of other floral notes such as jasmine, ylang-ylang, and rose. It can also be paired with woody and oriental notes, such as sandalwood, patchouli, and benzoin, in order to create richer and more sensual fragrances (Scentspiracy, 2024).

Vanilla was prized as an incense, flavoring, and perfume in ancient Mesoamerica by the Maya, Aztec, and Totonac cultures. The ancient Aztecs flavored a chocolate beverage, called Xocolall, with vanilla and to this day vanilla is a common ingredient in chocolate candies and beverages. Spanish conquistador Hernan Cortéz sampled this drink and returned to Spain with reports it contained magical powers (Mccormicks, 2024). Vanilla may be one of the most popular flavors today but for centuries, vanilla was thought of as nothing more than an additive for chocolate. Vanilla gained its independence from chocolate in the early 17th century when a creative apothecary developed a chocolate-free, vanilla flavored candy for Queen Elizabeth I. In France, vanilla quickly became a favorite flavor for ice cream and Thomas Jefferson brought the recipe home after a stint in Paris as American minister to France. By the late 1800s, demand for vanilla skyrocketed as it became an integral ingredient in soft drinks such as Coca-Cola and Pepsi (Mccormicks, 2024). For a long time, Mexico was the only exporter of vanilla since only insects native to Mexico were able to pollinate the plant. In fact, the Mexican city of Papantla was known as "the city that perfumed the world". Then in 1836, the Belgium's discovered a method to hand pollinate vanilla and Europeans quickly began to grow vanilla across their colonial empires. By the 1870s, the French island colonies of Madagascar and Bourbon (named after the Bourbon kings of France - now called Reunion Island) became the major world producers. To this day vanilla produced in this region is often referred to as "Bourbon" vanilla (Mccormicks, 2024). Dried seed pods are dark brown/black in color. Vanilla seeds are very dark brown/black. Vanilla extract is usually amber brown to dark brown and slightly turbid (cloudy). *Many people associate vanilla with the color white. Perhaps this is because a prominent use is for vanilla ice cream whose main color comes from milk and cream. Since vanilla is such a strong flavor, only a little is needed and the color gets diluted. Many imitation vanilla flavors are also white/clear* (Mccormicks, 2024).

Vanilla is a spice from the pods of the vanilla plant, a vine that attaches to trees and grows in tropical climates. The plant is a member of the orchid family and is the only edible fruit in this category. Vanilla is widely used to flavor foods and beverages as well as in medicines and fragrances (Whitbourne, 2024). Vanilla beans (bottom) can be used to flavor ice cream or as vanilla extract, among many uses (Whitbourne, 2024). Vanilla is one of the most expensive spices in the world because it is so labor-intensive to produce. Vanilla plant flowers are hand-pollinated, and the bean pods must be ripened, dried, and conditioned for months to get their distinctive flavor and aroma (Whitbourne, 2024). Because true vanilla extract is expensive and also in high demand, manufacturers make synthetic vanilla, mostly from guaiacol, a byproduct of petroleum, or else lignin, a byproduct of wood. Most of the vanilla consumed is synthetic. While synthetic vanilla is less expensive than the real thing, it doesn't offer as many health benefits as natural vanilla (Whitbourne, 2024). Natural vanilla grows in a 20-degree band on either side of the

Equator. It mainly comes from Indonesia and Madagascar, though the plant is native to Mexico. It can take up to three years for a plant to start producing flowers and the fruit (the vanilla beans) have to stay on the vine for nine months. At this point, the beans have no flavour (Whitbourne, 2024). Once they're harvested, workers treat them with hot water or heat and place them in the sun every day for several weeks until they've shrunk to 20% their original size. Then the beans are sorted for quality and rest another month or two to develop their full aroma and flavor. This laborious process is one reason why real vanilla beans are so expensive (Whitbourne, 2024). Vanilla extract is made by soaking dried vanilla beans in a mix of water and ethyl alcohol for several weeks. The FDA requires that vanilla extract contain at least 35% alcohol and 13.35 ounces of vanilla beans per gallon (Whitbourne, 2024). This is imitation or synthetic vanilla. It's not made from vanilla beans but rather from adding chemicals like synthetic vanillin, propylene glycol, and ethanol to water. (Vanillin is the chemical compound that gives vanilla its aroma and taste.) Synthetic vanillin comes mostly from the petrochemical guaiacol. Vanilla essence costs much less than vanilla extract though you might find the flavor is not as good. But it can easily substitute in recipes where vanilla is not the main flavor, like chocolate chip cookies (Whitbourne, 2024). You make vanilla paste by mixing vanilla bean seeds with vanilla extract, sugar, and a thickening agent. The result is a thick paste with a stronger flavor of vanilla than vanilla extract. It's often used in vanilla ice cream and other products where you want a vanilla-forward flavour (Whitbourne, 2024). Vanilla syrup can be made at home by adding vanilla paste or vanilla extract to a simple syrup (made by boiling up sugar and water for 5 minutes). Add this syrup to your favorite latte or on top of pancakes. The type of vanilla syrup you find in the supermarket or at a coffee house is usually made with sugar and synthetic vanillin (Whitbourne, 2024). Essential oils are extracted by the pressing or steam distillation of plant materials (leaves, roots, bark) to get at the compounds that make the fragrance. You might need many pounds of a plant to make one bottle of essential oil (Whitbourne, 2024). Technically, vanilla essential oil doesn't exist since it can't be made by these methods. Making "vanilla essential oil" usually involves soaking a dried vanilla bean in a neutral oil like almond oil to create a product called vanilla oleoresin. You can also remove the solvent from vanilla extract to get at the pure vanilla oils (Whitbourne, 2024). anilla oil is often added to skin care products or placed in a diffuser to relieve stress. You can add a few drops of vanilla essential oil to a carrier oil like jojoba oil to use on your body or add some vanilla oil to a spray bottle filled with distilled water and spray it on your pillow for a good night's sleep (Whitbourne, 2024). Another method for creating vanilla essential oil involves adding a solvent to vanilla oleoresin to extract a powerful oil. This is usually used for perfume only, as it is very strong (Whitbourne, 2024).

Vanilla beans have been used for more than 2,000 years by the Mayans and Aztecs to flavor and sweeten their cacao beverages (Norohy, 2024). Then, in the 16th century, the Spanish conquistadors discovered this drink of the gods and the elite, and brought it back to Europe. From that moment on, the Europeans tried many times to introduce vanilla vines back home, but for a long time, their attempts were met with failure. The plants would take and blossom, but nobody managed to produce any of those famous vanilla beans (Norohy, 2024). They didn't have *Mexico's melipona Bee*s, the only insect capable of pollinating this orchid (Norohy, 2024). In 1841, 22 years after the vanilla orchid was introduced to Bourbon Island (now known as Reunion Island), young slave Edmond Albius discovered a technique to pollinate the flower by hand. He managed to identify which was the flower's male organ and pollinate it using a small splinter of wood. A few days later, the flower transformed into a vanilla bean (Norohy, 2024). Vanilla is a member of the orchid family and a hemiepiphyte, that is, it grows on other plants for physical support (Norohy, 2024). Vanilla plants can grow 15 to 20 meters long and 1 to 2 cm in diameter, climbing tree trunks using tendril-like roots at the base of each leaf. These roots are thick and green, measuring 12 to 25 cm long and 5 to 8 cm wide (Norohy, 2024). As for the aromatic flowers, they are fragile and delicate. They take the shape of rather large, light yellow trumpets that are gathered on floral buds. Their petals and sepals only bloom for one morning in a season! On one flower bud, there can be up to 15 flowers at different stages of maturity. This means that the grower needs to be there at the right time to pollinate the plant and produce a fruit. However, they cannot pollinate all the flowers, otherwise they risk exhausting the plant and producing beans that are too small! (Norohy, 2024). Finally, we arrive at the vanilla bean, the plant's fruit, which measures 10 to 27 cm long and 8 to 15 mm in diameter. It reaches maximum size after 2 months, but it will only ripen after 8 to 9 months. Their oily pulp contains a significant number of dark black seeds and provides the vanilla's scent (Norohy, 2024). Because it manages every stage in the vanilla supply chain, norohy is able to select the finest "Black Non-Split" gourmet vanilla (Norohy, 2024). Back in the day, each grower had their own stamp to mark their beans and avoid theft. Nowadays, this practice still exists to keep the tradition alive, even if it's not widespread (Norohy, 2024). Vanilla planifolia produces a dehiscent fruit (just like grapes), which means that the beans naturally split while still on the vine when they are fully ripe. This is also known as "late harvest" vanilla. The bean splits by a few centimeters at the bottom depending on how ripe it is (Norohy, 2024). During processing, the beans lose some of their seeds but remain very high in vanillin. However, beans like this are relatively rare on the gourmet vanilla market, and non-split beans are the most common nowadays (Norohy, 2024). Frosted black vanilla beans are a very rare, exceptional product. They can be recognized by the white efflorescence on the lower part of the bean, a true sign of quality. This crystallization is connected to high vanillin content inside the bean (Norohy, 2024). The story of what some call French Polynesia's black gold begins in 1848. The Vanilla x tahitensis orchid was first found in a Tahitian private garden before being produced on a larger scale across the island. Today, this variety is highly valued by pastry chefs, however it is very rare, making up less than 10% of the worldwide vanilla production (mostly in French Polynesia and Papua New Guinea). Each flower is pollinated by hand and the pods are picked nine to ten months later as they reach their ripest (Norohy, 2024). When the beans turn brown, they are alternately sun-dried and shade-dried over a period of several weeks, during which time they gradually become supple and shiny. Finally, they go through a refining process to prepare them for use and help preserve them (Norohy, 2024). Unlike *Vanilla planifolia* and *Vanilla pompona*, *Vanilla x tahitensis* has a thinner stem and leaves. What makes Tahiti vanilla unusual is that the fruit does not open spontaneously when ripe (as it is what is known as an "indehiscent" plant). Among the vanilla found in Tahiti, there are no fewer than 14 cultivars of *Vanilla x tahitensis*, but only 2 are grown in large quantities – the "Tahiti" and the "Haapape". The second has sturdier vines, while the flowers of the first are easier to fertilize (Norohy, 2024). *Tahitian vanilla* is bursting with an aromatic bouquet made up of over 200 molecules. Its oily, aroma-rich beans offer intense aniseed and floral notes with a hint of almond, tonka bean

and balsamic vinegar (Norohy, 2024). You can see the difference between the Vanilla x tahitensis (on the left) and Vanilla planifolia – the beans of the first are thicker, brownish in color and moister (Norohy, 2024).

In this review article on Origin, Taxonomy, Botanical Description, Genetic Diversity, Breeding and Cultivation of Vanilla are discussed.

ORIGIN AND DISTRIBUTION

From historic archives, the first data on vanilla dates back to 1427-1440 AD, which is period when the Aztecs conquered the Totonacan empire, which offered vanilla to the conquerors as a duty. Vanilla was named "tlil-xochitl" in Nahuatl, which means "black flower". The Aztecs used vanilla as flavor and aroma ingredient for chocolate, a drink destined only for Aztec noble families. Spaniards took vanilla to Europe in 1519, when Hernán Cortés sent Francisco Montejo y Portocarrero to Spain as bearer of the profits from the expedition, together with a number of novel products, including vanilla. In 1793 vanilla was taken to Paris' botanical gardens, and then to England. In 1822 vanilla plants from France were sent to Reunion island from where this orchid was propagated through the Indic ocean countries. By 1850, more plants were taken from Reunion and Paris to Madagascar, where the crop became an important source of income such that Madagascar is now the largest producer of vanilla in the world (Medina *et al*., 2009). The history of vanilla begins with the ancient Totonaco Indians of Mexico. Until the mid-19th century, Mexico was the main producer of vanilla. In 1819, French shipped vanilla beans to the Réunion and Mauritius islands. Vanilla plants are grown in five main areas of the world- Madagascar, Indonesia, Mexico, Tahiti and India. In the last few years India has significantly expanded its cultivation to nearly 24,000 hectors with a estimate that the turnover of vanilla pods is about 700 tons. Vanilla plants are cultivated in the southern states of India *i.e.* Karnataka, Andhra Pradesh, Tamil Nadu, and Kerala. The plant is grown by hand pollination of the vanilla flower (Menon and Nayeem, 2013). *Vanilla planifolia* originates from the tropically-humid regions of Mexico and Central America, yet also grows wild in the virgin forests of South America where the native populations use it as a spice and also as perfume. Vanilla arrived in Europe during the Spanish conquest in the 15th century, and was later spread throughout Africa and Asia. It is particularly popular for fine, aromatic taste (Busungu, 2022).

V. planifolia spread from its native range in Mesoamerica across the Caribbean islands, into Europe, and then globally starting in the late 1500s. The development of manual pollination methods in 1837 and 1841 by Charles Morren and Edmund Albius, respectively, unlocked the potential of this species for commercial production outside Mesoamerica (Growables, 2024). Globally from latitudes 27°N to 27°S. Vanilla is indigenous to south-eastern Mexico, Guatemala and other parts of Central America and the Antilles. The important production areas are East Africa (Madagascar), the Comoro Islands, Reunion, Indonesia and French Oceania. In Indonesia vanilla is mainly cultivated on Java (Growables, 2024). Vanilla extract displays its distinctive color. *V. planifolia* – flower. The main species of vanilla cultivated is *V. planifolia*. Although it is native to Mesoamerica and South America, it is now widely grown throughout the tropics. Indonesia and Madagascar are the world's largest producers. Additional sources include *V. pompona* and *V. tahitiensis* (grown in Niue and Tahiti), although the vanillin content of these species is much less than *V. Planifolia* (Wikipedia, 2024). The oldest reports of vanilla come from the pre-Columbian Maya who used vanilla in a drink made with cocoa and other spices. As a native plant of Mexico, vanilla was historically pollinated by one species of bee unique to the region, so when the plants were brought to Madagascar in the late 1700s, where most of the world's vanilla is grown today, the bees didn't come with them and yields were poor. After decades of being unable to produce vanilla, it was discovered that without that specific bee species, vanilla needed to be hand-pollinated, one by one, by the farmers themselves. This simple yet labor-intensive method is still how vanilla is produced today (88acres, 2024). This species is native to southeastern Mexico, the West Indies, Central America, and the northern part of South America. Mexico, once the hub of vanilla production, now uses its land for other purposes. Today, almost all vanilla beans are grown on islands such as Madagascar and the Indonesian Islands. Extracts of *Tahitian vanilla*, grown on the French Pacific Islands, have a much different flavor profile than planifolia beans. Although *V. pompona* is rarely seen today, it has been used in the perfume industry. It is grown in Bangladesh, Brazil West-Central, Caroline Is., Cayman Is., Chagos Archipelago, Comoros, Cook Is., Dominican Republic, Ecuador, Florida, French Guiana, Gulf of Guinea Is., Guyana, Hawaii, Jamaica, Jawa, Leeward Is., Lesser Sunda Is., Madagascar, Malaya, Marianas, Marquesas, Mauritius, New Caledonia, New Guinea, Niue, Paraguay, Peru, Puerto Rico, Réunion, Seychelles, Society Is., Suriname, Tonga, Trinidad-Tobago, Tuamotu, Venezuela, Windward Is., Zaïre (Powo, 2024).

TAXONOMY

The vanilla bean is made up of different parts (Norohy, 2024).

- **The outer mesocarp**, that is, the brown layer that covers the fruit entirely.
- **The inner mesocarp**, which holds the seeds and allows the vanillin inside to synthesize. Vanillin is a natural aromatic chemical compound that develops in the bean. It is not the only aromatic component – hundreds of others are produced throughout the bean preparation stages, giving vanilla all its aromatic complexity.

The Vanilla plants are all terrestrial, climbing and although they do not branch or branch poorly in the shade, they do so when the vines are exposed to the sun. Vanilla genus contains about 110 species, all of them being distributed between latitude 27° north and 27° south on all continents except Australia (Fouché and Jouve, 1999). Vanilla comes from the fruit pods of a large, climbing tropical vine that is a member of the orchid family. The vanilla orchid is the only one of the 35,000 or more species in this family to produce an edible fruit. Although over 50 species of vanilla orchid exist, only three have been used commercially: *Vanilla planifolia*, *Vanilla tahitensis*, and *Vanilla pompona*. Almost all of the vanilla imported into the U.S. comes from *Vanilla planifolia*

Andrews (also known as *Vanilla fragrans* (Salisbury) Ames) (Supply, 1996). *Vanilla* is a large genus of about 110 species in the orchid family (Orchidaceae), including the species Vanilla planifolia from which commercial vanilla flavoring is derived. Since most species of vanilla are considered rare and endangered there is an urgent need to conserve them through genetic analysis and propagation/conservation studies on this crop (Verma *et al*., 2009). Vanilla planifolia (also known as Vanilla fragrans Salisb. Ames) is the most important and most studied variety. They described nearly 110 vanilla species distributed in tropical regions of the world. Vanilla planifolia belongs to the orchids family, la large family that comprises ca. 700 genera and over 20 000 species. However, vanilla is the only dible fruit that contains relevant flavor and aroma compounds (Medina et al., 2009). Commercially cultivated vanilla (*V. planifolia*) is native to Mexico and its cultivation and breeding programmes face major bottlenecks. The genus *Vanilla* includes about 110 species and the species have been treated in various monographic works including the life history of *V. planifolia. Vanilla planifolia* (Salisb.) Ames (syn. *V. fragrans* Andrews.), is a tropical climbing orchid known for yielding the delicate popular flavor, vanilla and is the second most expensive spice traded in the world market (Divakaran and Rafieah, 2021).

Vanilla is a genus of about 110 species in the orchid family (Orchidaceae), including the species *Vanilla planifolia* from which commercial vanilla flavoring is derived. The name came from the Spanish word "vainilla", diminutive form of "vaina" (meaning "sheath"), which is in turn derived from Latin "vagina" (Bionity, 2024). The three most common types of vanilla beans today are *Bourbon* or *Bourbon-Madagascar vanilla* beans, *Mexican vanilla* beans, and *Tahitian vanilla* beans. *Bourbon vanilla*, or *Bourbon-Madagascar vanilla*, produced from *Vanilla planifolia* plants introduced from the Americas, is the term used for vanilla from Indian Ocean islands such as Madagascar, the Comoros, and Réunion, formerly the Île Bourbon. They are the thinnest of the three types of beans and quite rich and sweet. *Mexican vanilla*, made from the native *Vanilla planifolia*, is produced in much less quantity and marketed as the vanilla from the land of its origin. It is thick, with a smooth, rich flavor. *Tahitian vanilla* is the name for vanilla from French Polynesia. It is the thickest and darkest of the three types, and intensely aromatic, but not as flavourful (Growables, 2024). Vanilla is a genus of about 110 species in the orchid family (Orchidaceae). Orchidaceae is the largest and most diverse of the flowering plant families, with over eight hundred described genera and 25,000 species. There are also over 100,000 hybrids and cultivars produced by horticulturalists, created since the introduction of tropical species to Europe (NWE, 2024).

Species with common names (Bionity, 2024)

- *Vanilla aphylla*: Leafless Vanilla
- *Vanilla barbellata*: Small Bearded Vanilla, Wormvine Orchid, Leafless Vanilla, Snake Orchid.
- *Vanilla chamissonis*: Chamisso's Vanilla
- *Vanilla claviculata*: Green Withe
- *Vanilla dilloniana*: Leafless Vanilla
- *Vanilla edwallii*: Edwall's Vanilla
- *Vanilla mexicana*: Mexican Vanilla
- *Vanilla odorata*: Inflated Vanilla
- *Vanilla phaeantha*: Leafy Vanilla
- *Vanilla planifolia*: Vanilla, Flat-plane Leaved Vanilla, West Indian Vanilla
- *Vanilla poitaei*: Poiteau's Vanilla
- *Vanilla siamensis*: Thai Vanilla

Synonyms (Powo, 2024)

- *Notylia planifolia* (Andrews) Conz. in Fl. Taxon. Mex. 3: 151 (1947)
- *Vanilla aromatica* var. *planifolia* (Andrews) F.Buyss. in L'orchidophile; Traité Théor. & Prat.: 513 (1878)
- *Epidendrum rubrum* Lam. in Encycl. 1: 178 (1783)
- *Myrobroma fragrans* Salisb. in Parad. Lond. 2: t. 82 (1807), nom. illeg.
- *Notylia sativa* (Schiede) Conz. in Fl. Taxon. Mex. 3: 151 (1947)
- *Notylia sylvestris* (Schiede) Conz. in Fl. Taxon. Mex. 3: 151 (1947), nom. illeg.
- *Vanilla aromatica* Willd. in Sp. Pl., ed. 4. 4: 121 (1805), nom. illeg.
- *Vanilla aromatica* var. *bicolor* F.Buyss. in L'orchidophile; Traité Théor. & Prat.: 513 (1878)
- *Vanilla aromatica* var. *claviculata* F.Buyss. in L'orchidophile; Traité Théor. & Prat.: 513 (1878)
- *Vanilla aromatica* var. *discolor* F.Buyss. in L'orchidophile; Traité Théor. & Prat.: 513 (1878)
- *Vanilla aromatica* var. *lutescens* F.Buyss. in L'orchidophile; Traité Théor. & Prat.: 513 (1878)
- *Vanilla bampsiana* Geerinck in Bull. Jard. Bot. Natl. Belg. 52: 345 (1982)
- *Vanilla duckei* Huber in Bol. Mus. Goeldi Hist. Nat. Ethnogr. 5: 327 (1909)
- *Vanilla fragrans* Ames in Schedul. Orchid. 7: 36 (1924), nom. illeg.
- *Vanilla planifolia* var. *angusta* Costantin & Poiss. ex C.Henry in Agric. Colon. 83: 135 (1924)
- *Vanilla rubra* (Lam.) Urb. in Repert. Spec. Nov. Regni Veg. Beih. 5: 157 (1920)
- *Vanilla sativa* Schiede in Linnaea 4: 573 (1829)
- *Vanilla sotoarenasii* M.Pignal, Azof.-Bolaños & Grisoni in Eur. J. Taxon. 284: 17 (2017)
- *Vanilla sylvestris* Schiede in Linnaea 4: 573 (1829)
- *Vanilla viridiflora* Blume in Bijdr. Fl. Ned. Ind.: 422 (1825)

Types of vanilla (NWE, 2024): The three most common types of vanilla beans today are Bourbon or Bourbon-Madagascar vanilla beans, Mexican vanilla beans, and Tahitian vanilla beans:

Bourbon vanilla*, or *Bourbon-Madagascar vanilla, produced from *Vanilla planifolia* plants introduced from the Americas, is the term used for vanilla from Indian Ocean islands such as Madagascar, the Comoros, and Réunion, formerly the Île Bourbon. They are the thinnest of the three types of beans and quite rich and sweet

Mexican vanilla, made from the native *Vanilla planifolia*, is produced in much less quantity and marketed as the vanilla from the land of its origin. It is thick, with a smooth, rich flavour. Vanilla sold in tourist markets around Mexico is sometimes not actual vanilla extract, but is mixed with an extract of the tonka bean, which contains coumarin. Tonka bean extract smells and tastes like vanilla, but coumarin has been shown to cause liver damage in lab animals and is banned in the United States by the Food and Drug Administration

Tahitian vanilla is the name for vanilla from French Polynesia. It is the thickest and darkest of the three types, and intensely aromatic, but not as flavorful

The term French vanilla is not a type of vanilla, but is often used to designate preparations that have a strong vanilla aroma, and contain vanilla grains. The name originates from the French style of making ice cream custard base with vanilla pods, cream, and egg yolks. Alternatively, French vanilla is taken to refer to a vanilla-custard flavor. Syrup labeled as French vanilla may include custard, caramel or butterscotch flavors in addition to vanilla. Vanilla powder is produced by grinding the whole, dried bean, while vanilla extract is made by macerating chopped beans in a solution to extract the flavor and then aging the mixture. FDA standards require that pure vanilla extract contain 13.35 ounces of vanilla beans per gallon during extraction and 35 percent alcohol. Imitation vanilla consists entirely of artificial flavourings (NWE, 2024).

3 main varieties of vanilla grown in the world (Norohy, 2024)

- ***Vanilla planifolia***, or "Bourbon vanilla", is mainly grown in the Indian Ocean. Its natural vanillin content and spiced, woody taste have made it the leading variety.
- ***Vanilla x Tahitensis*** is grown in Tahiti, French Polynesia, and in New Guinea. It has a particularly floral, aniseed-tinted flavor.
- ***Vanilla pompona*** originates from Central America. It is very long (up to 27 cm) and plump beans have given it the nickname of "banana vanilla". It has sweet, floral and fruity notes. Production remains rather low and it is mostly used for perfume-making.

To better understand vanilla, especially what makes its seeds and aromas so special and sought after, first we need to peel it.

Forms of vanilla: Vanilla beans can be used in their whole or ground form; however, they are most commonly used for producing extracts, flavors, oleoresins and powders (Supply, 1996). Vanilla is the only flavor with a U.S. FDA standard of identity in the Code of Federal Regulations (21 CFR 169). Single-fold extract must contain extractive material from 13.35 oz. of vanilla beans (at 25% moisture) per gallon and at least 35% alcohol by volume. Anything less than 35% must be labeled "vanilla flavor." Optional ingredients include glycerin, corn syrup, sugar and propylene glycol. Extracts are made by crushing the vanilla beans, extracting with an alcohol/water mixture, and separating the residue from the liquid. Variables such as extraction time and temperature affect the quality of the extract (Supply, 1996): Vanilla produced from Madagascar (Bourbon) beans has been considered the industry's gold standard, "but the quality of beans from that area has declined over the last 20 years because of political and economic instability," according to Benjamin H. Kaestner III, director of spice procurement for McCormick. "After the economy declined, there was very little incentive for the farmers and curers to do a good job. They used to keep a three- or four-year stock of vanilla beans, which continued to improve with age, but now they have less than a one-year inventory. Vanillin levels in Madagascar beans have decreased up to 40% in some cases. "On the other hand," he continues, "Indonesian vanilla quality has improved greatly over the last 20 years. Vanillin was measured in trace amounts; now the vanillin levels have equaled or surpassed that of Madagascar beans. Some continue to say Madagascar beans have the best flavor, while others claim Indonesian beans are the best." Because vanilla preference is subjective, vanilla users should not specify origin, but rather the flavor profile they want. Basic flavor characters are used to describe vanilla, such as vanillin, resinous/leathery, woody, "pruney," fruity, chocolate, smoky, and bourbon/rummy. A Bourbon vanilla is marked by moderate bourbon/rummy notes, slight to moderate resin, and slight vanillin, woody, pruney. While the flavor profile of high quality Indonesian vanilla is similar to Bourbon vanilla, a low quality Indonesian is moderately smoky, woody and leathery, with very slight vanillin and bourbon/rummy notes. Tahitian vanilla is characterized by moderate fruity, floral notes (heliotropin) with slight vanillin and bourbon/rummy notes (Supply, 1996).

BOTANICAL DESCRIPTION

Vanilla planifolia is a fleshy perennial vine, which climbs trees or other supports by means of adventitious roots called holders (aerial roots). If not trained, it can climb 10 to 15 meters. However, in commercial vanilleries it is trained to a height which allows hand pollination and harvesting carried out without using a ladder. The roots 2mm in diameter, long, aerial, adventitious are produced singly opposite the leaves and adhere firmly to the support. The roots at the base are shallow rooted and ramify in the humus or mulch, which are very important for that reason. The stems are long, cylindrical, simple or branched, succulent and brittle. They are 1-2 cm in diameter and are dark green. The internodes are at 5-15 cm intervals. The leaves are large, flat, fleshy,

alternate and oblong-elliptic. They are 8-20 cm long and 3-6 cm broad. At the joint of each stem and a leaf is a bud. This bud can develop into a root, a new growing shoot or inflorescence. Inflorescences are stout and simple and about five to eight cm long. Each inflorescence can bear from 15 to 30 flowers, which open from the base upwards. From one to three flowers open at a time and last only for one day. The large, waxy, pale greenish flowers are about seven to 10 cm in diameter (Busungu, 2022).

V. planifolia is a fleshy, perennial vine with green stems. The vines live for many years, and some species reach 60 m in length. The stem diameter increases as the plant matures. Vanilla is hemi-epiphytic, meaning it is capable of rooting in the ground and of growing on other plants without direct soil contact (Wu *et al.,* 2024). *V. planifolia* has succulent, bright green leaves. Mature leaves can vary in size, ranging from 8–25 cm long and 2–8 cm wide. They are lanceolate to oval-shaped with pointed tips and can survive about three to four years. Some types of *V. planifolia* have variegated leaves (Wu *et al*., 2024). Vanilla flowers once per year, usually between February and April in southern Florida depending on the species. *V. planifolia* flowers are large and fragrant, with waxy cream-green sepals and cream-to-yellow petals. *V. pompona* flowers are characteristically more yellow in color than those of *V. planifolia*. Flowers range from about 6–8 cm in length and about 5–10 cm in diameter. Two of the petals are similar in appearance to the sepals. The third petal is modified into a lip shape. This lip-shaped petal contains two pollinia (pollen masses) and the stigmata, mounted on a column. A structure situated between the stigma and pollinia, called the rostellum, effectively prevents auto-pollination (Wu *et al*., 2024). The flowers are formed in axillary bunches, with a few to many flowers per cluster, called racemes. They first appear two to three years after planting a new cutting. Vanilla tends to flower on larger vines when the diameter reaches 6–13 mm. Usually only one flower, but sometimes up to three, in a cluster can open at a time, usually early in the morning. Flowering usually occurs over a period of two months, but each individual *V. planifolia* flower lasts for only one day. Flowers of some other vanilla species can remain open longer than those of *V. Planifolia* (Wu *et al*., 2024). Following pollination, the ovary swells to produce a bean that can reach about 20 cm in length and takes between eight and nine months to ripen. Vanilla beans contain thousands of tiny black, round seeds. At maturity, the bean will split open along two longitudinal seams, exposing the seeds and ruining the bean for commercial purposes (Wu *et al.,* 2024). Vanilla produces two types of roots, aerial roots and terrestrial (ground) roots. Aerial roots are generally nonbranching and are formed on the stem opposite the leaves. Their primary function is to support the vine's climbing habit and are therefore very effective at adhering to supporting plants or structures. Terrestrial roots are usually found at the base of the vine or where the vine is in contact with the substrate. They are branched and possess root hairs that are often associated with mycorrhizae. As with other terrestrial roots, the primary role of these roots is the uptake of nutrients and water from the soil (Wu *et al*., 2024).

This genus of vine-like plants has a monopodial climbing habitus. They can form long thin stems with a length of more than 35 m, with alternate leaves spread along their length. The short, oblong, dark green leaves of *Vanilla* are thick and leathery, even fleshy in some species. But there are also a significant number of species that have their leaves reduced to scales or have become nearly or totally leafless and appear to use their green climbing stems for photosynthesis. Long and strong aerial roots grow from each node. The racemose inflorescence's short-lived flowers arise successively on short peduncles from the leaf axils or scales. There may be up to 100 flowers on a single raceme, but usually no less than 20. The flowers are quite large and attractive with white, green, greenish yellow or cream colors. The flowers' sepals and petals are similar. The lip is tubular-shaped and surrounds the long, bristly column, opening up, as the bell of a trumpet, at its apex. The anther is at the top of the column and hangs over the stigma, separated by the rostellum. Most *Vanilla* flowers have a sweet scent. Blooming occurs only when the flowers are fully grown. Each flower opens up in the morning and closes late in the afternoon on the same day, never to reopen. If pollination has not occurred meanwhile, it will be shed. The flowers are self-fertile, but need pollinators to perform this task. In the Neotropics, the flowers were historically presumed to be pollinated by stingless bees (*e.g*. *Melipona*) or hummingbirds, but this was never confirmed; the only actual documented pollination (*i.e*., producing seed set) is recorded for an orchid bee, *Eulaema meriana*, visiting *Vanilla grandiflora* in Peru, and pollinia of *Vanilla* species have been observed attached to other species of *Eulaema* in Panama, and pollinia of *Vanilla pompona* are carried by males of *Eulaema cingulata* in Peru. Hand pollination is the most reliable method in commercially grown vanilla.[9] Vanilla plantations require trees for the orchids to climb and anchor by its roots. The fruit is termed "vanilla bean", though true beans are fabaceous eudicots not at all closely related to orchids. Rather, the vanilla fruit is technically an elongate, fleshy and later dehiscent capsule 10–20 cm long. It ripens gradually for 8 to 9 months after flowering, eventually turning black in color and giving off a strong aroma. Each pod contains thousands of minute seeds, and both the pods and seeds within are used to create vanilla flavoring. Vanilla beans are harvested by hand from commercial orchards (Wikipedia, 2024a).

Vanilla planifolia grows as an evergreen vine, either on the ground or on trees. It will sometimes grow as an epiphyte without rooting in the soil. When rooted in the soil its terrestrial roots are branched and develop fine root hairs associated with mycorrhizal fungus. In the wild it easily grows to 15 meters in length, and may grow to as much as 30 meters. When growing in full shade the vine will very seldom branch, but when in sunlight it will develop multiple branches. Younger parts of the vine, well attached to their support, will have a zig-zag structure with an angle of about 120° at each node. To cling to trees or other surfaces it has thick, fleshy aerial roots that develop from the nodes. These aerial support roots almost never branch and are only present on younger parts of the vine while the older parts of the vine will hang down through the canopy to the forest floor. On the nodes opposite the root nodes it has a single flat bladed succulent leaf. When full grown the glossy, bright green leaves are 8–25 cm in length and 2–8 cm wide, lanceolate to oval in shape with a pointed tip. Leaves last for three to four years if not damaged. The flowers come from an axillary cluster that will have 12–20 buds. The flowers are greenish-yellow, with a diameter of 5 cm and only have a slight scent. The flowers require pollination to set fruit, but open in the morning and usually fade in rising temperatures of the same afternoon. Though each flower lasts only one day, the flowering of *Vanilla planifolia* takes place over a period of two months once a year. In the native lowland forest habitat flowering takes place in April and May towards the end of the dry season. The plants are self-fertile, and pollination simply requires a transfer of the pollen from the anther to the stigma, but have a

structure to prevent this from happening without intervention. In the wild, there is only around a 1% chance that the flowers will be pollinated. Fruit is produced only on mature plants. This takes 2-3 years for meter long cuttings and 3-4 years for 12 in cuttings or tissue cultures. The fruits are 15–23 cm long pods (often incorrectly called beans). Outwardly they resemble small bananas. They mature after about eight to nine months (Wikipedia, 2024e).

Perennial leafless geophytic or epiphytic herbs with climbing stems. Plants glabrous. Roots thin, appressed to the host or aerial, unbranched. Stems monopodial, thick, erect, elongate, climbing, branched, green, smooth or warty, sometimes grooved. Leaves distichous or spirally arranged, sessile or petiolate, membranous to fleshy, sometimes reduced to evanescent bracts. Inflorescence axillary, racemose to paniculate, rarely cymose, multiflowered. Peduncle wiry, about as long as the rhachis or longer, glabrous. Sterile bracts small to large, sometimes foliaceous. Rhachis condensed to elongate, straight or curved. Floral bracts reduced and scale -like. Pedicels long, straight or curved, merging with the ovary. Ovary short, barely indistinguishable from the pedicel, smooth. Flowers resupinate, often not opening widely, the flowers gullet-shaped, pale coloured (greenish or yellowish), short-lived, opening sequentially in a spiral, pedicellate. Perianth segments incurved to spreading, fleshy. Dorsal sepal free, subsimilar to the lateral sepals, smooth, granular or warty. Lateral sepals free, subsimilar to the dorsal sepal, smooth, granular or warty. Petals free, narrower than the sepals, undulate to contorted, often with a dorsal ridge. Labellum variously fused to the column margins, rarely free, forming a saccate or funnel-shaped chamber (pseudospur), dissimilar in size and shape to the sepals and petals, ecalcarate. Labellum lamina stalked at the base, unlobed or 3-lobed; ventral surface glabrous or pubescent, sometimes warty; margins entire or undulate/crispate. Nectar unknown. Spur absent. Column elongate, narrow, straight or curved, terete or trigonous, lacking free filament and style, glabrous or pubescent, sometimes with basal keels. Column foot absent. Pseudospur present Column wings apical. Anther terminal, 2-celled, persistent, versatile, with a short rostrum. Pollinarium absent. Pollinia 2, poorly formed, powdery, sticky, yellow. Pollen grains in monads. Viscidium absent. Rostellum poorly developed, ventral, sometimes sticky. Stigma entire, concave, with thickened margins, sometimes the lobes extended as flaps. Capsules dehiscent, (sometimes a partly dehiscent berry), elongate-cylindric, glabrous, pendulous; pedicels not elongating in fruit; peduncle not elongating in fruit. Seeds numerous, large, sclerotic, wingless, smooth or slightly warty (CPBR, 2024). This evergreen genus occurs worldwide in tropical and subtropical regions, from tropical America to tropical Asia, New Guinea and West Africa. It was known to the Aztecs for its flavoring qualities. It is also grown commercially (esp. *Vanilla planifolia*, *Vanilla pompona* and *Vanilla tahitensis*). This genus of vine-like plants has a monopodial climbing habit. They can form long vines with a length of more than 35 m, with alternate leaves spread along its length. The short, oblong, dark green leaves of the *Vanilla* are thick and leathery, even fleshy in some species, though there are a significant number of species that have their leaves reduced to scales or have become nearly or totally leafless and appear to use their green climbing stems for photosynthesis. Long and strong aerial roots grow from each node. The racemose inflorescences short-lived flowers arise successively on short peduncles from the leaf axils or scales. There may be up to 100 flowers on a single raceme, but usually no more than 20. The flowers are quite large and attractive with white, green, greenish yellow or cream colors. Their sepals and petals are similar. Each flower opens up in the morning and closes late in the afternoon, never to re-open. If pollination has not occurred meanwhile, it will be shed. The lip is tubular-shaped and surrounds the long, bristly column, opening up, as the bell of a trumpet, at its apex. The anther is at the top of the column and hangs over the stigma, separated by the rostellum. Blooming occurs only when the flowers are fully grown. Most species have a sweet scent. The flowers are self-fertile but need pollinators to perform this task. The flowers are presumed to be pollinated by stingless bees and certain hummingbirds, which visit the flowers primarily for its nectar. But hand pollination is the best method in commercially grown *Vanilla*. The fruit ('vanilla bean') is an elongate, fleshy seed pod 10-20 cm long. It ripens gradually (8 to 9 months after flowering), eventually turning black in color and giving off a strong aroma. Each pod contains thousands of minute seeds, but it is the pod that is used to create vanilla flavoring. Significantly, *Vanilla planifolia* is the only orchid used for industrial purposes (in the food industry and in the cosmetic industry) (Bionity, 2024).

V. planifolia has succulent, bright green leaves. Mature leaves can be variable in size ranging from 8–35 cm long and 2–8 cm wide. They are lanceolate to oval-shaped with pointed tips and can survive about 3–4 years. Some types of *V. planifolia* have variegated leaves and are usually grown for ornamental purposes. *V. planifolia* flowers are large and fragrant. Waxy cream-green sepals form on axillary inflorescences. *V. pompona* flowers are diagnostically yellow compared to *V. planifolia* . Flowers can reach about 6 to 8 cm in length and about 5 to 10 cm in diameter. Two of the petals are similar in appearance to the sepals. The third petal is modified into a lip shape. This lip-shaped petal contains two pollinia (pollen masses) and the stigma, mounted on a column. A structure situated between the stigma and pollinia, called the rostellum, effectively prevents auto-pollination. The flowers typically appear during the drier times of year and are triggered by the lack of rainfall. They form in clusters of around 15 flowers, with only one flower opening each day. They first appear 2–3 years after planting a new cutting. Vanilla tends to flower on larger vines when the diameter reaches 6–13 mm. Usually one but sometimes up to three flowers in a cluster can open at a time, usually early in the morning. Flowering usually occurs over a period of about 2 months, once a year, but each individual *V. planifolia* flower lasts for only one day. If pollination does not occur the flower withers and drops in 1-2 days. The fruit reaches its maximum length about 6 weeks after fertilization, and ripens 7-9 months after flowering. Following pollination, the ovary swells to produce a long seed capsule (bean) that can reach about 20 cm in length and takes between 8–9 months to ripen. Vanilla beans contain thousands of tiny black, round seeds. At maturity, the bean will split open along two longitudinal seams, exposing the seeds and ruining the bean for commercial purposes. The root system is both epiphytic and terrestrial. The epiphytic or aerial roots are relatively long appresoria that anchor the vine on the tutor. They originate from the nodes in the stems and are seldom branched, light grey to tan with green to greenish-white tips formed by rapidly dividing and very active meristematic cells which can easily absorb water, and which owe their greenish colour to the chlorophyll they contain, which allows for a certain degree of photosynthesis in these tips. The central core of these roots is surrounded by the velamen, an extra layer of dead cells, which protects the vital tissues of the roots from drought, heat, and excessive sunlight, acting as a 'weather jacket'. The same roots can grow down and bury themselves into the soil, then becoming terrestrial roots. But the most common terrestrial root systems

growing into the soil originate from nodes in the stems that are buried in the soil. They are identical to the epiphytic roots, but they lose their green tips and grow horizontally to about 10 meters from the crown in the upper 20 to 25 cm of soil. They are generally much thicker than the aerial roots and are almost always branched (Growables, 2024). Botanical description is given in Fig. 2.

Floral biology: Flowering times of vanilla vary with the world region. Generally, the first flowers vanilla appear 2-3 months following the third year after planting. Each plant blooms for one month. Each inflorescence has only a single flower open at any one time and a flower lasts only one day. A vanilla plant bears 10-12 inflorescences by tuft and by year or even more if it is very vigorous. Orchid flowering has been studied by a number of researchers (Fouché and Jouve, 1999). The flowers are formed on axillary inflorescence which are generally simple but rarely branched. Vanilla flowers are large, pale greenish yellow, bisexual and zygomorphic. Petals and sepals together are called perianth. The lower petal is short, broad and modified in to a labellum which envelops a central structure called 'column' at its lower end. The tip of the column bears a single stamen with two pollinia covered by a hood like structure called 'rostellum' below which is the stigma. The rostellum acts as a physical barrier between the stigma and the anther (pollinia).With the flowers thus adapted to aided pollination, the information available on the breeding behaviour of vanilla is rather confusing. Major observations on the breeding behaviour of *V. planifolia* are reported from Mexico. Indian studies are restricted to some observations on pollination time, stigma receptivity, fruit development, etc. Reproductive biology of *V. planifolia*, such as time of pollination, stigma receptivity, effect of pollen load on the size of the beans etc. were studied in India. These authors reported the ideal time for pollination from 6 am to 1 pm, and stigma receptivity up to 24 hrs. They also observed that complete transfer of pollen results in maximum fruit growth. The floral biology of cultivated vanilla though adapted to out crossing, differing natural self pollination rates up to 20% are reported in some *V. planifolia* 'cultivars' from Mexico, Puerto Rico and Central America. Self incompatibility too is reported in *V. planifolia* 'cultivar', 'Orega de Burro'.

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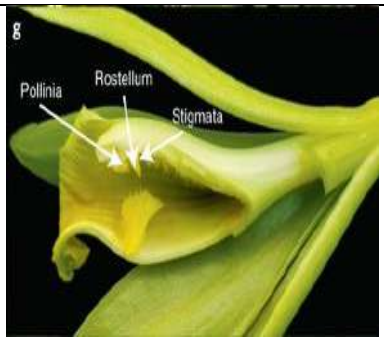
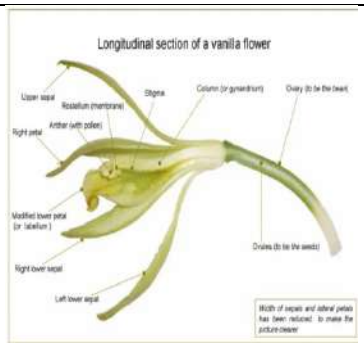
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Plantation</td><td>Flowers</td><td>Flower</td></tr>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Flower</td><td>Flower</td><td>Flower stem</td></tr>
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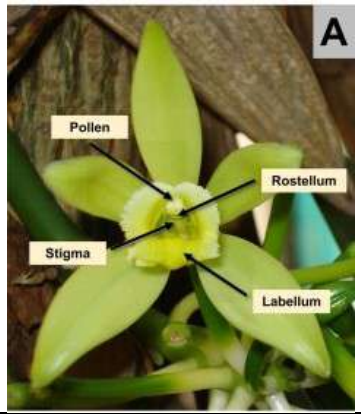
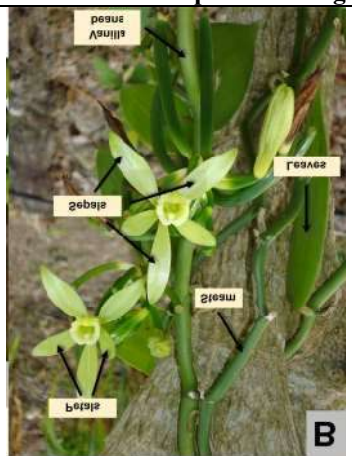
		
Flower and seed pods forming	**Flowers**	**Parts of flower**
		
Cutting	**Planting**	**Planting in a "shader"**
		
Close-up	**Young seed pods**	**Green fruits**
		
Pods	**Drying pods**	**Drying pods**

Continue ….

Good quality bean

Inside the vanilla bean

Grading

Fig. 2. Botanical Description

It thus appears that there is even region wise variation in the occurrence of the self incompatible and self compatible forms of *V. planifolia*. Further, even though the floral biology basically favours allogamy, bees of the genus *Melipona*, humming birds, *Euglosa viridisima*, *Eulaema* spp. etc. are considered to be pollinators of vanilla. In the absence of the pollinators, hand pollination is resorted to ensure fruit set, especially in India and even in some parts of Mexico (Sasikumar, 2010).

Pollination: In Mexico, where vanilla is native, a specific pollinator, a small stingless *Melipona* bee, pollinates the flowers. However, only 1% of all flowers are pollinated this way. Two artificial pollination methods can be used to increase fruit production. One method uses auxin 2, 4 dichlorophenoxy acetic acid (2, 4-D) and results in few, small parthenocarpic fruit. Such fruits do not produce an aroma and this technique has now been abandoned. The second method involves hand pollination. It is also employed for ornamental orchids. However, it is slow and difficult to carry out. Albius simplified the process and converted it into a fast and efficient process. The original or Albius method is by far the most widely used procedure in Réunion. First, the labellum is pulled down with a needle (cactus pine) to the base of the flower to free the gynstemium, rostellum and pollinia. The needle is then placed below the rostellum pushing it toward the base of the anther, uncovering the stigma. In the last step, the anther is held between the thumb and the index finger and pressed gently onto the stigma causing the pollinia to stick to it. The tearing technique is a slight modification of the Albius method. It differs in that the labellum is torn away and collected by workers so that the number of pollinated flowers can be recorded. Pollination is facilitated through the exposure of the sexual part. The tearing technique method is used in Madagascar to evaluate production and to count the number of pollinated flowers. Pollination must be carried from dawn until not long after noon and the outcome is strongly dependent on climatic and human factors. For example, success is highest during sunny days. An experienced worker can carry out between 1500-2 000 pollinations per day (Fouché and Jouve, 1999).

Pollinators and Visitors: Although information regarding pollination and biological interactions of *Vanilla* are scarce and natural pollination is still poorly understood, there have been recent efforts for their elucidation. Hummingbirds and small *Melipona* bees were thought to be the pollinators of Vanilla in Mexico. Although birds and different insects are commonly observed visiting *Vanilla* flowers, bees are often considered potential or effective pollinators. Visits by birds were also observed in *V. planifolia* flowers, which were occasionally visited by hummingbirds and visits by the bird *Zosterops* were observed in vanilla plantations in Reunion Island. On the other hand, our study group observed floral herbivory by ants in flowers of *V. planifolia* (de Oliveira et al., 2022).

GENETICS AND CYTOGENETICS

Vanilla planifolia is diploid (2n = 32) though variation in chromosome number is reported (Sasikumar, 2010). Chromosome number analysis was performed in 55 germplasm collections of Vanilla from root tip cells by lactopropionic orcein staining. Of the 45 collections of *Vanilla planifolia*, 44 showed 2n=28 as the most frequently occurring chromosome number, while one showed 2n=56 indicating polyploid nature. Variation of chromosome number in the different somatic cells of the same genotype was a frequent phenomenon. *Vanilla tahitensis* showed 2n=32 as most frequent chromosome number which is the one reported for *V. planifolia* also by many of the earlier workers. Analysis of a few interspecific hybrids of *V. planifolia* x *V. tahitensis* revealed a variation in chromosome number ranging from 2n= 28-32 (Nair, 2013). The chromosome number for *V. planifolia* has been reported as 2n = 32. Most *V. planifolia* accessions are considered to be diploid with a 2C-value of 5.03 pg, but due to the large size and complexity of the *V. planifolia* genome, limited sequence resources are currently available (Rao *et al*., 2014). The basic chromosomal number of the vanilla genus is 16 (x=16), however, Vanilla planifolia, Vanilla pompon and Vanilla tahitensis are diploid with 2n=32 (Simiyu *et al.,* 2020).

GENETIC DIVERSITY

Vanilla planifolia, a highly prized tropical crop, produces commercial vanilla. We investigated RAPD genetic diversity and geographical structure within *V. planifolia*. Multivariate analyses revealed three separate geographical groups of *V. planifolia*: a) a Costa Rican group; b) a Mexican group consisting only of cultivated plants from north of the Trans-Mexican Volcanic Belt; and c) a Mexican group from Oaxaca, Chiapas, and Quintana Roo, which are wild and wild-sourced cultivated plants. It appears likely that human action has resulted in movement of northern Mexican plants into the region south of the Volcanic Belt. When supposed translocants are included, a significantly higher genetic diversity is observed south of the Volcanic Belt compared to northern Mexico. Furthermore, cultivar names used in *V. planifolia* do not appear to reflect genetically defined groups (Schlüter *et al.,* 2007). Vanilla is a large genus of about 110 species in the orchid family (Orchidaceae), including the species *Vanilla*

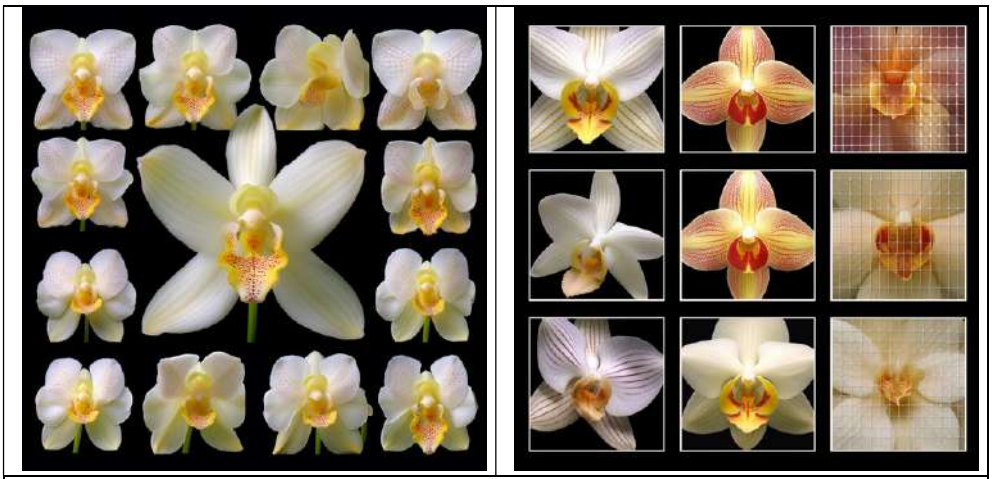
planifolia from which commercial vanilla flavoring is derived. Since most species of vanilla are considered rare and endangered there is an urgent need to conserve them through genetic analysis and propagation/conservation studies on this crop. The present study investigated the genetic diversity among nine leafy- and leaf-less *Vanilla* species employing 30 decamer RAPD primers and 10 ISSR primers. The species under study were diverse and displayed a range of variability (0–66% and 0–81% for RAPD and ISSR, respectively). A total of 154 RAPD polymorphic markers (83.24%, h = 0.378) and 93 ISSR polymorphic markers (86.11%, h = 0.363) were used to generate a genetic similarity matrix followed by the cluster analysis. Specific groupings were revealed by each cluster analysis with slight variation between two different markers. Among the nine species studied, *V. planifolia, Vanilla aphylla* and *Vanilla tahitensis* revealed very low level of variation within their collections, thus indicating a narrow genetic base (Verma et al., 2008). The present study investigated the genetic diversity among nine leafy- and leaf-less *Vanilla* species employing 30 decamer RAPD primers and 10 ISSR primers. The species under study were diverse and displayed a range of variability (0–66% and 0–81% for RAPD and ISSR, respectively). A total of 154 RAPD polymorphic markers (83.24%, *h* = 0.378) and 93 ISSR polymorphic markers (86.11%, *h* = 0.363) were used to generate a genetic similarity matrix followed by the cluster analysis. Specific groupings were revealed by each cluster analysis with slight variation between two different markers. Among the nine species studied, *V. planifolia*, *Vanilla aphylla* and *Vanilla tahitensis* revealed very low level of variation within their collections, thus indicating a narrow genetic base. The large genetic distance of *Vanilla andamanica* from other species suggests its different origin. A close genetic affinity was observed between the pairs *V. planifolia*, *V. tahitensis* and *Vanilla albida*, *V. aphylla*. These are the first comparative results for RAPD and ISSR reporting inter-relationship among nine cultivated, wild and hybrid *Vanilla* species (Verma *et al*., 2009). It is generally agreed that the present day vanilla cultivars originated from a narrow genetic base. History gives ample evidence that the colonial rulers took special interest in introducing the crop to their colonies. In most cases the first introduction came from just a handful of cuttings. Being perpetually propagated vegetatively from this original germplasm, a wide genetic base in the primary gene pool of vanilla is very unlikely especially in the secondary areas of domestication of the crop which may lead to genetic vulnerability. However, over the years of domestication and selection by farmers some new variants ('sub cultivars') have been recognized in Mexico and Reunion Islands. Somatic crossing over, spontaneous mutation (bud sports) or even sexual recombination and natural seedlings, epigenetic variation as well as fresh unofficial introductions are all attributed to the origin of variation. In Reunion Islands the planters distinguish two types of variants of *V. planifloia viz*., 'Classique' with light green flat leaves and tapering pods and 'Mexique' or 'Bleue' with dark bluish leaves with a central gutter and curved sides producing cylindrical pods. 'Aiguille', 'Grosse Vanille', 'Sterile', 'Variegata' are the other minor variants recognized in the species. Four major types of *V. planifolia* variants are known in Mexico. 'Mansa' or 'Dura', with two sub types based on stem and leaf colour namely, 'Amarilla' and 'Verde' is the most common one. 'Rayada' or 'Variegata', 'Albomargina' and 'Oreja de Burro' are the other types. These four types can be distinguished based on the stem and leaf colour, leaf margin nature. 'Oreja de Burro' is self incompatible too. These variants may not represent clones of the same species or even can be inter-specific hybrids. Intraclonal variation in clonally propagated crops is of course a fact, as reported in black pepper. A preliminary Indian study on the genetic variability of six accessions of *V. planifolia* using PAGE indicated variability in peroxidase, esterase and amylase profile (Sasikumar, 2010).

Diversity assessment of vanilla (*Vanilla* species) in Kenya is a key strategy for germplasm conservation and improvement. Production of vanilla crop in Kenya is limited due to inadequate knowledge on genetic diversity. This study was carried out to characterize 76 vanilla accessions from five counties of Kenya using 14 microsatellite DNA markers. POPGENE version 1.32 was used to compute variety factors. Amplicons ranged between 1 and 4. A total of 27 (96.43%) alleles were observed and their number ranged from 1.00 to 2.00 with a mean of 1.93. Effective allele values ranged from 1.00 to 1.99 with a mean of 1.63. Gene diversity ranged from 0 to 0.50 with a mean of 0.35, mean Shannon information index was 0.50 and Polymorphic information content values ranged from 0 to 0.38 with a mean of 0.35. Jaccard's similarity coefficient ranged from 0.08 to 1.00 with an average of 0.54. Unrooted phylogenetic tree was constructed in DARwin 6.0.8 using Unweighted Pair Group Method with Arithmetic Mean, clustering the samples into 3 main clusters (A 99.6%, B 98.96% and C 100%) and 6 sub-clusters (A1, A2, B1, B2, B3 and C1). Vanilla accessions grown in Kenya have a broad genetic background but low genetic diversity. Results inform the need to introduce other vanilla species as sources of genetic variation for breeding (Simiyu *et al.,* 2020).

The genetic diversity of the most cultivated vanilla species – *Vanilla planifolia* – has been previously reported to be very narrow due to its restricted initial diversity from a handful Mexican cuttings used as unique genetic basis in all areas of introduction. The classical markers such as isozymes, RAPD, RFLP, microsatellites; previously used did not successfully explain the variation within *V. planifolia*. The aim of the present work was first to evaluate the current genetic resources of the unexplored cultivated vanilla in Madagascar, in the attempt of supporting future conservation and breeding programs. Secondly, in order to address the knowledge gap about vanilla, the study seek to understand the contribution of space and environment parameters in the genetic variation of the crop. For these purposes, we used the single nucleotide polymorphism (SNP) markers, a high throughput and the most abundant marker across genomes, successfully used in several crop plants with low diversity and recently used in vanilla. A large-scale prospect was conducted to cover as much diversity present in Madagascar as possible. Our sampling included 246 accessions collected from the four major vanilla production regions distributed from north to south and northwest of the country. A total of 46 accessions from a local germplasm collection built from the ancient breeding program was also included. The developed SNP markers were genotyped with enough depth of coverage and were proportionally distributed among the 14 vanilla chromosomes. The set of targeted accessions were genetically segregated according to their respective taxonomic/phenotypic groups with a number of private alleles in each group. The success of the chosen marker was also underlined by the revealed structuration within species. In particular, our results revealed a clear genetic structure of the Malagasy germplasm and highlighted original varieties, mainly arising from the past breeding program. The 17,948 developed high-quality SNPs distinguished the 246 accessions from the field into five genetic groups – *V. planifolia, V. pompona*, Big Vanilla and two intermediate groups with a similar phenotype intermediate between the two first groups. Two additional genetic groups were identified in the local collection.

Intra-species genetic structuration was also revealed from the current study. *V. planifolia* accessions were structured into 3 major genetic groups with high variability (9,281 SNPs) (Pierre, 2023).

Vanilla planifolia is a tropical orchid originally from Mexico. It is known for its fragrant pods, which contain a variety of aromatic compounds, including vanillin, which is responsible for the distinctive vanilla taste and smell. Although vanilla is one of the most valuable spices in the world, there is still a lot of confusion about the genetic diversity of this plant. To learn more about the genetic structure and diversity of *Vanilla planifolia*, researchers genetically analyzed a group of plants from different regions of Mexico. The results were fascinating. The researchers found that *vanilla planifolia* exhibits high genetic diversity. This suggests that the plant is likely the result of hybridization and multiple domestication events. Genetic diversity is important for plant survival and adaptability. Plants with high genetic diversity tend to have a greater ability to adapt to changing environmental conditions and resist disease. The high genetic diversity of *Vanilla planifolia* could help make the plant more resilient to environmental changes and ensure its long-term viability. However, the nature of vanilla production, which often relies on manual pollination and vegetative propagation, has resulted in low genetic diversity within the cultivated species. This could affect the plant's ability to adapt to changing environmental conditions. The results of this study could have far-reaching implications for the vanilla industry. By understanding the genetic diversity of *Vanilla planifolia*, breeders and researchers can develop new strategies to improve vanilla plants. This could mean that in the future we will see vanilla varieties that are more disease resistant, produce higher yields, or have an even more unique aroma (Fig. 3) (Ellestad *et al*., 2023).



Fig, 3. Genetic diversity

BREEDING

Germplasm

Even though the basic chromosome number of the genus Vanilla germplasm is maintained in India at the Indian Institute of Spices Research (IISR), P. O. Marikunnu, Calicut, Kerala(about 300 accessions) and at the Indian Cardamom Research Institute (ICRI), Spices Board, P.O. Kailasanadu, Idukki, Kerala(about 21 accessions) (Sasikumar, 2010).

Breeding methods (Sasikumar, 2010)

Keeping in view the breeding objectives such as better quality profile of the produce, selffertilization, plant type, high yield, disease resistance one or the other of the following known strategies may be adopted to improve the crop .

Inter 'cultivar' hybridization: The variability that is observed in the so called 'cultivars' can be exploited to produce new varieties of vanilla having better quality profile through hybridization followed by in vitro seed culture. Recombinants with new traits are a possibility.

True Vanilla seedling selection: Vanilla being a heterozygous vine propagated vegetatively, selfing can lead to release of the residual variability. Selfed seeds can be cultured in vitro and new variants can be picked up from the seedling progenies.
Mutation: In vitro and in planta mutation induction of the vegetative tissue/seeds can also be a gainful breeding strategy for vanilla especially in view of the limited variability in the germplasm.

Germplasm selection: Collection and evaluation of the germplasm may also be useful in vanilla improvement. Polyploidy breeding and inter-specific hybridization are worth attempting in improving the crop.

Breeding

Crop improvement work of vanilla is in progress at the Kerala Agricultural University, Vellanikkara, Trissur, Kerala, also. The accessions conserved in these clonal repositories mainly belong to the commercially cultivated species, *Vanilla planifolia*. The species which are endemic to India such as *Vanilla andamanica* Rolfe, *V. pilifera* Holtt, V.walkeriae Wright and *V. wightiana*

Lindl.ex J.D. Hook are also being conserved. A germplasm collection, mainly Central American collections of vanilla, in CATIE (Centro Agronomico Tropical de Investigation y Ensenanza) of Turrialba (Costa Rica). Other germplasm collections of vanilla are maintained in French Polynesia and Fiji. Reunion Islands and at the Institut de Recherches Agronomiques a Madagascar (IRAM) (Sasikumar, 2010). *Vanilla planifolia* is the botanical source of vanilla extract, but has not generally benefited from strategic plant breeding. *V. planifolia* was cultivated in pre-Columbian Mesoamerica for its desirable aroma, and spread globally by vegetative cuttings starting in the 1500s. In 1837 a method to artificially pollinate Vanilla flowers enabled commercial production outside the native range. Today, Madagascar leads Vanilla production with significant contributions from other nations. The mass propagation of a few foundational clones has resulted in a global industry reliant on a very narrow germplasm base with threats from multiple biotic and abiotic stresses. Further, the lack of molecular, genomic and definitive phenotypic characterization inhibits improvement within this genus. The establishment of modern Vanilla breeding programs could leverage increasingly accessible technologies including advances in genomics and biotechnology to rapidly improve this species for high priority traits like disease resistance, total bean yield, pod uniformity, vigor, non-splitting pods, flower longevity, extract quality and flowers that are able to self-pollinate without manual intervention. While plant breeding is generally a long-term prospect, the potential benefits are justified by the increasing demand for premium ingredients like natural vanilla extract. In the future, genetic improvement of this species could result in more resilient and higher-quality cultivars that reduce price volatility, support growers, improve sustainability and excite modern consumers (Chambers, 2019).

An ambitious vanilla breeding program was started in Madagascar in the early 1950s to control *Fusariosis*, a serious crop disease caused by the soil fungus *Fusarium oxysporum*. The breeding program has produced tens of thousands of new vanilla genotypes of which a small number have been selected and conserved. This article examines the history of the Malagasy breeding work during the second half of the twentieth century, and outlines a possible strategy to exploit the data and exceptional genetic resources it has produced. The National Center for Research Applied to Rural Development has preserved 19 of the very diverse and original hybrids at the vanilla station in Ambohitsara (Antalaha, Madagascar). Two of them are particularly remarkable, namely *Manitra ampotony* for its exceptionally high vanillin content and *Tsy taitra* for its strong resistance to Fusariosis and its aromatic profile, which is similar to that of *Bourbon vanilla*. However, the global vanilla industry remains fragile because varietal diversity now available cannot overcome current and foreseeable constraints. The hybrids formed from multiple crosses between *V. planifolia* and three aromatic species (*V. pompona* Schiede, *V. tahitensis* J.W. Moore and *V. phaeantha* Rchb.f.), constitute a preferred resource for further vanilla breeding (Grisoni and Nany, 2021).

Inter-specific hybridization: The variation that exists among the cultivated species of vanilla or even in some related species can be combined to produce new types. The secondary gene pool of vanilla may contain useful genes for self pollination, root rot and virus resistance, larger fruits, reduced photo sensitivity, better aroma profile and pod indehiscence for incorporating to the cultivated vanilla. Interspecific compatibility between some vanilla species though doubtful, attempts may be made to hybridize the different species and raise the progenies through in vitro seed culture.
The xenia/metaxenia aspects too can be looked into inter alia as it is observed that pollen of some vanilla species has a positive effect on the pod size of *V. planifolia*. In Madagascar successful inter-specific hybrids between *V. planifolia* x *V.tahitensis* and *V. planifolia* x *V. pompona* have been produced (Sasikumar, 2010).

Tissue culture: Tissue culture was first used as a means of creating vanilla plants during the 1980s at Tamil Nadu University. This was the part of the first project to grow *V. planifolia* in India. At that time, a shortage of vanilla planting stock was occurring in India. The approach was inspired by the work going on to tissue culture other flowering plants. Several methods have been proposed for vanilla tissue culture, but all of them begin from axillary buds of the vanilla vine. In vitro multiplication has also been achieved through culture of callus masses, protocorms, root tips and stem nodes. Description of any of these processes can be obtained from the references listed before, but all of them are successful in generation of new vanilla plants that first need to be grown up to a height of at least 30 cm (12 in) before they can be planted in the field or greenhouse (Wikipedia, 2024).

Cultivars (Wikipedia, 2024)

- **Bourbon vanilla or Bourbon-Madagascar vanilla**, produced from *V. planifolia* plants introduced from the Americas, is from Indian Ocean islands such as Madagascar, the Comoros, Mauritius and Réunion, formerly named the Île Bourbon. It is also used to describe the distinctive vanilla flavor derived from *V. planifolia* grown successfully in tropical countries such as India. However, there is no Bourbon whiskey in Bourbon vanilla extract, despite common confusion about this.
- **Mexican vanilla**, made from the native *V. planifolia*, is produced in much less quantity and marketed as the vanilla from the land of its origin.
- **Tahitian vanilla** is from French Polynesia, made with *V. tahitensis*. Genetic analysis shows this species is possibly a cultivar from a hybrid of *V. planifolia* and *V. odorata*. The species was introduced by French Admiral François Alphonse Hamelin to French Polynesia from the Philippines, where it was introduced from Guatemala by the Manila Galleon trade.https://en.wikipedia.org/wiki/Vanilla#cite_note-ucr-34 It comprises less than one percent of vanilla production and is only grown by a handful of skilled growers and preparers.
- **West Indian** vanilla is made from *V. pompona* grown in the Caribbean and Central and South America.

Varieties: A better understanding of the genome is vital for varietal improvement of a crop whose diversity is currently very limited, notably via the identification of genes that could benefit the sector, for instance those coding for the synthesis of vanillin, a major vanilla flavour component, or for disease resistance. “Breeding a new vanilla variety from seed takes between seven and eight years per generation”, says Michel Grisoni, a CIRAD researcher and co-author of the study. “We are talking of a long-term

process before we can offer producers new varieties. To save time, we need to choose parents with the right genes and rapidly breed the most promising progenies. This is why it is vital to know the genome inside out". In particular, CIRAD and its partners are working to develop a vanilla variety with greater resistance to stem rot, a worldwide disease caused by a soil fungus that can kill up to 67% of the plants in a plantation. "Being able to use the scientific progress made in this research to develop more vigorous, resistant and productive vanilla varieties would really benefit our industry, as it could have a significant impact on the quality and price of the pods produced" (Inrae, 2022). *V. planifolia* has not generally benefited from modern plant breeding, so few named cultivars exist. Only a single cultivar, 'Handa', has been patented. This variety was developed by researchers from Réunion, and the future availability of this material is unknown. Otherwise, a few distinguishable types of *V. planifolia* have been characterized. These include 'Mansa' types originating from Mexico, which are commonly cultivated for commercial production. There are also two types of variegated *V. planifolia* generally available online and grown only for ornamental purposes. *V.* × *tahitensis* is the second vanilla type grown on a commercial scale. Our current understanding is that *V.* × *tahitensis* is genetically mostly *V. planifolia* with a little *V. odorata* (another vanilla species) in its ancestry. *V. pompona* is commonly grown in southern Florida by hobbyists and is also commonly mistaken for *V. planifolia. V. pompona* is vigorous but reportedly produces a lower quality extract (Growables, 2024).

Uses

Most vanilla used in the food industry is in dairy products, followed by beverages, baked goods and confections. However, vanilla is often used as a background note or flavor enhancer to round out the flavor profiles of many food products. The type of vanilla used depends on the product, the ingredients in the base formulation, and the desired flavor profile (Supply, 1996). Vanilla flavoring in food may be achieved by adding vanilla extract or by cooking vanilla pods in the liquid preparation. A stronger aroma may be attained if the pods are split in two, exposing more of a pod's surface area to the liquid. In this case, the pods' seeds are mixed into the preparation. Natural vanilla gives a brown or yellow color to preparations, depending on the concentration. Good-quality vanilla has a strong, aromatic flavor, but food with small amounts of low-quality vanilla or artificial vanilla-like flavorings are far more common, since true vanilla is much more expensive (Wikipedia, 2024).

Traditional Uses: Vanilla plant has been used for several diseases traditional some which include in the treatment of dysmenorrhea, fever, hysteria, dyspepsia, prevents dental caries, alleviates tooth ache and ulcers. It has antispasmodic, anti-inflammatory and analgesic activity. Vanilla is also used for respiratory pain and congestion, deep coughs, stomach ailments etc. Vanillin is used extensively as flavoring agent in food, beverage, perfumery and pharmaceutical industries (Menon and Nayeem, 2013).

Other

Uses: Vanilla is one of the most recommended products for • Sweetness potentiator, • Bitterness maskant, • Reduces burning, biting sensations, • Essential oils of vanilla and vanillin are used in aromatherapy: pain reduction in women; calming, reduces the startle reflex, • Fragrance: Perfume, candles, air fresheners, incense, household, • Baby, and personal care products, • Medicinal: psychological, Sloane-Kettering reported 63% reduction in stress level of MRI patients; reported cure of sexual dysfunction in men, • Insect Repellant and • Odor Maskant: paint, industrial chemicals, rubber tires, plastics (Growables, 2024).

Medicinal

Properties: In traditional medicine vanilla fruits are used as an aphrodisiac, carminative, emmenagogue and stimulant; they are said to reduce or cure fevers, spasms and caries. Vanilla extracts (especially tinctures according to pharmacopoeias) are used in pharmaceutical preparations such as syrups, primarily as a flavouring agent (Growables, 2024).

Flavor enhancer

Chocolate: The marriage of vanilla and chocolate has been a successful one dating back to the 1500s when Montezuma welcomed Cortes to Mexico with a vanilla-cocoa beverage. Vanilla softens or rounds out harsh, bitter notes in most chocolate applications such as ice creams, cakes and syrups. In confections such as chocolate bars, powdered vanillin is used most often.

Fruits/sweet flavours: Vanilla is often used to enhance fruit flavors in many dairy and beverage applications. It rounds out many fruit flavors and takes off some of the tart edges. It is generally used as a background note in a variety of sweet and fruit flavors to round out the flavor profile.

Sweetness: "Vanilla enhances the sweetness perception of foods, especially in bakery products," explains Jean Kuster, product manager-dairy, Beck Flavors, St. Louis. "If you had a product with and without vanilla, most people would perceive the one with added vanilla as sweeter. If you are designing reduced calorie products and are cutting back on sugar in order to achieve that goal, you might be able to add a little bit more vanilla to enhance the sweetness perception." (Supply, 1996).

Dairy products

Vanilla is the most popular flavoring for ice cream. The type, or "category," of vanilla used determines how ice cream is labeled:

Category 1: Natural vanilla extract. Two-fold vanilla is commonly used. Ice cream products must be labeled as "vanilla ice cream."

Category 2: Vanilla-vanillin extract. This is considered natural and artificial (N&A), where the natural component is the characterizing flavor. Ice cream products must be labeled as "vanilla flavored ice cream."

Category 3: Natural and artificial vanilla flavors or artificial vanilla flavors, where the artificial component predominates. Ice cream products must be labeled "artificially flavored vanilla ice cream." Altering the balance of ingredients such as fat, sweetener, or milk solids in dairy product formulations means that food product designers may need to alter their flavor systems, as well. Changing one or more ingredients usually affects the type of vanilla used in the product, a consideration that is often ignored. The amount of fat in ice creams greatly influences the type of vanilla used. "With a 10% to 14% butterfat content, Bourbons work very well," according to Craig Neilsen, vice president, Neilsen-Massey Vanillas, Waukegan, IL. "At the 14% to 16% fat level, the fat tends to mask the vanilla flavor, so a blend of Bourbon/Indonesian is more effective. This blend delivers an initial impact of vanilla in the front of the mouth, followed by the Bourbon in the back of the mouth. As the fat increases, the overrun decreases, which impacts the level of vanilla. Generally, you have to use more vanilla in a higher fat base because there isn't as much air carrying it through to the product." (Supply, 1996).

Bakery products

Pure vanilla extract is generally not used for baking because the aromatic components of extracts begin to volatilize at about 280° to 300°F, a temperature that is readily attained in cookie baking. Cakes rarely exceed 210°F internally, so an extract or blend of extracts may be used successfully, but a stronger extract such as a two-fold may be more effective. Vanilla-vanillin extracts and artificial flavors are generally recommended for baking applications. Natural and/or artificial flavors give food product designers the added benefit of blending vanilla with various flavor notes such as buttery, nutty and brown sugar (Supply, 1996).

Beverages: Vanilla is an important flavor component in colas, in addition to the complex of spice and citrus notes. A recent publication listed vanilla as well as 25 other flavor notes responsible for a cola flavor. Cream sodas, root beer, and some fruit beverages also may contain vanilla. Vanillin or vanilla flavors are used in many alcoholic beverages, such as whiskeys, cordials and cocktails, to round out and smooth the harsh edges of the alcohol. In whiskey products, vanillin is one of the chemicals extracted from the oak barrels in which the products age. Generally, vanillin and flavorings, rather than vanilla extract, are used in alcohol-containing beverages because of the regulations governing this industry (Supply, 1996).

Health Benefits of Vanilla (Whitbourne, 2024)

Traditionally, vanilla has been used in many cultures therapeutically, including as an aphrodisiac and to aid with gas relief. Studies have shown that both the flavor and aroma of the spice can offer some health benefits. Here are some health uses for vanilla:

Provides a calming effect: A study showed that smelling vanillin calmed newborns having their blood taken. The smell of vanilla also lessened crying in newborns. Smelling vanilla can have calming effects on adults too. It reduces startle reflexes and provides some relief from sleep apnea, a sleep disorder in which breathing repeatedly stops and starts.

Curbs sugar intake: Because vanilla has fewer calories and carbohydrates than sugar but tastes naturally sweet, it can be used to reduce your sugar intake.

Eases tooth ache: The alcohol in vanilla extract can numb some toothache pain, while its antioxidants may provide healing effects. To use this alternative remedy, put a couple of drops of vanilla extract on a cotton ball and apply it to the affected area in your mouth.

Reduce obesity and cholesterol: Mice fed a high-fat and high-sugar diet as well as vanillin were found to have better insulin sensitivity and glucose tolerance, and lower body weight, than mice who got the same diet but weren't given vanillin, according to one study.

Antioxidant properties of vanilla: Vanillin has strong antioxidant properties. Test-tube studies have shown that vanillin and vanillic acid (a form of vanillin) can protect brain cells from oxidative stress. Oxidative stress plays a role in developing conditions like cancer and heart disease. A study done on aging rats found that vanillin could play a role in reducing inflammation and improving antioxidant defenses. Since none of these studies were done with people, it's not clear whether these benefits would be happen in humans.

Vanilla and mental health benefits: Animal studies have shown that vanillin can reduce anxiety and depression. In one study, just smelling vanillin reduced signs of depression in rats. The vanillin increased levels of serotonin and dopamine, chemicals in the brain that improve mood. Another study found that giving rats high doses of vanillin worked better than the antidepressant drug fluoxetine to lift depression. But the doses were much higher than humans would typically take. Animal studies have shown that vanillin, when given orally, could reduce some kinds of pain, like pain from nerve damage or inflammation. Much more research needs to be done on vanilla and mental health benefits with human subjects before any recommendations can be given. So far, most of the human studies have been few and small. Researchers are also looking into whether vanillin can play a role in

addressing issues like neurodegeneration (degeneration of neurons especially in the brain), antibiotic resistance, sickle cell disease, viral infections, and food preservation.

CUTIVATION

Propagation: Vanilla is an easy plant to propagate. A cutting from a mature plant, with 12 to 24 nodes or 1 to 1.5 meters long, is all that is needed to start a young vine of your own. The longer the cutting the faster it will produce flowers. Be sure to take cuttings only from healthy plants that appears free from disease and don't take too much from any one plant, as it will set back any future flowering by at least one year. The cuttings are very hardy and can survive in a shady moist place for many weeks until you are ready to plant them. Be sure to keep the cuttings out of the sun (Porvenir, 2018).

Vanilla is primarily propagated by cuttings. It is important to let cut sites heal prior to planting by leaving fresh cuttings at room temperature under low light for 1–2 days. All other factors being equal, the longer the cutting, the more quickly the vine will establish and begin to flower. Cuttings that are 30 cm long will generally require 3–4 years to flower, while meter-long cuttings should flower in 2–3 years. Vanilla is not commonly propagated by seed due to germination challenges. The thick, highly lignified seed coat prevents timely germination, and seeds take significantly longer to grow into mature plants than cuttings. In addition, seed germination is likely reliant on associations with fungi or other microorganisms. Such constraints have supported the use of cuttings as the primary propagation method. When propagating vanilla orchids from cuttings or harvesting ripe vanilla pods, care must be taken to avoid contact with the sap from the plant's stems. The sap of most species of Vanilla orchid which exudes from cut stems or where beans are harvested can cause moderate to severe dermatitis if it comes in contact with bare skin (Growables, 2024).

Cultivation

Vanilla planifolia originates from the Mexican tropical rain forest. Its cultivation requires the same climatic conditions. The temperatures should be between 20 and 30 °C. Nevertheless, plants could accept a maximum about 33 °C and a minimum not lower than 10 °C. Rainfall must be evenly distributed, with a minimum of 2 000 mm.year-1. Vanilla, being a forest climber, requires moderate shade. However, excessive shade can be deleterious: the vine become thin and susceptible to diseases (mildew and root rot) and yields drop (Fouché and Jouve, 1999). Under natural conditions, a vanilla plant climbs, cover its support, and flowers when it reaches the top of the canopy, 15-20 m high. Seed germination is rarely observed in the forest, but it is possible to see young vines developing from fragments that fall on the forest floor. These thin vines never flower, creep along on the floor until they encounter a support onto which they cling and climb to the canopy, where the light intensity is appropriate. Vines attach to the support with adventitious (or aerial) roots. One or two aerial roots develop from a node on the side that is in contact with the phorophyte. These roots are glabrous, non-branched and have a dorsiventral organization. Their root hairs secrete amorphous cement, which glues them to the phorophyte . Their length is 0.05-15 cm. The roots have a short life span (1-2 years). These aerial roots are not replaced after death. At the base of the vine, terrestrial roots take up nutrients from the soil. These roots are branched, have well-developed root hairs and velamen cells. Their length varies and depends only on the distance between the vine and the substratum. When terrestrial roots die, they are replaced quickly by new ones. The new roots originate either at the same node or on another node. The vine may 'zigzag' and form a 120° angle between internodes. This angle increases with age and when the vine detaches from its support. If a large vine becomes detached from its support, it breaks and falls on the forest floor where it can root. During growth, stem diameter increases with plant length. The diameter of the base increases with time (*i.e.*, plant age) and is smaller into shade than in sunlight. During growth on the porophyte, winds frequently destroy the apex of the vanilla plant. The branching resulting from vanilla plant apex decapitation (due to mechanic damages, wind, *etc.*) presents nodes with a larger diameter than the internode from which it arises. Indeed, the diameter value is important, for when it reaches 6 to 13 mm, the vine can flower. There is a threshold diameter for flowering: if the diameter of a stem is less than 6 mm, vanilla does not flower. Under natural conditions, inflorescences can be found at a minimum of 20 nodes below the apex. If the apex is removed, inflorescences appear on the second or the third node below the decapitation and a new shoot arise from the first one. This new branch can fall if it encounters no support. Should this happen, there are two possible outcomes: the vine can break, fall and act as a cutting, which produces a new shoot or when the apex is not broken, the vine continues to grow in length. If it does not encounter a support immediately, it creeps until it reaches one. Thus, several independent vines may grow on one support. Leaves of young vines are small, narrow, and last 3-4 years. Vanilla planifolia is a monopodial orchid. Its apex has the potential for indefinite growth if it is not damaged. The distribution of inflorescences in vanilla is strongly associated with the architecture of the plant and is expressed in accordance with precise morphogenetic gradients. Apex degeneration or decapitation that favor the appearance of new branch (es) can affect these gradients (Fouché and Jouve, 1999). The ovary develops after pollination. After 5-6 weeks, it reaches full size development. All unpollinated flowers and fruits, which are small or deformed, are removed after one month. To ensure normal fruit size, no more than 10 capsules should be allowed to develop on the same inflorescence. Considering that a capsule, measuring 24 to 28 cm, weight about 150 g, a 5-year-old Vanilla plant producing five inflorescences composed of six fruits may produce an harvest weighting about 4.5 kg capsule per plant. Nevertheless a reasonable estimation has to consider that 50-70% of all fruits abscises since one week to two months after pollination (Fouché and Jouve, 1999). Fruits mature eight to nine months after pollination. If harvested before maturation capsules have reduced aroma after post-harvest treatment and may deteriorate. If harvested too late, the capsules split. The best stage for harvesting the 'beans' is the so-called 'canary-tail' ('queue de serin'). At this stage, the fruit is green, but its base is canary-yellow. Harvesting at this stage is a requisite for producing 'vanilla beans' of high quality and with good aroma. Capsules are harvested one at a time as they mature. At harvest time, the capsules do not have any aroma. The aroma forms only after a long process that spans nine months, during which the green capsules become black

'vanilla beans' (Fouché and Jouve, 1999). Snails, insects and birds eat young shoots or flower buds causing bud malformation and damaging to aerial roots. But fungal diseases cause the worst problems (Fouché and Jouve, 1999).

The basic production methods (NWE, 2024)

- **Harvest**: The pods are harvested while green and immature. At this stage, they are odorless.
- **Killing**: The vegetative tissue of the vanilla pod is killed to prevent further growing. The method of killing varies, but may be accomplished by exposure to sunlight, oven heating, hot water, scratching, or freezing.
- **Sweating**: The pods are held for 7 to 10 days under hot (45º-65°C or 115º-150°F) and humid conditions; pods are often placed into fabric covered boxes immediately after boiling. This allows enzymes to process the compounds in the pods into vanillin and other compounds important to the final vanilla flavor.
- **Drying:** To prevent rotting and to lock the aroma in the pods, the pods are dried. Often, pods are laid out in the sun during the mornings and returned to their boxes in the afternoons. When 25-30 percent of the pods' weight is moisture (as opposed to the 60-70 percent they began drying with) they have completed the curing process and will exhibit their fullest aromatic qualities.
- **Grading**: Once fully cured, the vanilla is sorted by quality and graded.

Harvesting

Harvesting vanilla fruits is as labor-intensive as pollinating the blossoms. Immature, dark green pods are not harvested. Pale yellow discoloration that commences at the distal end of the fruits is not a good indication of the maturity of pods. Each fruit ripens at its own time, requiring a daily harvest. "Current methods for determining the maturity of vanilla (*Vanilla planifolia* Andrews) beans are unreliable. Yellowing at the blossom end, the current index, occurs before beans accumulate maximum glucovanillin concentrations. Beans left on the vine until they turn brown have higher glucovanillin concentrations but may split and have low quality. Judging bean maturity is difficult as they reach full size soon after pollination. Glucovanillin accumulates from 20 weeks, maximum about 40 weeks after pollination. Mature green beans have 20% dry matter but less than 2% glucovanillin." The accumulation of dry matter and glucovanillin are highly correlated. To ensure the finest flavor from every fruit, each individual pod must be picked by hand just as it begins to split on the end. Overmatured fruits are likely to split, causing a reduction in market value. Its commercial value is fixed based on the length and appearance of the pod (Wikipedia, 2024). If the fruit is more than 15 cm in length, it is categorized as first-quality. The largest fruits greater than 16 cm and up to as much as 21 cm are usually reserved for the gourmet vanilla market, for sale to top chefs and restaurants. If the fruits are between 10 and 15 cm long, pods are in the second-quality category, and fruits less than 10 cm in length are in the third-quality category. Each fruit contains thousands of tiny black vanilla seeds. Vanilla fruit yield depends on the care and management given to the hanging and fruiting vines. Any practice directed to stimulate aerial root production has a direct effect on vine productivity. A five-year-old vine can produce between 1.5 and 3 kg of pods, and this production can increase up to 6 kg after a few years. The harvested green fruit can be commercialized as such or cured to get a better market price (Wikipedia, 2024).

Yield: The yield of vanilla varies depending upon the age of vines and the method of cultivation. Normally it starts yielding from the third year and the yield goes on increasing till the seventh or eighth year. Thereafter the yield slowly starts declining till the vines are replanted after another seven to ten years. In one acre you can plant about 3000 vanilla plants. Each plant is expected to yield about 500-800 grams of green beans per year. Under reasonable level of management, the yield range of a middle aged plantation will be about 500 kg-1000 kgs of green beans per acre. For every 5 kgs of green beans you can get around 1 kg of cured beans (Busungu, 2022). In 2020, world production of vanilla was 7,614 tonnes, led by Madagascar with 39.1% of the total, and Indonesia with 30.3% (table). Due to drought, cyclones, and poor farming practices in Madagascar, there were concerns about the global supply and costs of vanilla in 2017 and 2018. The intensity of criminal enterprises against Madagascar farmers is high, elevating the worldwide cost of using Madagascar vanilla in consumer products (Wikipedia, 2024).

Producing Countris: *Vanilla planifolia* is the only orchid of significant economic importance as an edible (i.e., condiment) crop. In 1992, major vanilla cultivating countries are Madagascar (700 tons), Indonesia (400 tons), Comoros Islands (150 tons), Réunion (12 tons), Mayotte (1 ton), Mauritius, Tonga, Tahiti and Mexico and China each produce less than 50 tons a year. The total annual production is 2000 tons of vanilla beans estimated at US$ 120000000. The USA is the major consumer (1000 tons), followed by Europe (250 tons) and Japan (32 tons). Vanilla provides the aroma in 50% of aromatic compounds and is the most widely used fragrance in perfume production. Because of the great demand, vanillin is also produced synthetically from wood, but the natural preparation is superior in flavour. Still, synthetic vanillin production today is estimated to 12 000 tons.year-1 versus 20 tons.year-1 of natural vanillin (Fouché and Jouve, 1999). The major vanilla producing countries are Madagascar, Comoro, Indonesia, Mexico and the Reunion, of which, Madagascar holds the prominent position (Divakaran and Rafieah, 2021).

Processing

Curing: Several methods exist in the market for curing vanilla; nevertheless, all of them consist of four basic steps (Supply, 1996):

- **Wilting or killing** of the beans stops their respiration. Heat is applied to the pods either by letting them sun-dry, as in the traditional Mexican method, or by submersing them in hot water for several minutes, as in the Bourbon process.

- **Sweating** the wilted beans involves rapid dehydration and slow fermentation to develop key flavor components. The beans are alternately sun-dried during the day and wrapped in boxes at night for several weeks until the beans acquire a deep chocolate-brown color.
- **Drying** the beans very slowly at low temperatures results in a final moisture level of about 20% to 25%. Over-drying or rapid drying reduces flavor quality. In the past, Indonesians used wood fires to accelerate the drying process, which causes the beans to develop a smoky aroma and flavor.
- **Conditioning** is an aging process necessary for flavor development that involves placing the dried beans into closed boxes for several months.

McCormick & Co. Inc., Hunt Valley, MD, uses a one- to two-week curing process in which the beans are chopped and placed into a curing tank for about 72 hours until they are no longer green. Then they are dried in a rotary or fluidized dryer, and spread out in a perforated conditioner until the desired moisture level is achieved. After curing, the vanilla beans are graded and bundled. Top-grade beans are oily, smooth, aromatic and very dark brown. The beans are then packed in boxes and shipped by boat. The beans continue to age during shipping; it may take several months for them to reach their destinations (Supply, 1996).

Killing: The vegetative tissue of the vanilla pod is killed to stop the vegetative growth of the pods and disrupt the cells and tissue of the fruits, which initiates enzymatic reactions responsible for the aroma. The method of killing varies, but may be accomplished by heating in hot water, freezing, or scratching, or killing by heating in an oven or exposing the beans to direct sunlight. The different methods give different profiles of enzymatic activity. Testing has shown mechanical disruption of fruit tissues can cause curing processes, including the degeneration of glucovanillin to vanillin, so the reasoning goes that disrupting the tissues and cells of the fruit allow enzymes and enzyme substrates to interact. Hot-water killing may consist of dipping the pods in hot water (63–65 °C (145–149 °F)) for three minutes, or at 80 °C (176 °F) for 10 seconds. In scratch killing, fruits are scratched along their length. Frozen or quick-frozen fruits must be thawed again for the subsequent sweating stage. Tied in bundles and rolled in blankets, fruits may be placed in an oven at 60 °C (140 °F) for 36 to 48 hours. Exposing the fruits to sunlight until they turn brown, a method originating in Mexico, was practiced by the Aztecs (Wikipedia, 2024).

Sweating: Sweating is a hydrolytic and oxidative process. Traditionally, it consists of keeping fruits, for 7 to 10 days, densely stacked and insulated in wool or other cloth. This retains a temperature of 45–65 °C and high humidity. Daily exposure to the sun may also be used, or dipping the fruits in hot water. The fruits are brown and have attained much of the characteristic vanilla flavor and aroma by the end of this process, but still retain a 60–70% moisture content by weight (Wikipedia, 2024).

Drying: Reduction of the beans to 25–30% moisture by weight, to prevent rotting and to lock the aroma in the pods, is always achieved by some exposure of the beans to air, and usually (and traditionally) intermittent shade and sunlight. Fruits may be laid out in the sun during the mornings and returned to their boxes in the afternoons, or spread on a wooden rack in a room for three to four weeks, sometimes with periods of sun exposure. Drying is the most problematic of the curing stages; unevenness in the drying process can lead to the loss of vanillin content of some fruits by the time the others are cured (Wikipedia, 2024).
Conditioning: Conditioning is performed by storing the pods for five to six months in closed boxes, where the fragrance develops. The processed fruits are sorted, graded, bundled, and wrapped in paraffin paper and preserved for the development of desired bean qualities, especially flavor and aroma. The cured vanilla fruits contain an average of 2.5% vanillin (Wikipedia, 2024).

Grading: Once fully cured, the vanilla fruits are sorted by quality and graded. Several vanilla fruit grading systems are in use. Each country which produces vanilla has its own grading system, and individual vendors, in turn, sometimes use their own criteria for describing the quality of the fruits they offer for sale. In general, vanilla fruit grade is based on the length, appearance (color, sheen, presence of any splits, presence of blemishes), and moisture content of the fruit. Whole, dark, plump and oily pods that are visually attractive, with no blemishes, and that have a higher moisture content are graded most highly. Such pods are particularly prized by chefs for their appearance and can be featured in gourmet dishes. Beans that show localized signs of disease or other physical defects are cut to remove the blemishes; the shorter fragments left are called "cuts" and are assigned lower grades, as are fruits with lower moisture contents. Lower-grade fruits tend to be favored for uses in which the appearance is not as important, such as in the production of vanilla flavoring extract and in the fragrance industry (Wikipedia, 2024). Higher-grade fruits command higher prices in the market. However, because grade is so dependent on visual appearance and moisture content, fruits with the highest grade do not necessarily contain the highest concentration of characteristic flavor molecules such as vanillin, and are not necessarily the most flavourful (Wikipedia, 2024).

Drying and Fermentation: Pick the beans when they are ready—full, with just a hint of yellow at one tip, not splitting or fully yellow. Immediately kill the beans by putting them in direct sun for a few hours, until they feel very hot. Sort them by size, with the larger and smaller ones grouped in different piles. Separation is necessary because larger and smaller beans cure at different rates. Wrap the beans in their respective piles in pieces of black cotton. Put this bundle in a plastic bag inside a closed box, over night. This begins the process of sweating, which you will continue to alternate with sunning for the next few weeks. Each day, unwrap the beans and spread them out in the sun for about three hours, then wrap them back up in the cotton and plastic, and sweat in the box. Repeat this process daily for two to three weeks, or until the beans are soft, fragrant, pliable, and relatively flat. Small beans can tolerate less sun than large beans, and will take a shorter period of time to cure. You must avoid overexposing the beans, in which case they will dry out and harden (Porvenir, 2018). Curing dehydrates the bean, and ferments the interior which improves the fragrance and flavor. The beans should never, ever, get hard or crispy, and they should never grow mold. The point is for them to become thoroughly immersed in their own oils. It can help to rub each bean between your hands each day to spread the oils. After the beans are sunned and sweated until black, fragrant, and pliable, its time to slow dry them in a shady indoor place on a

rack. Do this for about three months, monitoring them closely to remove any that show signs of mold. When properly sunned and sweated, they should not mold. At this point the vanilla can be stored in glass containers, or used to make vanilla extract (Porvenir, 2018).

Value Adding: Perhaps the easiest way to preserve vanilla post harvest is by making an extract of the cured pods. To do this, mince the vanilla beans into fine pieces. Mix one part minced vanilla by two parts vodka or other alcohol, at least 30% alcohol by volume. Put in a dark place and let sit for six months to a year, shaking weekly. When the liquid smells and tastes like vanilla, and the vanilla pieces no longer have any of their own fragrance or flavor, strain out the pieces and bottle the liquid extract. There are many variations of this recipe (Porvenir, 2018).

Packing: After sorting, the beans are tied into bundles, usually 70 to 130, weighing between 150 and 500 g. (Fig 22). These are then packed into cardboard or tin boxes lined with waxed paper. The beans are now ready for shipment.

Vanilla extract: Spices like vanilla comprise a small portion of our diet, but have major impacts on the sensory quality of our food. Vanilla extract comes from the cured beans of either *Vanilla planifolia* or *V. x tahitensis* as legally defined by the FDA. *V. planifolia* is native to North and Central America, but Madagascar is today's leading vanilla grower. Domestic vanilla production is becoming increasingly attractive as international supplies are perennially strained and demand for vanilla extract increases as companies like MARS, Unilever, and Nestle pledge to remove artificial ingredients from their products. Most vanillin, the primary flavor component of vanilla extract, is chemically synthesized, but vanilla extract has the potential to support growers in Florida, Hawaii, and Puerto Rico striving to meet an evolving consumer base favoring local, organic, and natural products. Vanilla is somewhat unique in that the species not been domesticated through plant improvement, and today's industry rely cultivated, wild clones (NALUS, 2024).

Types of flavourings: Ice cream is flavored by artificial or natural vanilla flavoring. Artificial flavorings contain 100% vanillin, the main ingredient that contributes to natural vanilla extract's flavor. Natural vanilla extract also contains nearly 200 more compounds in addition to vanillin. The different chemical properties of these compounds may cause compatibility issues with different ice cream preparations. Vanilla ice cream may be classified by the type of flavoring used. If natural vanilla extract is used, then the product is called "vanilla ice-cream". If vanillin from natural vanilla is used, then the product is called "vanilla flavored ice cream". If artificial vanillin is used, then the product is labelled as an "artificially flavored vanilla ice-cream". The United States Food and Drug Administration characterizes vanilla ice cream into three categories: (1) the ice cream only contains vanilla extract; (2) the ice cream contains 1 ounce (28 g) of synthetic vanillin per gallon (3.8 L) of one-fold vanilla extract; (3) the ice cream only contains synthetic ingredients (Wikipedia, 2024d).

The risk of mold for vanilla beans: Vanillin acts as a natural anti-mold agent, protecting the bean. Vanilla that is harvested when ripe and prepared correctly will reach the right balance between vanillin content and moisture, and is at no risk of growing mold (Norohy, 2024).

Storing vanilla beans: To keep vanilla in optimal conditions, you need to follow a few instructions. First of all, it's important to know that vanilla does not like heat, moisture, light, or air. Glass tubes or jars that are not too big are a good option. As they are fully airtight, the beans keep well inside. It's best to use a container that fits the vanilla snugly and therefore limits the amount of air inside. Rather than cork, an aluminum or plastic cap is better to avoid the risk of mold. A metal box that is similar in size to the beans is also a viable option that limits contact with the air. Or, vanilla beans can be kept in sous vide packaging, which preserves all their aromatic qualities! Over time, vanilla will generally lose moisture as it evolves. If you follow the above advice, you will be sure to be able to keep your vanilla beans at their aromatic best for 12 to 18 months, so that your vanilla is still soft when you come to use it. Also, it is not advised to keep vanilla beans wrapped in aluminum, paper towels, plastic wrap or a plastic bag. These will all dry out the bean and could lead to mold growing. You should also avoid storing vanilla with other spices, otherwise you risk mixing and changing the aromas (Norohy, 2024).

Quality Assurance: Many food products containing our vanilla beans have been produced by our commercial customers around the world. Our commercial customers require assurance that we meet standards of food safety and that our vanilla beans are high quality, free from harmful substances and organisms and meet international regulatory food requirements. For this reason our quality assurance requires that our Food Safety Program, Product Specifications and Microbiology Certificate of Analysis are all maintained to international standards (Natural, 2024.).

Commercial preparations of natural vanilla (Fig. 4) (NWE, 2024)

- Whole pod
- Powder (ground pods, kept pure or blended with sugar, starch or other ingredients) The U.S. Food and Drug Administration requires at least 12.5 percent of pure vanilla (ground pods or oleoresin) in the mixture (FDA 1993).
- Extract (in alcoholic solution). The U.S. Food and Drug Administration requires at least 35 percent vol. of

Pest and disease management: Vanilla is susceptible to many fungal and viral diseases. Fusarium, Sclerotium, Phytophthora, and Colletrotrichum species cause rots of root, stem, leaf, bean, and shoot apex. Development of most diseases is favoured by unsuitable growing conditions such as overwatering, insufficient drainage, heavy mulch, overpollination, and too much shade. Fungal diseases can be controlled by spraying Bordeaux mixture (1%), carbendazim (0.2%) and copper oxychloride (0.2%) (Wikipedia, 2024). Biological control of the spread of such diseases can be managed by applying to the soil Trichoderma (0.5 kg (1.1 lb) per plant in the rhizosphere) and foliar application of pseudomonas (0.2%). Mosaic virus, leaf curl, and cymbidium mosaic potexvirus are the common viral diseases. These diseases are transmitted through the sap, so affected plants must be destroyed. The insect pests of vanilla include beetles and weevils that attack the flower, caterpillars, snakes, and slugs that damage the tender parts of shoot, flower buds, and immature fruit, and grasshoppers that affect cutting shoot tips. If organic agriculture is practiced, insecticides are avoided, and mechanical measures are adopted for pest management. Most of these practices are implemented under greenhouse cultivation, since such field conditions are very difficult to achieve (Wikipedia, 2024). Insect pests generally do not typically cause serious damage. Snails and slugs, however, can be problematic if not controlled. We have noticed larval feeding on young plants, but we were able to manually remove the pests (Growables, 2024). A major limitation to vanilla production in many regions is root and stem rot disease caused by *Fusarium oxysporum*. Fusarium is a ubiquitous soilborne fungus that causes rot in many species. One specialized type (*Fusarium oxysporum* f. sp. *radices-vanillae*) causes rot in vanilla in all major producing areas by penetrating roots and spreading throughout the plant (Growables, 2024).

Contact dermatitis: The sap of most species of vanilla orchid which exudes from cut stems or where beans are harvested can cause moderate to severe dermatitis if it comes in contact with bare skin. The sap of vanilla orchids contains calcium oxalate crystals, which are thought to be the main causative agent of contact dermatitis in vanilla plantation workers (Wikipedia, 2024). The sap of most species of *Vanilla* orchid which exudes from cut stems or where pods are harvested can cause moderate to severe dermatitis if it comes in contact with bare skin, though it is water-soluble and can be removed by washing. The sap of vanilla orchids contains calcium oxalate crystals, which appear to be the main causative agent of contact dermatitis in vanilla plantation workers (Wikipedia, 2024e).

Vanilla rum

Vanilla Extract

Vanilla ice cream

Vanilla powder

Ice Cream Maker

Fig. 4. Products of Vanillas

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