

1

Mexican Vanilla Production

Juan Hernández-Hernández

1.1 Introduction

The vanilla species of commerce, *Vanilla planifolia* G. Jacks, known as “Mexican” or “Bourbon” vanilla, is native to tropical forests of southeastern Mesoamerica (Portères 1954; Soto-Arenas 2003; Hågsater *et al.* 2005). By at least the nineteenth century, *V. planifolia* was introduced into other tropical countries in Asia and Africa from the original Mexican cultivated stock (Bory *et al.* 2008; Lubinsky *et al.* 2008). Vanilla was used in pre-Hispanic Mesoamerica for a variety of purposes: tribute, fragrance, cacao flavoring, medicinal, etc., and by numerous indigenous groups such as the Maya, Aztec, and Totonac. In this sense, vanilla is a gastronomic legacy that Mexico has imparted to the world.

Beginning in the mid- to late eighteenth century, the Totonac of the Papantla region of the state of Veracruz were the first and only vanilla exporters in the world for nearly 100 years, in part because of the exceptional quality of the vanilla that was produced. Gold medal prizes for Mexican vanilla were awarded in Paris (1889) and Chicago (1892) (Chávez-Hita and González-Sierra 1990), as Papantla was famed as, “the city that perfumed the world.” Initially, Mexican vanilla production depended on harvesting the fruits from the wild, which were the result of natural pollination by bees that are endemic to the New World tropics.

The Mexican monopoly on vanilla fell apart with the discovery of a method for hand pollination of vanilla in Belgium in 1836. This knowledge enabled other countries to become vanilla producers. By 1870, French colonies in the Indian Ocean, especially Reunion and Madagascar, surpassed Mexico as the leading producer. Madagascar has retained the leading role in production since that time (Bruman 1948; Bory *et al.* 2008).

Although Mexico has lost its standing as the major vanilla exporter, it continues to be the center of origin and genetic diversity for this important orchid. Cultivation in Mexico endures to the present, mostly by the Totonac, who have continued to use their vanilla crop as a means to obtain cash, and because it is part of their historical and cultural fabric.

The area of vanilla production in Mexico is found between the coast and Sierra Madre Oriental on the Gulf, from sea level to a height of 700 m, where the climate is hot,

humid, and tropical. Average temperatures are around 24 °C, relative humidity is 80%, and average annual precipitation is 1,200 to 1,300 mm. A marked dry season occurs from March to June. In winter, there are humid, cool winds of low intensity called “*nortes*” that bring cool temperatures to the area, which is believed to stimulate the flowering in vanilla.

The state of Veracruz accounts for 70% of national production. Oaxaca and Puebla together produce most of the remaining 30%, and small quantities of vanilla are also supplied by San Luis Potosí, Hidalgo, Chiapas, and Quintana Roo. The municipality (*municipio*) of Papantla, located in northern Veracruz and inhabited by Totonac communities, is the largest producer in the country, and is the center of vanilla curing and commercialization.

An estimated 4,000 families are engaged in vanilla cultivation, mostly indigenous people, who exclusively sell green vanilla. Six private companies and four farmer cooperatives also exist, and participate in curing and selling of vanilla to national and international markets.

Annual production in Mexico varies from 80 to 200 tons of green vanilla (10–30 tons cured vanilla beans), depending on climatic conditions and the intensity of flowering, among other factors. In 2008/2009, according to estimates by the Consejo Nacional de Productores de Vainilla, 150 tons of green vanilla beans were produced (ca. 20 tons cured vanilla beans).

The principal limiting factors to vanilla production in Mexico are:

- drought and high temperatures, which occur during flowering and fruit development;
- the fungus *Fusarium oxysporum*, which causes mortality and reduces the productive life of individual cultivated areas (*vainillales*); and
- high production costs and low prices for vanilla.

1.1.1 The Mexican Vanilla Legend

The Mexican vanilla legend, which is an oral Papantla tradition, is compiled and interpreted by Professor J. Núñez-Domínguez (Curti-Díaz 1995):

At the summit of a mountain close to Papantla, was the temple of Tonacayohua, the goddess of food and planting crops. During the reign of King Teniztli III, one of his wives gave birth to a daughter whose beauty was so great that she was named Tzacopontziza (“Bright Star at Sunrise”), and was consecrated to the cult of Tonacayohua.

As time passed, a young prince named Zkatán-Oxga (“Young Deer”) and Tzacopontziza fell in love, knowing that this sacrilege was condemned by death.

One day, Bright Star at Sunrise left the temple to look for tortillas to offer to Tonacayohua, and fled with the young prince to the jagged mountains in the distance. Not before long, a monster appeared and surrounded them by a wall of flames, and ordered them to return.

When the couple returned to the temple, a group of irate priests had been waiting for them, and before Zkatán-Oxga could say anything, the young lovers were shot with darts, and their bodies were brought to a temple where their hearts were removed, and their carcasses were thrown down into a canyon.

In the place where the bodies landed there was a herb, and its leaves started to wilt as if the scattered blood of the victims had scorched the plant like a curse. Sometime later a new tree began to grow, and within days its vigorous growth covered all the ground around it with its brilliant foliage.

When finally it stopped growing, next to its trunk began to grow an orchid that climbed and also was amazingly vigorous. Within a short amount of time, it had branched and covered the trunk of the tree with its fragile and elegant leaves, and protected by the tree, the orchid grew more until finally it took the form a woman lying in the embrace of her lover.

One day the orchid became covered with small flowers and the whole area was filled with an exquisite aroma. Attracted to the pleasant smell, the priests and the pueblo came to observe, and no one doubted that the blood of the young lovers had transformed into the tree and the climbing orchid.

To their surprise, the beautiful little flowers also transformed into large, thin fruits. When the fruits matured, they released a sweet, subtle perfume whose essence invoked the innocent soul of Bright Star at Sunrise and the most exotic fragrances.

This is how the vanilla was born, the one that is called “*Caxixanath*” (Recondite Flower), which is a sacred plant and a divine offering in Totonac temples.

1.2 Cultivation Methods

Vanilla is a hemi-epiphytic orchid that in cultivation needs a tree to provide physical support, shade, and organic material.

In Mexico, vanilla is cultivated in different settings:

- in environments similar to the natural habitat, i.e. a forest composed of mostly secondary vegetation (“*acahual*”), which is the “traditional” style;
- intercropped with other crops such as coffee or orange;
- “intensively”, with *Erythrina* sp. or *Gliricidia sepium* as support trees; and
- “intensively”, in shade houses.

1.2.1 “Traditional”/Acahual

Acahual refers to a secondary forest or fallow that is regenerating, in many cases following maize cultivation. These sites are where vanilla is primarily cultivated, and are very similar to the natural habitat of the species. Over 90% of vanilla growers, mostly from indigenous groups, use this setting, which is almost always less than 1 ha.

Species commonly encountered in *acahual* are used as support trees for vanilla. They include: “laurel” (*Litsea glaucescens*), “pata de vaca” (*Bahuinia divaricata*), “cojón de gato” (*Tabernaemontana* sp.), “cacahuapaxtle” or “balletilla” (*Hamelia erecta*), and “capulín” (*Eugenia capuli*), among others (Curti-Díaz 1995). A relatively low density of vanilla plants is cultivated without irrigation and with minimal overseeing. Consequently, yields are low, varying between 50 and 500 kg of green vanilla/ha, with an average yield of 200 kg/ha.

This “traditional” style of cultivation is also used where vanilla is intercropped with coffee, where the vanilla benefits from the abundant organic matter and shade typical of

such *cafetales*. Support trees in this setting are trees that are used to provide shade to the coffee, such as *Inga* sp., or are species introduced to the site, such as *Erythrina* sp.

The advantage of the coffee-vanilla production system is that the grower diversifies his/her economic activities, obtaining two products from one site.

Establishing a “traditional” *vainillal* requires an initial investment of around \$2,000 USD/ha, with maintenance costs typically totaling \$1,500 USD per year.

1.2.2 Intensive System (Monoculture)

This system is normally practiced in deforested areas that have been used to cultivate another crop. The name of this system is “pure cultivation” (Chauds 1970), and the first step consists of planting support trees. After a year, when there is sufficient shade (50%), the vanilla is planted (Pennigton *et al.* 1954). This system is utilized by growers with more economic means, in lots of 0.5 to 2 ha per grower.

Support trees that are regularly used are “*pichoco*” (*Erythrina* sp.) and/or “*cocuite*” (*Gliricidia sepium*), two leguminous trees with the capacity to fix atmospheric nitrogen and that can be propagated clonally through cuttings. Per ha, 1,000 to 5,000 support trees are planted, as are 2,000 to 10,000 cuttings of vanilla (2 vanilla plants/support tree). The planting distances between trees are 1 × 2 m, 2 × 2 m, 1.5 × 2.5 m, and 3 × 3 m.

This system of vanilla cultivation has the advantage of relatively high yields, but generally only in the fourth or fifth year after planting (second or third harvest). After this time, yields decline drastically, most likely due to the difficulties of managing mature plants in such a confined space (especially for adequate shade and ventilation).

Yields of green vanilla beans vary from 1 to 2 tons per ha in rain-fed systems, and 2 to 4 tons per ha with a higher density of plantings (10,000 plants per ha) and with irrigation.

Establishing a monoculture of vanilla from a cleared area requires around \$10,000 USD to cover the costs of establishing support trees and the high density of plantings. Maintenance costs per year average \$7,500 USD.

1.2.3 Vanilla Cultivation in Existing Orange Groves

Orange trees are excellent support trees for vanilla, because their branches are durable and grow laterally and are able to support a good quantity and distribution of shoots (Figure 1.1). These features help mitigate the problem of the shoots shading out other shoots. The canopy of orange trees is capable of providing vanilla plants with sufficient sunlight throughout the year. In most systems with orange trees as supports, vanilla flowers in the second year.

This system is one of the best ventilated, with a low incidence of pests and diseases. Yields are higher and costs of production are lower because orange trees in coastal Veracruz have been extensively cultivated for decades.

Many of the vanilla growers started off cultivating oranges and continue to do so when managing vanilla. The vanilla plants are established when the orange grove is producing. Orange trees that are selected as supports have an average height of 4 m and a well-formed canopy. Dry branches (“*chupones*”) are pruned, as are those in the interior of the canopy that impede the spread of vanilla plants as they are growing or block out too much sunlight.



Figure 1.1 Vanilla vines growing on orange trees as a support.

Densities of orange tree plantings vary between 204 to 625 individuals per ha. Trees are spaced on a grid of 4×4 m, 5×5 m, 6×6 m, and 7×7 m, and 3 to 6 cuttings of vanilla are planted per orange tree, yielding a total of between 1,224 and 1,875 vanilla plants per ha.

Growers manage 1 to 5 ha and harvest 500 to 2,500 kg of green vanilla/ha, although most obtain 1 ton.

Establishing vanilla cultivation in an existing orange grove requires a minimum initial investment of \$7,000 USD/ha. The orange trees represent an economically sustainable resource in the sense that they do not have to be purchased or planted. Annual maintenance costs average \$6,000 USD/ha per year.

1.2.4 Shade Houses

This is the most recent and intensive form of vanilla management in Mexico. Its principal feature consists of substituting or complementing natural shade with artificial shade by means of shade cloth (black or red) of 50% luminosity, which is stretched above all the support trees at ca. 3 to 5 m high, at the four sides of the planted area. These systems are referred to as “shade houses”. In size, they are usually on the order of 25×40 m ($1,000 \text{ m}^2$) and some are up to 1 ha.

Shade houses most commonly feature artificial or “inert” support tress, such as concrete posts, or posts made from wood or bamboo. On occasion, living support trees, such as “*pichoco*” (*Erythrina* sp.) or “*cocuite*” (*Gliricidia sepium*), are used in lieu of or in combination with artificial supports. High planting densities are typical of this system, with 254 to 2,500 supports and 1,524 to 2,500 vanilla plants per $1,000 \text{ m}^2$.

Shade houses are appropriate on flat ground that has been deforested or on patios, and for use by growers with relatively more economic means. The initial investment is

high, usually \$10,000 USD per 1,000 m², with annual maintenance costs of \$2,000 USD. For this reason, most shade houses in Mexico are subsidized by the government.

The first yields from shade houses have been variable, with the maximum thus far being 514 kg green vanilla per 1,000 m², from 1,524 vanilla plants. This value theoretically scales up to 5,140 kg green vanilla per ha, similar to yields obtained from shade house production systems in other countries.

Growers agree that shade houses provide for a system of better care and overseeing of vanilla plants, which tend to grow vigorously as a consequence. However, it is yet to be determined what the real outcomes and economic viability of this system of production are.

In whatever system of vanilla cultivation, the maximum yields occur in the fourth or fifth year following after planting (second or third harvest). After this time, production volume can be lower or higher, but after 9 years, yields steadily decline until productivity ceases almost completely by the twelfth year.

1.3 Vanilla Propagation Techniques

Vanilla is propagated almost entirely by stem cutting. The cuttings are procured from another grower or from a government agricultural entity. Cuttings are made from highly productive and vigorous individuals that have never produced fruits. The cutting itself should not be a flowering shoot and should have at least 3 nodes with viable axillary buds for producing new shoots from which the plant will grow. Cuttings should be free of damage or symptoms of pests/diseases so as to avoid future proliferation of disease. A best practice is to ensure that the cuttings are certified as virus-free. Cuttings are normally 6 to 8 nodes (80–20 cm long, 1 cm in diameter) in length. Longer or thicker cuttings form new vegetative and reproductive shoots more rapidly (Ranadive 2005), but are more difficult to deal with during planting, and are more expensive.

1.3.1 Preparation and Disinfection of Cuttings

Cuttings are prepared prior to planting. The three most basal leaves are removed by hand by twisting at the petiole and taking care not to tear into the stem where open wounds can facilitate the spread of pathogens.

In order to prevent stem rot, caused primarily by *F. oxysporum*, stem cuttings are disinfected prior to planting. The basal portion of the cutting is submerged for 2 to 5 minutes in a fungicidal solution. The solution may consist either of carbendazim (2 g/L) or Bordeaux mixture (1 kg lime + 1 kg copper sulfate in 100 L of water), the latter being less effective but authorized for the production of organic crops. Fungicidal solutions are handled with rubber gloves to avoid harmful exposure to the body.

After disinfection, cuttings are hung separately on a structure 1 to 1.5 m tall, in a shaded and well-ventilated area for a period of 7 to 15 days. The cuttings slightly dehydrate allowing for more flexible material for planting. Calluses form over areas of the cuttings that were damaged during leaf removal.

1.3.2 Establishing Cuttings – Timing

Cuttings are planted when support trees have developed sufficient foliage to prevent the young vanilla plants from being burned. With shade cloth, cuttings are planted

immediately after the establishment of support trees. The best conditions for planting cuttings are in humid substrates during warm, dry months preceding the onset of the rainy season (Ranadive 2005). This timing favors a high percentage (>90%) of successfully established cuttings, since high temperatures are conducive to the emergence of new shoots and roots.

1.3.3 Establishing Cuttings – Planting

Cuttings are planted in the following manner. Adjacent to the support, a shallow ditch is dug 5 to 10 cm deep, into which the cutting is placed horizontally (but only the part that has had the leaves removed). The cutting is then buried with 3 to 5 cm of organic material and/or fertile soil or leaves, which will serve as a mulch and as a source of nutrients. The extreme basal end of the cutting (2–3 cm) is left uncovered to prevent rot (Wong *et al.* 2003; Ranadive 2005), especially when the substrate is humid. Some cuttings are established without making ditches, and are simply placed on top of a humid substrate.

Once planted, the rest of the cutting (with leaves, ca. 4–5 nodes) is positioned vertically on the support and fastened with bio-degradable material such as banana leaves, tree bark, or henequen fiber.

Under optimal conditions of humidity and temperature, and with vigorous, healthy cuttings, the first roots begin to emerge the first week after planting and the first shoots in about 1 month.

1.3.4 New Bud Formation and Root Growth

Warm temperatures stimulate both bud break and the longitudinal growth of shoots. In Mexico, most vegetative growth occurs in spring and summer (58–67.8 cm/month). In fall and winter, this rate of growth declines to 22 to 52.2 cm/month.

In general, growth is affected by humidity, nutrition, health, environmental conditions, etc. Vegetative growth during the first 2 years (3.97–5.94 m/year) is markedly less than when the plant is in the third and fourth years (7.49–7.63 m/year). After the fourth year, vegetative growth declines (5.74–6.8 m/year).

The first 2 years following establishment of the vanilla consist almost entirely of vegetative growth. By the third year, plants begin to flower and produce, when shoots have reached a minimal length of 10 m. The plants continue to produce from there on.

1.4 Irrigation

The main vanilla production region of Mexico – the Papantla area in northern Veracruz – characteristically suffers drought on an annual basis. The drought is most pronounced during the most critical season for vanilla, during flowering and pollination. Most growers in Mexico nonetheless cultivate vanilla in rain-fed systems.

The most frequent form of irrigation in Mexico is the use of micro-emitters to moisten the mulch layer where the vanilla roots are growing. One criterion for irrigation is to maintain at all times a moist layer of mulch without reaching saturation levels. During the dry season, watering is performed once to twice per week.

1.5 Nutrition

The primary source of nutrition for vanilla in cultivation is organic material (humus) that results from the natural decomposition of vegetable/animal residues (mulch), composting (via micro-organisms), or vermi-culture (worm-mediated breakdown of organic material).

1.5.1 Mulch

In addition to providing nutrients, the benefits of mulch are:

- it helps maintain soil humidity;
- it serves as a porous substrate, aiding soil aeration and permitting the unrestrained development of roots;
- maintains an adequate temperature; and
- decreases the incidence of weeds.

The most common mulch for vanilla is from decaying leaf litter derived from leaf fall, pruning, and from herbaceous plants in the *vainillal*.

The mulch should be 10 to 20 cm deep and laid down on either side of the support where the vanilla roots will grow. To prevent the loss of mulch from runoff from heavy rains, most prevalent in *vainillales* managed on slopes, borders are constructed out of trunks of wood, bamboo canes, rocks, or other materials. New applications of mulch are made when roots are observed growing out of the surface of the mulch, generally 2 to 3 times/year, and mostly in the hot/dry months, when mulch is carefully managed to prevent dehydration.

1.5.2 Building Compost

In addition to available natural organic material, the nutritional requirements of vanilla can also be met by developing a composting system.

Compost can be made from a diversity of primary organic materials, but it is best to use locally abundant resources. Fresh sawdust may contain substances that are toxic to plants, such as phenols, resins, terpenes, and tannins. Fresh manure or manure that has not decomposed adequately, can cause burning or root-rot and eventual mortality. When using either of these materials as fertilizer, it should be ensured that they are first well decomposed to avoid causing damage to the plant.

Compost is developed in many ways, but a simple and practical method for composting for vanilla, which gives good results, has been developed by growers in San Rafael, Veracruz. Vanilla plants are grown on orange tree supports, and are fertilized with a mixture of sheep manure and pine sawdust.

This compost is made by:

- mixing 70% pine sawdust with 30% dry sheep manure. The mixing is done on the ground with a shovel until the mixture homogenizes.
- applying water until 45 to 65% moisture is achieved. In practice, a grower decides when this percentage is arrived at by inspecting a small amount (a pinch) of the mixture in his hands. The water should not drop down onto the hands, but adhere to the mixture, and the moisture should be felt between the fingers.

- covering the mixture with plastic to protect it from the rain. High temperatures are generally not a problem, but should not exceed 65 °C, which could cause the death of the microorganisms responsible for breaking down the organic material. If this temperature is exceeded, the plastic cover is removed, and the compost is re-mixed (aerated) and water is also applied.
- turning the compost over every 15 days to accelerate decomposition and to maintain good aeration, especially during the initial stages of degradation, since the microorganisms (bacteria and fungi) depend on oxygen to live.
- Compost is ready to use in generally 3 months, when the compost pile cools and has the color and smell of earth; the best indicator is when young herbs start to germinate from the compost. At this stage, the compost should have about 30% moisture.

Composts are applied 1 to 2 times each year. Immediately after they are applied, growers irrigate in order to facilitate the absorption of the nutrients.

1.6 Weed Control

Between rows, weeding is performed with a hoe or machete. At the base of the plants themselves, weeds are carefully pulled out by hand in order to not disturb the shallow rooting structure of the vanilla plants. After removal, weeds that are annual herbs can be added to the mulch or composted and added later. Perennial weeds, such as *Commelina diffusa* and *Syngonium podophyllum*, are removed from the *vainillal* because they do not readily decompose. Weeds should be dealt with whenever they impede access to the vanilla plants and/or when support trees defoliate a disproportionate amount. In general, weeding is performed 3 to 4 times per year.

In shade houses, the rows between plantings are covered with milled “tezontle” (reddish, porous volcanic rock) or ground limestone, in order to prevent the growth of weeds.

1.7 Shade Management (Pruning of Support Trees)

In *vainillales* with living support trees such as *Erythrina* sp. or *Gliricidia maculata*, shade is controlled by periodic pruning, usually 2 or 3 times per year. Pruning should be timed to take place in the rainy season (July–November) to avoid the development of diseases in vanilla due to inadequate sunlight. Shade levels are between 30 to 50% during the rainy season. In dry and hot times of the year (March–June), which coincide with flowering/pollination and fruit development, support trees should have a denser canopy to provide 70 to 80% shade, which conserves humidity, prevents burning from intense sunlight, and decreases the incidence of young fruit drop.

Pruning is accomplished by removing the thicker central branches and leaving the laterals in order to achieve a canopy in the shape of a parasol that also maximizes the equitable distribution of vanilla shoots. Branches are pruned with either saws or machetes, down to about 40 cm from where they diverge from the trunk. The thinnest of the cut branches are broken into longitudinal pieces and placed at the base of the support as an additional source of organic material. Thicker branches are removed from the *vainillal* entirely. Over-pruning results in sunburn to the vanilla plants, and should be avoided.

With orange tree supports, shade management also consists of eliminating young buds, which impede the growth of the vanilla plant. Shoots of the orange tree are pruned when they over-shade the vanilla, which are generally the unproductive or dry/dead shoots. This pruning is generally performed once to twice per year following flowering and the harvest.

1.8 Shoot Management – Looping

The most common practice involving shoot management is “looping”, i.e. re-directing a growing shoot over a branch and towards the ground once it reaches the height of the first branches of the support tree. This practice maintains the height of the vanilla at roughly 2 m, facilitating hand pollination and harvesting. Another consequence of looping is hormonal induction promoting flowering and new shoot formation (usually just below the height of the fork in the tree where the shoot is bent). Shoots are managed so that they are equally distributed among the branches of the support tree such that no one shoot shades out another.

1.9 Shoot Management – Rooting

Once a shoot has been looped and has reached the level of the ground, a portion of it, usually 2 to 3 internodes long, is buried, leaving the growing apical meristem uncovered. This practice promotes root formation at the buried nodes. The shoot apex is fastened back to the support tree to continue growing. Rooting of shoots is performed every instance a new shoot has reached ground-level, helping to maintain the vigorous growth of the plant, which obtains more nutrients and is more resistant to *F. oxysporum*. In this way, rooting helps counteract the mortality of plants due to pathogens (Hernández-Hernández 2005).

1.10 Main Vanilla Insect Pest

The “*chinche roja*” (*Tenthercoris confusus* Hsiao & Sailer [Hemiptera: Miridae]) is a small insect that passes through many life stages, including 4 instars. At the nymphal stage, it measures less than 5 mm in length (Figure 1.2). It is at this stage that it causes the most damage to vanilla. As an adult, the *chinche* measures 5 to 6 mm and is black and red, from where it gets its name (Pérez 1990; Arcos *et al.* 1991; Sánchez 1993).

The *chinche* is the single most damaging vanilla pest, causing tissue damage in the leaves, stems, and fruits. The wounds left by the *chinche* allow for the colonization of fungus and bacteria that cause rot, wilting, and defoliation.

The *chinche* is controlled when it is present at low population density, simply by killing them by hand in the early morning hours (when they are most present and least active). An organic control is prepared from 3 onions, 3 heads of garlic juiced in a blender, and a bar of pH neutral soap (in pieces), all dissolved in 40 L of water. The solution is left to sit for 48 hours and applied to the vanilla plants with a sprayer. Applied



Figure 1.2 The main vanilla insect pest, “chinche roja” (nymphal stage).

correctly, it is more effective at eliminating *chinchas* than other insecticides (Hernández-Hernández 2008).

An alternative organic control is oil from the neem tree (*Azadirachta indica*). The dosage is 4 mL of neem oil per 1 L of water. Neem oil is a natural insecticide that is biodegradable and non-toxic to beneficial insects and to humans.

Vanilla also suffers herbivory from caterpillars that occasionally damage floral buds.

1.11 Main Vanilla Diseases

Root/stem rot (*Fusarium oxysporum* f. sp. *vanillae*) is a fungus that causes rotting of the roots, stems, and fruits, and plant mortality. It is found to some degree wherever vanilla is cultivated, principally where management is deficient and/or in plants that are bearing fruit. In Mexico, it is estimated to kill 67.4% of vanilla plants within 4 years of planting (Hernández-Hernández 2004).

When *Fusarium* infects the plant, it is very difficult or impossible to eliminate. Prevention is the best practice, and can be achieved by different techniques: using well-drained ground, planting only healthy and vigorous plants, ensuring the roots are always protected with a layer of organic material/compost, meeting nutritional requirements, looping and rooting shoots, avoiding over-pollination, regulating shade, and eliminating diseased plants or buds.

Fungicides may be applied during the rainy season, once to twice per month to prevent infection. Either carbendazim or Bordeaux mixture can be used, in the dosages indicated.

1.11.1 Anthracnose

This disease, caused by the fungus *Colletotrichum* sp., attacks leaves, fruits, stems, and flowers. It is identified by small, sunken spots that are dark brown. Infected fruits fall from the plant before they mature, and so overall yield decreases, sometimes by as much as 50%.

Anthracnose is prevented by ensuring that roots are healthy and that the plant is well-nourished. Fungicides can also be applied, such as inorganic copper oxy-chloride or Mancozeb at concentrations of 2 g/L in water or Bordeaux mixture. The application is done immediately after the cool winter winds (nortes) begin.

1.11.2 Rust

Rust (*Uromyces joffrini*) is identified by the presence of round pustules that are yellow-orange on the underside (abaxial side) of the leaves. As the rust develops, the pustules grow and merge together, eventually drying out the entire leaf. Rust is most frequently encountered in more traditional cultivation systems where there is little ventilation, excessive shade, and where precipitation is too great.

Plants infected with rust cease to develop, and so their productive capacity is reduced. Untreated, rust can defoliate entire plants or plantings.

When the symptoms of rust are first observed, growers immediately eliminate leaves, increasing the amount of light filtering to the plants. Bordeaux mixture or other products that contain copper are then applied weekly, at concentrations of 2.5 g/L of water. Infected leaves are taken out of the *vainilla* and buried.

1.11.3 Yellowing and Pre-mature Fruit Drop

Yellowing and fruit drop of immature fruits manifest at high temperatures exceeding 32 °C, and low relative humidity (<80%), during months of intense sunlight.

The fruit drop occurs 2 months after pollination, mostly in June, after a strong rainfall. Fruit drop varies from 15 to 90%, depending on the cultivation system.

In diseased fruits, two fungal species have been identified: *Fusarium incarnatum-equiseti* species complex and *Colletotrichum* sp. The *Fusarium* is the most commonly encountered, and is thus considered more responsible for causing fruit drop, but only under the environmental conditions cited earlier. In Mexico, these species have only recently been identified (Hernández-Hernández 2007). In India, other species of *Fusarium* have also been identified and reported to produced the same problem (Vijayan and Kunhikannan 2007), although *Colletotrichum vanillae* has also been isolated there as well (Anandaraj *et al.* 2005).

During flowering and fruit development, growers should eliminate the stressful conditions that lead to fruit drop, by maintaining 50% shade and by misting plants. Vanilla should not be cultivated in areas with poor ventilation since this raises temperatures, and leads to problems of stress and pathogen development.

1.12 Flowering and Pollination

In general, the first flowering, or “rehearsal” (“*ensayo*”), happens 3 years following planting. When *Citrus* sp. are used as supports, or when vanilla is cultivated in shade houses,

flowering initiates in the second year since the plants tend to grow more vigorously as a result of more consistent shade and management.

The physiological cue to flower is promoted by climatic or mechanical stress. The principal stress in Mexico that induces flowering are the low temperatures of Autumn and Winter, when cool air masses known as “*nortes*” blow down unimpeded from the Arctic Circle, dropping temperatures to below 10 °C; the lower the temperature, the greater the expectation of a good flowering year. The cool temperatures “burn” the apical tip, killing it, and break the apical dominance of the plant while stimulating lateral floral buds to develop. The flowering season is March to May, with peak flowering occurring in April.

1.12.1 Percent of Flowering Plants

The percentage of plants that flower varies each year. The first flowering usually involves a low percentage (27.19%) of plants, but by the third year of flowering (fourth or fifth year after planting) this amount reaches 97.07%. After the third flowering, the percentage of plants that flower may increase or decrease. Heavy flowering in one year is generally followed by reduced flowering the following year, due principally to the low number of developed flowering shoots. There are also numerous other mitigating factors, such as the amount of light filtering through to the vanilla plants, the health of the plants, etc.

1.12.2 Natural Pollination

Mexico is one of few countries where it is possible to obtain vanilla beans through natural pollination, although it happens rarely, accounting for only about 1% of all fruits. The identity of the natural pollinator(s) of vanilla is unclear, and for a long time it has been said that bees (*Melipona beechii*), hummingbirds (*Cynniris* sp.), and bats pollinate vanilla. The preponderance of evidence favors the hypothesis that the most common pollinator is the shiny green orchid bee *Euglossa viridissima* (Soto-Arenas 1999a, 2003; Hagsater *et al.* 2005; Lubinsky *et al.*, 2006). These bees have been documented visiting vanilla flowers but their visits are irregular and their potential for effecting pollination even smaller, perhaps only just 1 fruit per 100 or 1,000 flowers (Soto-Arenas 1999a,b).

Other orchid bees, namely, individuals of *Eulaema* sp. (“*jicotes*”), frequently visit the flowers of *V. pompona* in northern Veracruz, Mexico (Figure 1.3). On rare occasions, they also effect pollination of the flowers (5%) while looking for nectar inside and at the base of the labellum. The mechanism by which these bees actually pollinate vanilla flowers is yet to be documented.

1.12.3 Hand Pollination

Inside the labellum of the vanilla flower, the part which attaches to and wraps around the column, is a tissue that flaps down from the column, called the rostellum. The rostellum hangs exactly in between the stigma (female organ) and the anther sac (male organ), and is considered to be a product of evolution selected to prevent self-fertilization. In hand pollination, pollen is manually moved from the anther sac to the stigma, bypassing the rostellum.



Figure 1.3 An *Eulaema* sp. bee on a flower of *V. pompona*.

Hand pollination is performed with a small, thin stick roughly the size and shape of a toothpick, but can be made from bamboo, bone, spines, or other materials (Figure 1.4). The method of hand pollination consists of:

- i) Use a toothpick or similar tool to make a longitudinal slit in the labellum on the side opposite of the column to reveal the reproductive structures.



Figure 1.4 Hand pollination of a vanilla flower.

- ii) With the same end of the toothpick, lift underneath the rostellum and flip vertically so that the anther sac can hang down unimpeded over the stigma lobes.
- iii) Gently press the anther to the stigma until the two stick together and then remove the toothpick.

Hand pollination is performed from 7 am to noon, or a little bit later when it is overcast, but never when the flowers have already closed or withered. Hand pollination should be conducted by able and experienced people. Women are more commonly involved in the task. An experienced person pollinates 1,000 to 1,500 flowers per 5 to 7 hour period (ca. 4 flowers/minute), assuming that the plants are in the same area. The first flowers in the raceme that are pollinated yield longer and straighter fruits, while the last flowers to open characteristically produce smaller and curved fruits that have less value.

Hand pollination is a daily task for a period of 3 months. Per hectare, 300 to 600 days of work are required to carry out pollination, depending on the abundance of flowers, their location, efficacy of the pollinator, and distance between plants.

1.12.4 Quantity of Flowers to be Pollinated

In general, 6 to 8 flowers per raceme are pollinated to ensure obtaining a minimum of 4 to 5 fruits of acceptable quality (pollination is not 100% successful). Obtaining 100 to 120 fruits per plant requires 8 to 5 flowers per raceme to be pollinated. These approximations are rough since much depends on environmental conditions, the position and vigor of the plants, as well as the biological characteristics of the clone or cultivar. Vanilla growers determine the amount of flowers to be pollinated by considering pricing as well. Over-pollination leads to an abundance of many smaller fruits of lesser value that increase the cost of pollination and exert a heavy cost on the plants. Over-pollination is also associated with major fluctuations in production volume from year to year (Hernandez 1997).

1.12.5 Fruit Development

Immediately following hand pollination, pollen tubes begin their germination and growth and eventual fertilization of the ovules. The ovary quickly begins to enlarge and assume a strong, dark green aspect as it orientates itself downward. The maximum length and diameter of the fruit is achieved 45 days after hand pollination (Figure 1.5). Afterwards, growth ceases, and the fruit enters into a period of maturation lasting roughly 7 to 8 months.

1.13 Harvesting

The harvest in Mexico begins on December 10 of each year, in respect of an agreement taken by growers, curers, and industrial manufacturers. Growers harvest their entire crop in a single day, with the fruits at different stages of development. These stages can be significantly different, since flowering occurs over at least a 3-month time period. The heterogeneity in harvested fruits effects attempts at dehydrating the beans during the curing process, since immature fruits lose water more quickly than mature fruits.

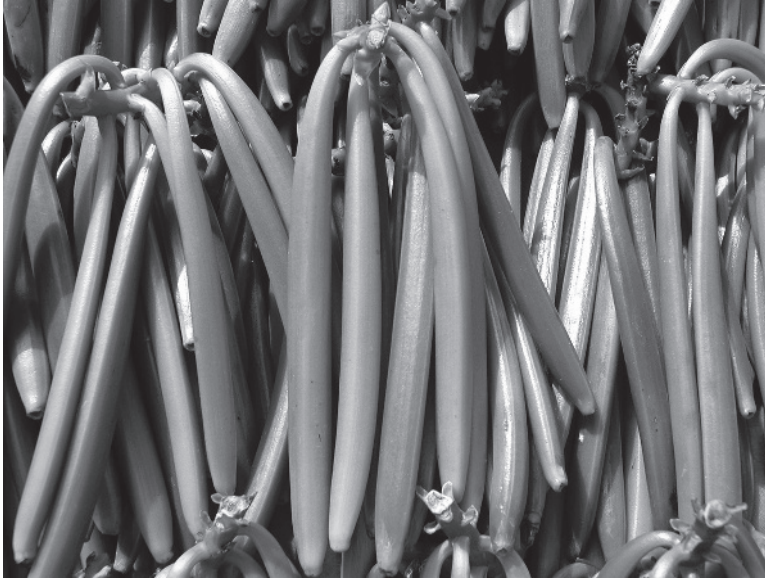


Figure 1.5 Developing vanilla fruits.

The ideal is for fruits to be harvested only when they have reached a ready stage for commercialization, that is, when the distal tip of the bean changes color from green to yellow. This transition normally occurs 8 to 9 months following pollination.

1.13.1 Harvesting Practices

In order to avoid rapid dehydration, the whole bundle or raceme of fruits is harvested with hand shears. The central stalk of the inflorescence, the rachis, remains attached. Harvested fruits are placed in baskets or plastic crates to prevent mechanical damage, which can lead to pathogen infection. The fruits are also kept in well ventilated and shady areas.

After harvesting, it is customary to prune shoots that have already flowered. These shoots will not produce again (or as much) unless they retain buds. The pruning is performed with a knife or blade that is disinfected prior to use in a solution of 1 part bleach to 6 parts water.

The removal of “spent” shoots serves to eliminate unproductive parts of the plant that occupy space and deplete the plant’s energy resources. Their removal facilitates the maintenance of adequate ventilation and light conditions for the plant. Some of these spent shoots may serve as cuttings to start new plants if they retain meristematic tissue.

1.13.2 Preventing Theft

Mexico has taken some actions to prevent theft:

- i) Each grower should have a permit to transport and sell vanilla. The permits can be obtained direct from SAGARPA, from the Consejo Nacional de Productores de

Vainilla, from regional government offices, or from local officials. Officials may confiscate vanilla from a person who cannot present their permit. Middle-men are notified that they should not buy vanilla from a grower who does not present his/her permit, since the vanilla could have been stolen. In practice, middle-men do make purchases without permits, since they can obtain more vanilla for a cheaper price.

- ii) Growers have sought out and receive help from state security forces to protect and transport vanilla (via horse-back escorts or helicopters). This happens when the price of vanilla is high, so when the risk of theft is high.

1.14 Green Vanilla Commercialization

The majority of vanilla growers in Mexico sell non-value-added, green vanilla to middle-men and processors who cure and export the cured vanilla beans. The two cities of Papantla and Gutiérrez Zamora, both in Veracruz, serve as the centers of vanilla curing and export. Green beans are sourced from growers in the state of Veracruz, as well as from Puebla and Oaxaca.

1.14.1 Prices

Prices for green vanilla are set by curers-exporters who consider world prices, supply and demand, costs for curing and exporting, etc., in order to ensure a profit. In recent years, vanilla growers have been forced to sell green vanilla at a loss, on average \$4 USD/kg. One exception are growers who sell to the Consejo Nacional de Productores de Vainilla (Asociación de Vainilleros), at a fixed price of \$8 USD/kg (2008–2009 harvest), for beans that are larger and better quality than average. Growers are paid only after the vanilla is cured and sold. Some growers have also sold green vanilla to private companies, for as much as \$12 USD/kg, but for individually harvested beans longer than 20 cm.

1.15 Curing

The curing process allows for the development of aromatic compounds and flavor in vanilla beans that can be used in different industries and applications.

In Mexico, curing is accomplished in a traditional, artisan style that includes ovens, and sun curing of vanilla beans laid out on mats of woven palm (“*petates*”) to facilitate cellular breakdown and dehydration (Figure 1.6). The entire process lasts 3 to 5 months (January–May), and consists of:

- i) *Selection and “despezonado”*: Beans are detached from the rachis, or “*pezón*”, and sorted by size and type. The type classes are “entire”, “split” (i.e. when the vanilla beans have opened), “painted/spotted” (fruits infected by *Colletotrichum* sp.), and “*zacatillo*” (i.e. small and curved beans). Each class is cured separately, because of the differences in quality.
- ii) *Cellular breakdown in ovens, or “killing”*: This step terminates the cellular processes of the beans, and among other consequences, prevents beans from opening



Figure 1.6 Sun curing of vanilla beans on mats of woven palm.

further. The fruits are placed in wooden boxes or inside folded *petate* mats, and placed in ovens from 24 to 48 hours at a temperature of 60°C. Afterwards, the fruits are removed and placed in larger “sweat boxes” for usually 18 to 24 hours (but sometimes as long as 48 hours) to receive their first sweat. The sweat-boxes are capped with matting and *petates* to prevent heat loss so that the beans continue to sweat. In recent years, some curers have replaced the oven method with the Bourbon process of killing beans in hot water, as is used in Madagascar.

- iii) *Sun curing and successive sweating*: The fruits are removed from the sweat boxes and placed on *petates* on a patio with full sun for 3 to 4 hours, during which they are allowed to reach a maximum temperature of 50 to 55°C. Immediately afterwards the beans are returned to the sweat-boxes and once more are insulated with a covering of *petates* in order to conserve heat and allow the beans to gradually lose water. The following morning, usually between 9 to 10 a.m, the beans are taken out of the boxes and repositioned on the patio in full exposure to the sun. This cycle of sun curing followed by sweating is repeated until the beans reach a 30% humidity content and a dark brown color, usually after 11 cycles for younger, less mature fruits and 24 cycles for fully mature fruits.
- iv) *Classification of cured beans*: Due to the fact that the curing process is not uniform, beans are re-classified according to how they feel and look. This is usually done after 8 to 11 cycles of curing. The beans are grouped according to their thickness (thick, intermediate, or thin), which is an indicator of moisture content. Once sorted and separated, these groups receive different amounts of curing/sweating. When curing is finished, the beans are re-classified again, this time according to



Figure 1.7 Classification of cured vanilla beans.

thickness, flexibility, and color. The classification scheme includes three categories, “supple/raw”, “bland”, and “dry”, indications of the progress of the curing.

- v) *Conditioning*: Beans classed as “dry” are no longer cured, but instead placed on wooden racks (“*camillas*”) so that they continue to gradually develop flavor and aroma. The beans are also inspected at this point to verify that they were adequately cured. If the beans show indications of colonization by fungus, their moisture content is too high, and the beans are returned to the sun to be dry further. Conditioning lasts 30 to 45 days, with every 15-day period serving to mark another round of inspection.
- vi) *Classification*: Beans that show no problem of developing fungus are classified by length and quality (color, sheen, flexibility, and aroma) (Figure 1.7).

1.15.1 Yield Ratio of Green/Cured Vanilla

The normal yield ratio of green to cured vanilla is 5:1. In other words, 5 kilos of green vanilla are needed to produce 1 kilo of cured vanilla. This ratio varies according to weight, size, and maturity of the green vanilla beans.

1.16 Grading

Cured vanilla is classified as either “whole”, “split”, or “*picadura*” (“chopped”). *Picadura* refers to beans that have been cured from immature, small, or damaged fruits or were

improperly cured beans. For whole and split beans, five categories have been established in Mexico (Galicia *et al.* 1989; Curti-Diaz 1995):

- i) *Extra*: Thick beans, flexible and lustrous, dark brown “chocolate” color, sweet and delicate aroma, with a vanillin content greater than 2.5% of dry weight. These beans are harvested at the optimal time and are well cured.
- ii) *Superior*: Similar to “extra”, but less thick and lustrous, with a vanillin content between 2.25 and 2.29%.
- iii) *Good*: Flexible and lustrous, sweet aroma, dark brown color with red longitudinal streaks, and a vanillin content of between 2 and 2.24%.
- iv) *Medium*: Little flexibility/sheen, light aroma, dark brown with light edges, with a vanillin content between 1.75 and 1.99%.
- v) *Ordinary*: No flexibility/sheen, weak aroma, light brown with dark edges, with a vanillin content between 1.5 and 1.74%.
- vi) *Picadura*: Lowest quality beans, both physically and in aroma. Sold in small pieces of about 1 cm for use in extracts.

In practice, this grading system may or may not be used in lieu of standards set by other countries and/or standards set by the buyer such as “gourmet”, “splits”, “small”, “chopped”, etc.

1.16.1 Packing

Mexican vanilla is traditionally shipped in bulk, wrapped in wax paper, and packaged in cardboard boxes (Figure 1.8). “Extra” or “gourmet” vanilla is also sold in rolls called “mazos”.



Figure 1.8 Packaged cured vanilla beans.

1.17 Buyers

The principal buyers of Mexican vanilla are international companies such as Aust Hatchman, McCormick, Eurovanille, Vanipro, Coca-Cola, Vanilla Saffron Imports, International Flavors & Fragrances (IFF), Nielsen-Massey Vanilla, and Dammann & Co., among others. Most of these are based in the United States, France, Germany, and Canada. Within Mexico there are also business that buy vanilla for extract manufacture and for re-sale.

1.18 Export Volume

The majority of Mexican vanilla is destined for export. In the past 3 years, since the price has been less than \$50 USD/kg, not all of the vanilla in Mexico has been sold, and has remained in warehouses until prices improve.

Usually, Mexico annually exports 20 to 30 tons of cured vanilla, about 1% of total annual supply worldwide. The United States is the number one buyer of Mexican vanilla, followed by Germany, France, Japan, and Canada. About 5% of the supply of Mexican vanilla is sold within Mexico for extracts and for making handicrafts.

1.19 Prices

The price for cured vanilla is set by international companies, and is normally similar to the price in Madagascar. In the last 3 years, these companies have offered less than \$50 USD/kg, except in some instances where small quantities of gourmet beans have been sold for \$80 USD/kg. Mexico does not enjoy a different price for its quality of vanilla since the international companies/brokers re-sell the Mexican vanilla to the same markets where vanilla from other countries is also sold.

1.20 Aromatic Profile

The aroma of Mexican vanilla is described as intense, sweet, lightly spicy, with tobacco notes. The vanillin content is generally 2%. The characteristic aroma of Mexican vanilla is due to the presence of vanillin as well as other volatile compounds that, while present at low concentrations, nevertheless strongly impact the overall flavor of the beans.

One study found that Mexican vanilla contains 65 volatile compounds, predominantly acids and phenolics (Pérez-Silva *et al.*, 2006). Another study (Hartman 2003) identified 61 volatile compounds, 11 of which were unique to Mexican vanilla: hexanoic acid, vanillyl methyl ketone, methyl eicosanoate, 4-butoxy-3-methyl-2-butanone, methoxy-methylacetate, 4-hexen-1-olacetate, 3-ethyl-3-methylpentane, 2,4-dimethyl-1-heptanol, 4-methylene-2-oxethanone, 2-methyl-3-ethylpentane, and 2-ethyl-1,3-dioxolane. In comparison to vanilla from other countries, Mexican vanilla tends to have greater concentrations of acetic acid and less anisyl compounds (Black 2005).

Mexican vanilla is preferred in the international markets for gourmet uses and for household consumption because of its exquisite taste and aroma. It differs in its aroma and taste from other countries because of its unique compounds and in the curing method it receives.

1.21 Summary

Growers of vanilla in Mexico have started to organize themselves in national and state associations in accordance with legal and judicial frameworks in order to obtain economic resources from the government. Growers have also sought out from the government technical assistance, help with establishing their own curing facilities and organizations (in which growers receive a better price by selling a value-added product), and in linking directly to external markets. In other words, growers have been trying to break the traditional commercialization scheme. As part of this initiative, some growers have also been promoting shade-house cultivation, subsidized by the government, that they hope will produce higher yields because of the high density of plantings and increased overseeing and technology.

A typical feature of vanilla growers in Mexico is that personal investment in time and resources directly correlates with good prices for vanilla. When prices fall, growers decrease their own investments, to the extent of abandoning vanilla cultivation altogether, as is happening currently. This is the main factor that explains why the volume of Mexican vanilla production has been so low for the last 50 years. The interest to cultivate vanilla in Mexico among growers is strong, but the price factor and fluctuations in international demand are the prime determinants for the increase or decrease in Mexican vanilla production.

Few scientific/technical studies in Mexico have addressed how vanilla cultivation can improve, mainly because of a lack of government funds since vanilla does not represent a crop of major socio-economic or political importance in Mexico. There remain few institutions that conduct vanilla research, most of which are thesis projects by university students.

Only the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) has two full-time vanilla researchers who have contributed fundamentally to the technological improvement of vanilla cultivation, and to capacity-building, via work-shops and courses for growers. The majority of the applied knowledge in vanilla cultivation is the product of cumulative experience of growers, from generations of transmitting knowledge from fathers to sons.

INIFAP and other institutions have made commitments to establish a germplasm repository and to identify cultivated material, but the lack of funding has made it difficult to realize such advances.

References

- Anandaraj, M., Rema, J., Sasikumar, B. and Suseela Bhai, R. (2005) *Vanilla* (extensión pamphlet) Indian Institute of Spices Research.
- Arcos, C.G., Jiménez, H.R. and Pérez, A.V. (1991) Dinámica poblacional y ciclo biológico de *Tenthecoris confusus* Hsiao and Sailer en vainilla. 4^o. *Reunión anual del INIFAP en el estado de Veracruz (resultados y avances de investigación)*. Resumen de trabajo.

- Black, J.M. (2005) Vanilla bean volatile analysis, origin and species. Flavor and Fragrance Research, LLC. Presentation (conference) from Vanilla 2005. *The International Symposium on the Vanilla Business*. Veracruz, Mexico. 15–16 November. www.Spectraflavor.com/pdfs/vanilla-GCO-presentation.pdf. Site accessed August 3, 2009.
- Bory, S., Lubinsky, P., Risterucci, A.M. et al. (2008) Patterns of introduction and diversification of *Vanilla planifolia* (Orchidaceae) in Reunion Island (Indian Ocean). *American Journal of Botany*, 95, 805–815.
- Bruman, H. (1948) The culture history of Mexican vanilla. *The Hispanic American Historical Review*, 28, 360–376.
- Chauds, P. (1970) Les Derniers résultats obtenus par la recherche agronomique dans la culture du vanillier (a la Réunion). *Plantes a épices*, 25, 101–112.
- Chávez-Hita, A. and González-Sierra, J. (1990) Papantla Veracruz: Imágenes de su historia. Archivo General del estado de Veracruz ISBN-968-6171-32-0. Litográfica Turmex. S.A. de C.V. México, D.F.
- Curti-Díaz, E. (1995) Cultivo y beneficiado de la vainilla en México. *Folleto técnico para productores. Organización Nacional de Vainilleros Indígenas*. Papantla, Veracruz.
- Galicia, R., Garcia, M. and Curti-Díaz, E. (1989) Anteproyecto de norma oficial mexicana - Especies y Codimentos - *Vanilla fragans* (Salisbury) Ames o *Vanilla planifolia* (Andrews) Entera en estado seco. Comisión Nacional de Fruticultura. Memorias, Primera Semana Nacional de la Vainilla. pp. 93–112.
- Hagsater, E., Soto-Arenas, M.A., Salazar-Chávez, G.A., Jiménez-Machorro, R., López-Rosas, M.A. and Dressler, R.L. (2005) *Las orquídeas de México: Orquídeas y gente*. Instituto Chinoín, México D.F. pp. 38–71.
- Hartman, T.G. (2003) *Composition of vanilla beans from different geographical regions*. Presentation in Vanilla: First International Congress, Princeton, NJ, November 11–12.
- Hernández, A.M. (1997) *Crecimiento y reproducción de Vanilla planifolia (Orchidaceae) en Usila*, Oaxaca. Tesis de maestría en ciencias. UNAM.
- Hernández-Hernández, J. (2004) Tecnología para producir vainilla. *Memoria técnica no. 12. Día del Productor Agropecuario y Forestal*. Campo Experimental Ixtacuaco. pp. 1–21.
- Hernández-Hernández, J. (2005) Comparación de dos sistemas de producción intensiva de vainilla. resultados finales. In: *Avances en la Investigación Agrícola, Pecuaria, Forestal y Acuícola en el Trópico Mexicano 2005*. Libro Científico No. 2. Veracruz, México pp 81–94.
- Hernández-Hernández, J. (2007) Bad weather and hurricane Dean: the beginning and end of México's vanilla production collapse of 2007. *Presentation in Vanilla 2007, International Congress*. Jamesburg, NJ, 6–8 November.
- Hernández-Hernández, J. (2008) Manejo integral de plagas y enfermedades en vainilla. *Revista Agroentorno* 96, 21–25.
- Lubinsky, P., Van Dam, M. and Van Dam, A. (2006) Pollination of vanilla and evolution in Orchidaceae. *Lindleyana*, 75, 926–929.
- Lubinsky, P., Bory, S. Hernández-Hernández, J., Kim, S.C. and Gómez-Pompa, A. (2008) Origins and dispersal of cultivated vanilla (*Vanilla planifolia* Jacks. (Orchidaceae). *Economic Botany*, 62, 127–138.
- Pennigton, C., Jiménez, F.A. and Theis, T. (1954) A comparison of three methods of vanilla culture in Puerto Rico. *Turrialba*, 4, 79–87.
- Pérez, P.E. (1990) *Dinámica poblacional e identificación de la chinche roja en el cultivo de la vainilla (Vanilla planifolia A.) en el municipio de Papantla, Ver. Tesis de Licenciatura*. Universidad Autónoma del Estado de Morelos. Cuernavaca, Mor.

- Pérez-Silva, A., Odoux, E., Brat, P., et al. (2006) GC-MS and GC-olfactometry analysis of aroma compounds in a representative organic aroma extract from cured vanilla (*Vanilla planifolia* G. Jackson) beans. *Food Chemistry*, 99, 728–735.
- Portères, R. (1954) Le genre *Vanilla* et ses espèces. In: Lechevalier P. (Ed) *Le vanillier et la vanille dans le monde*, Lechevalier, P. (ed.), Encyclopédie Biologique XLVI. Paris. France. pp. 94–290.
- Ranadive, A.S. (2005) Vanilla cultivation. In: *Vanilla: First International Congress*. Allured Publishing Corp., Carol Stream, IL, pp. 25–31.
- Sánchez, M.S. (1993) Manual de producción de vainilla en el estado de Veracruz. *Folleto para productores No. 6. Campo Experimental Papantla*. CIRGOC-INIFAP.
- Soto-Arenas, M.A. (1999a) Conservation of the genetic resources of vanilla. *Journal of the Canadian Orchid Congress* 11 (Abstract).
- Soto-Arenas, M.A. (1999b) Fitogeografía y recursos genéticos de la vainilla de México. *Project J101*. Comisión Nacional para el conocimiento uso de la biodiversidad, Mexico City, Mexico.
- Soto-Arenas, M.A. (2003) Vanilla. In: *Genera Orchidacearum Vol. 3 Orchidoideae (Part 2). Vanilloideae*, Pridgeon, A.M., Cribb, P.J., Chase, M.W. and Rasmussen, F.N. (eds), Oxford University Press, Oxford, pp. 321–334.
- Vijayan, A.K. and Kunhikannan, C. (2007) Assessing the risk of aflatoxin in vanilla for export from India to USA. Workshop. Indian Cardamom Research Institute and Institute of Forest Genetics and Tree Breeding. <http://www.angrau.net/participantsPresents.htm> (accessed August 14, 2009).
- Wong, C., Wong, M. and Grisoni, M. (2003) Culture de la vanille. *Fiches techniques/technical leaflets*. 37 p. (audiovisual material).