Essay

Phytophthora cinnamomi Rands in avocado

María Eugenia Agapito Amador[1]
Víctor David Cibrián-Llanderal[2]
Mónica Gutiérrez Rojas[3]
Daniel Ruiz-Juárez[4§]
Betzabe Ebenhezer López Corona[4]
Edgar Omar Rueda-Puente[5]

[1]Master in Agricultural Sciences-Metropolitan Autonomous University-Xochimilco Unit. Causeway of the Bone 1100, Coyoacán, Mexico City, Mexico. ZC. 04960. (m.eugenia.a059@gmail.com). [2]Postgraduate in Forest Sciences-Postgraduate College-*Campus* Montecillo. Mexico-Texcoco Highway km 36.5, Texcoco, State of Mexico. ZC. 56230. (vicillan@yahoo.com.mx). [3]Department of Agricultural and Animal Production-Metropolitan Autonomous University-Xochimilco Unit. (mgutierrez@correo.xoc.uam.mx). [4]Department of Research and Postgraduate in Food-University of Sonora. (betzabe.lopez@unison.mx). [5]Department of Agriculture and Livestock-University of Sonora. Blvd. Luis Encinas y Rosales s/n, col. Center, Hermosillo, Sonora. (erueda04@santana.uson.mx).

[§]Corresponding author: druiz@correo.xoc.uam.mx.

Abstract

The objective of this review is to present the epidemiological status of *Phytophthora cinnamomi* Rands in interaction with *Persea americana* Mill. and the authorized phytosanitary management alternatives. The trial was conducted based on reports from official and scientific authorities on plant health, of epidemiological outbreaks of the avocado sadness disease caused by *P. cinnamomi*. Worldwide, the loss of avocado trees was exponential, due to the disease caused by the oomycete *P. cinnamomi*, which presented epidemiological behavior at the national and international levels. In 1942, in Puerto Rico, the pathogen was isolated for the first time by Tucker in avocado plants. In Mexico, the first epidemiological outbreak due to this pathogen was in 1952, with losses of 90% of avocado production, the distribution of the disease spread to different parts of the world. In favorable conditions it affects the root and base of the crown, invades vascular bundles and takes the nutrients for its development. Pathogenesis is influenced by temperature, precipitation, moisture, pH, nutrient availability, and soil texture. In the field, the biological effectiveness of the molecules, for the control of the oomycete, may present limitations that impact the microbiota, flora and fauna; in addition, the effects that are reflected in the quality and safety of fruits due to the accumulation of synthetic pesticide molecules. Given the phytosanitary situation expressed by avocado production, it is necessary to implement sustainable management alternatives, such as endotherapy, through the injection of selective products in specific doses, which control the disease without affecting the quality and safety of the fruit.

Keywords: avocado sadness, endotherapy, risk analysis.

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P. cinnamomi is within the class of Oomycetes, they are Eukaryotes that belong to the Protista group (filamentous), their way of feeding is as saprophytic, biotrophic, hemibiotrophic or necrotrophic (Engelbrecht *et al*., 2013). The taxonomic description of the genus *Phytophthora* is based on its morphology and structural characteristics (sporangium, antheridium, oogonium or mycelium), referred by authors as Martínez (2015); McGowan *et al*. (2018). *Phytophthora* belongs to the kingdom chromista order peronosporales (Rays and Brett, 2012; Sharma *et al*., 2021). *Phytophthora* species devastate native ecosystems, forests, ornamental plants and intensive agricultural crops (Kurbetli *et al*., 2020a). It is considered one of the soils phytopathogens with the highest degree of impact on fruit growing, due to the impacts it has caused to commercial production units, with losses of 45 to 90% (Ramírez, 2018; Sánchez *et al*., 2019).

Avocado (*Persea americana* Mill.) is also affected by Avocado Sadness disease caused by *P. cinnamomi* Rands (Berg *et al*., 2021). Under favorable conditions the pathogen affects roots and stem base of avocado trees (Zapata *et al*., 2018). In the root, it enters through the root pore and intercellular spaces, damages the primary walls of the cells of the endodermis, which integrate the Casparian strip, invades the vascular bundles and takes nutrients for its development, alters the phenology and physiology of the fruit tree (Osorio *et al*., 2017; Zapata *et al*., 2018).

In cellular tissue, it induces water stress, promotes wilting, drying of plant structures and finally induces descending death of the tree (Osorio *et al*., 2017). The symptoms are recognized by the appearance of small leaves with the presence of chlorosis, vegetative growth stops, partial defoliation of the leaves begins, and fruit production decreases (Osorio *et al*., 2017). In the absence of a host, the microorganism has the ability to feed on decaying organic matter and prevails in the soil for up to six years (Toapanta *et al*., 2017; Ruiz *et al*., 2019) and according to Kurbetli *et al*. (2020a, 2020b), in the world, the disease is distributed in the main avocado production areas. Under favorable conditions, commercial production units are devastating (Almaraz *et al*., 2016; Gómez, 2018).

The alternatives for the management of the disease and the causative agent are increasingly aggressive with the biotic and abiotic factors that interact with the development of the crop (Ramírez, 2018). Based on the above, this essay consists of presenting the epidemiological status of *P. cinnamomi* in interaction with *P. americana* and authorized phytosanitary management alternatives.

Phytosanitary risks of *Phytophthora* spp. in fruit trees

Kurbetli *et al*. (2020a) reported that *Phytophthora* spp., was detected in pomegranate trees with 10 years of commercial production, the incidence of the disease was 4.59%; that is, for every hundred trees, five were infected with *P. nicotianae* and *P. palmivora*. The damage expresses itself affecting the root neck causing descending death to the pomegranate trees. In addition, Dai *et al*. (2019) mention that *P. hibernalis* affects the vascular bundles of citrus trees, causes brown rot and generates gummosis, which is expelled by the lenticels of the stem. In California and Florida, USA, production was affected by 46%, with economic losses of 30 to 60 million dollars (Sáenz *et al*., 2019). In China, since 2007 *P. hibernalis* is considered a quarantine pest (Dai *et al*., 2019). In 2015, China detected the presence of the pathogen in citrus shipments that entered through Shanghain, suspended citrus imports from Tulare California, United States of America (Dai *et al*. 2019). Sánchez *et al*. (2019) mention that the in valleys of Northern Patagonia, *P.* cactorum, *P. inundata*, *P. rosacearum*, *P. lacustris* and *P. termopila* cause rot in the neck of the root or base of the crown in pear trees.

Physiology of parasitism

Phytophthora sp., forms chlamydospores, sporangia and oospores that allow it to live in the soil as a saprophyte for up to six years (Toapanta *et al*., 2017). In temperatures from 21 to 28 °C, humidity of 78%, soil texture, pH 6-7 and saturated or flooded soils, the asexual phase begins (Toapanta *et al*., 2017), in this sense, the presence of water is fundamental for the multiplication and spreading phase in the host (Vicent *et al*., 2016). Mature sporangium releases between 30 and 40 zoospores, they spread through water through the mechanical action of flagella (Almaraz *et al*., 2016; Zentmyer, 1985).

Zoospores are attracted to amino acid exudates from the elongation zone, which is secreted by the secondary roots and adsorption villi (García *et al*., 2016; Pliego *et al*., 2016; Zapata and Leal, 2018). In interaction with root tissue, zoospores become cystic and anchored to the root epidermis, giving rise to the stage of penetration and infection of the epidermis, endodermis and vascular bundles of the radicle, due to the presence of the germ tube or pathogenic cells of the hyphae that make up the mycelium of the oomycete, the colonization process of the primary structures of the radicle lasts 24 h on average (Zapata and Leal, 2018).

The mycelium of the phytopathogen reaches its optimal development after the parasitism of the cambium, it immediately goes to the vascular bundles and, due to the proliferation of hyphae, causes clogging of xylem (Huaman *et al*., 2015; Hardham and Blackman, 2018). The obstructions of the vascular bundles limit the mobilization of water and nutrients, stimulate water stress and malnutrition of the tree due to the lack of water and nutrition, consequently, the radicle becomes necrotic (Huaman *et al*., 2015; Hardham and Blackman, 2018). Later, the mycelium invades the base of the crown or vascular bundles of the root neck, where the canker disease expresses itself, which reaches up to 2 m in height, from the base of the crown, light to dark brown coloration, more aqueous exudate, is observed (Andrade *et al*., 2015). During this process, the mycelium will give rise to chlamydospores, giving formation to the germ tube, to form the sporangium, where zoospores will be produced and when the sporangium matures, it releases zoospores and forms several generations of asexual production (Hardham and Blackman, 2018) (Figure 1).

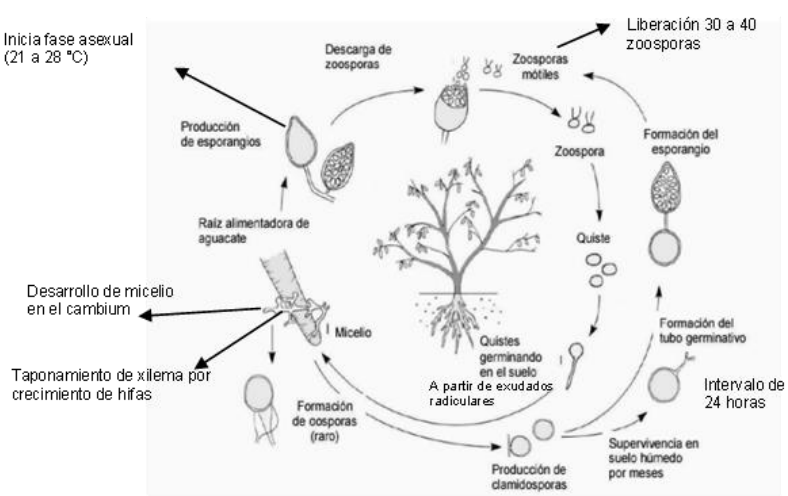

Figure 1. Life cycle and physiology of the parasitism of *Phytophthora cinnamomi* modified from Pegg *et al*. (2002).

The sexual phase begins in the mature mycelium, Ainswort (1985) describes that, in the sexual phase, *P. cinnamomi* forms resistance structures called gametangia, where the oogonium binds with the antheridium; through a fertilization tube and it fuses with the nucleus of the egg. The oospheres secrete a wall to form the oospores, after a period of rest, the oospores are released, then they produce a germinative tube that will give rise to the sporangium, which in favorable conditions will give rise to the following generations of the phytopathogen (Alexopoulus and Mims, 1985).

Economic impact due to the epidemiological behavior of avocado sadness

According to Rodríguez *et al*. (2017), avocado sadness is the main limitation of avocado production, under favorable conditions, the epidemiological risk of impact on commercial orchards is 75%, with annual losses of up to 30 million dollars (Kurbetli *et al*., 2020b). The spatial distribution of the disease has spread in different regions of the world where *P. americana* is grown. Since the first epidemiological outbreaks of *P. cinnamomi*, the increase in the disease has grown exponentially (Ramírez, 2018).

In Latin America, avocado sadness eliminated important areas of commercial avocado production in Mexico, Peru, Colombia, and Chile (Toapanta *et al*., 2017). In 1942, the pathogen was isolated from avocado roots by Tucker (Zapata and Leal, 2018). In the same year, in California, USA, it was isolated from avocado orchards (Serrano and Garbelotto, 2020) and in 1980, in the USA, the disease devastated 1 500 ha of avocado (Flores, 2015; Kurbetli *et al*., 2020b). In South America, 1950, 50 000 diseased trees were detected in Peru (Flores, 2015).

In Colombia, the losses of seedlings were 50% and in avocado plantations 47% (Pérez *et al*., 2014). In the avocado zone of Chile, this disease is also limiting in avocado cultivation (Sepúlveda *et al*., 2013). In 1986, *P. cinnamomi* Rands appeared in avocado plantations in Ecuador, where it was classified as an easily spreading disease with high incidence and mandatory control (Toapanta *et al*., 2017).

In 1965, in Australia, forest soils were also positive for the presence of *P. cinnamomi* Rands (Flores, 2015) in one million ha, the oomycete destroyed more than 400 hosts (Almaraz *et al*., 2013).

In 1970, in South Africa with the introduction of avocado cultivation, the number of infected orchards grew exponentially, and losses were estimated at 20% of total production (Flores, 2015). Also, in the region of Andalusia, Spain, 40% of avocado orchards were affected by *P. cinnamomi* (Kurbetli *et al*., 2020b). In 1982 the disease of avocado sadness was identified, the incidence in avocado orchards in Israel increased (Kurbetli *et al*., 2020b).

Currently, the avocado sadness disease has crossed borders and continents (Gómez, 2018). Derived from this essay, Figure 2 makes the contribution with the spatial distribution of the disease with epidemiological outbreaks, where Australia, New Zealand, Africa, Israel, Spain, Morocco, the USA and Mexico stand out (Gómez, 2018).

Figure 2. Worldwide distribution of *Phytophthora cinnamomi* Rands, generated with data taken from EPPO (2021).

Phytosanitary situation of avocado sadness in Mexico

In 1952, in Mexico, the first epidemiological outbreaks of avocado sadness caused by *P. cinnamomi* reached losses of 90% in avocado orchards (Almaraz *et al*., 2016). In 1994, in Uruapan, Michoacán, the disease caused the death of 100 100 Hass avocado trees (Andrade *et al*., 2017). According to Ochoa *et al*. (2015), 4 000 ha of avocado are affected by *P. cinnamomi*. Also, in Atlixco, Puebla, large avocado-producing areas have disappeared, Ochoa *et al*. (2015). Currently, Puebla, Chiapas, Veracruz, Nayarit, Morelos and Michoacán have this disease with different degrees of impact in orchards that produce this Lauraceae (Gómez, 2018). Ramírez (2018) mentions that, in avocado-producing areas of the Mexican Republic, they had an incidence of 5% of the avocado sadness disease.

Phytosanitary measures for the control of avocado sadness

For the control of the disease and increase the tolerance of the host during the critical period of infection, it is necessary to implement integrated management based on cultural, biological, genetic, physical and chemical control (Andrade *et al*. (2017). According to Ramírez *et al*. (2014), the application of species of microorganisms of the genera *Pseudomonas*, *Trichoderma* and mycorrhizal fungi has an effect of extermination on *P*. *cinnamomi* and progress in the growth of the avocado tree. In addition, the genus *Trichoderma* sp., has antagonistic properties for the control of *Phytophthora* sp., *Rhizoctonia* sp., *Sclerotium* sp., *Pythium* sp. and *Fusarium* sp., present in the soil, which cause fungal diseases (Andrade *et al*., 2017).

The mode of action of *Trichoderma* sp., is increased by direct competition with phytopathogens, for space and nutrients, production of volatile or non-volatile metabolites and parasitism (Andrade *et al*., 2017). The alternative of genetic improvement is based on obtaining avocado rootstocks tolerant to *P. cinnamomi* (Pérez *et al*., 2015). Also, tolerant materials are grafted onto landrace varieties such as *P. americana* var. *drymifolia*, S. F Blake, Duke 6, Duke 7 and Thomas, materials that are resistant to root diseases (Rincón *et al*., 2011).

Another alternative is physical control, where solarization is used to reduce the prevalence of the pathogen, it is based on removing the treetop at a height of 1.5 m, the trunk and branches are painted with salt, lime and water, the *cajete* (a border of soil around the plant) is cleaned of residues, the soil is leveled around the tree, within a radius of 4 m, immediately irrigation is applied to field capacity and finally black plastic of caliber 150 of 6 x 6 m is placed on the surface of the soil, from the center of the tree to the periphery, which allows the increase in temperature to 32 ° C and 65 ° C, in this sense, the greenhouse effect is lethal for the pathogen, likewise, the population of saprophytic microorganisms increases, which compete for space and antagonisms are generated for the phytopathogen (Flores, 2015).

In the cultural control, ridges of 0.5-1 m in height are made to increase the drainage of the water, this aims to ensure that the roots are in the soil and that it is not compacted (Sepúlveda *et al*., 2010). Among the main practices, adequate irrigation should be carried out to reduce excess moisture and avoid flooding of the planting hole or *cajete* of the crop (Sepúlveda *et al*., 2010). In chemical control, specific fungicides such as acylalanines or phenylamides are applied for pathogens of the kingdom Straminipila (Leal *et al*., 2014). The molecules destroy the development of *Phytophthora* sp., their mechanism of action is on DNA biosynthesis; however, there is a high risk of generating resistance, to prevent the oomycete from generating resistance to molecules, the combination with broad-spectrum fungicides Benalaxyl, Furalaxyl and Metalaxyl is suggested (Leal *et al*., 2014).

Phosphonates can also be applied, due to the mechanism of systemic action (Sepúlveda *et al*., 2010). In this group are fosetyl-al and phosphorous acid, which have shown effectiveness in foliage, soil and by injection into the tree for the control of *Phytophthora* sp., (Sepúlveda *et al*., 2010). Another of the treatments that can be applied are phosphites, their action is systemic, the application is by direct spraying on leaves, soil and it is also sought that the supply is by injection. Among the most outstanding benefits are root growth and plant height (Rodrígues *et al*., 2016).

Endotherapy

Faced with this phytosanitary problem, endotherapy is an alternative method of control and low environmental impact (Espinosa *et al*., 2013). The mechanism of action consists of the translocation and disposition of the specific ingredient aimed at the vascular bundles of the tree and the botanical structures colonized by the oomycete (Espinosa *et al*., 2013; Alayon *et al*., 2015). Endotherapy is a technique that begins in the Hellenistic era, it was used for therapeutic purposes from the mid-twentieth century (Estévez *et al*., 2011). According to García (2011), Endotherapy was used by Leonardo Da Vinci, in apple trees, who applied the first tests with arsenic and thus prevented the theft of the fruits (Estévez *et al*., 2011).

For 30 years, in regions of Asia, Latin America and Africa, endotherapy has been used successfully against pests and diseases in palm trees, also in date palms or coconut trees for the control of the red palm weevil (Estévez *et al*., 2011). In Egypt and the Gulf, this practice is applied for 20 years to date and in Spain for 10 consecutive years, it is a common tool for the control and management of the disease (Estévez *et al*. 2011). The application in the trees implies intervals of 30 s up to 10 min, the treatment is specific, it acts based on the capacity of sap flow that occurs inside the vascular tissues (xylem) (García, 2011).

To optimize the effectiveness of the technique, different micro and macro injection equipment have been designed, which have served for research, control and prevention of diseases and pests (Li and Nangong, 2021). The first technique consists of the application by microinjection (Doccola and Wild, 2012; Tanis and McCullough, 2016). The system uses an outlet nozzle or needle-type injector, low volume (1 to 3 ml) of systemic product is applied, in liquid presentation (Doccola and Wild, 2012; Tanis and McCullough, 2016). The hole is less than 4.9 mm in diameter and maximum depth of 30 mm (Doccola and Wild, 2012; Tanis and McCullough, 2016).

For each injection, air/hydraulic is applied with low pressure of 172 to 1 379 kilopascal (kPa) or 40 pounds per square inch (PSI) (Doccola and Wild, 2012; Tanis and McCullough, 2016). This system is injected into the sapwood and cambium tissues of the woody tissue, the uniformity of distribution of the product is in a few hours, which increases according to transpiration and is related to the loss of water; in addition, endotherapy reduces the risk of chemical leaks, spills and wounds in trees (Cibrián, 2021; Li and Nangong, 2021).

The macroinjection system has a metal cone at the tip of the injector, which allows holes of 9 mm and with a maximum depth of 70 mm to be made, in addition to using an expansion anchor valve; this technique injects greater volume during the application of the systemic treatment, prevents the product from spilling and potentially improves the translocation of the fungicide in the vascular bundles of the tree (Arriola *et al*., 2014; Tanis and McCullough, 2016; Cibrián, 2021). The system can last up to three years, because it has high precision, the volume of the product is reduced, the permeability is increased and the fungicide is absorbed with greater speed (Li and Nangong, 2021).

The infusion system method of flow by gravity or passive injection is also used, in this sense, the external pressure is not necessary, and the biological effectiveness will depend on the fungicide, which will be introduced to the vascular bundles (Cibrián, 2021). Finally, the implant system consists of perforating the epidermis and endodermis, until reaching the xylem and cambium of the host (Cibrián, 2021). In the conductor, an agar cover is embedded with the mixture of the systemic fungicide, the active ingredient is released through the water, which allows the translocation of the product to the affected area, that is, the product is released and translocated to the affected part of the tree (Cibrián, 2021).

Conclusions

Worldwide, the epidemiological behavior of *P. cinnamomi*, the causative agent of avocado sadness, is distributed in avocado-producing areas. The increase in the disease has grown exponentially, in addition, it is the main limitation of production of the crop *P.* a*mericana*. Given the phytosanitary situation expressed by avocado production, it is necessary to implement sustainable management alternatives, such as Endotherapy; through the injection of selective products in specific doses, which controls the disease, without affecting the quality and safety of the fruit.

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