

Pests and diseases of papaya (*Carica papaya* L.) cultivation on the Oaxaca Coast region: current state of knowledge

Plagas y enfermedades del cultivo de papaya (*Carica papaya* L.) en la región Costa de Oaxaca: situación actual del conocimiento

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RESUMEN

The state of Oaxaca is the leading producer of papaya nationwide, and the Oaxaca Coast region, the main producing region for the state. Papaya cultivation is frequently affected by various pests and diseases that occur throughout different phenological stages of the crop, including postharvest. This document provides an analysis of the phytosanitary conditions of papaya cultivation on the on the coast region of Oaxaca. Among the most economically important pests are phytophagous mites such as *Tetranychus urticae* and *Eotetranychus lewisi*, as well as insects, including whiteflies (*Aleurotrixus* sp. and *Trialeurodes* spp.) and aphids (*Aphis* spp. and *Myzus persicae*); root damage caused by root-knot nematodes (*Meloidogyne*) and wireworms (*Agriotes* sp.). Major diseases affecting papaya, include those caused by fungi and oomycetes, such as root rots (*Phytophthora*, *Fusarium*, and *Pythium*) and flower and fruit rots (*Colletotrichum* spp., *Asperisporium* spp., and *Phytophthora*); *Papaya ringspot virus* PRSV-P and bacterial rots caused by *Erwinia papayae* and *Pseudomonas* spp. Phytoplasmas from groups 16Srl (subgroup AF), 16SrX, and 16SrXIII, as well as rickettsia-like organisms associated with “Bunchy Top” disease, may pose a threat to the crop. Given the high diversity and prevalence of pests and diseases in papaya cultivation in the Oaxaca Coast region, further diagnostic studies and the development of integrated pest and disease management strategies are deemed necessary.

PALABRAS CLAVE: Mites, insects, fungi, viruses, *Carica papaya* L.

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ABSTRACT

El estado de Oaxaca es el principal productor de papaya a nivel nacional, y la Costa de Oaxaca, la principal región productora para el estado. Frecuentemente, la producción es afectada por diversas plagas y enfermedades que se presentan en diferentes etapas fenológicas del cultivo, incluso en postcosecha de los frutos. El presente escrito brinda un análisis de la fitosanidad del cultivo de papaya en la Costa de Oaxaca. Entre las plagas de mayor importancia económica, se encuentran los ácaros fitófagos como *Tetranychus urticae* y *Eotetranychus lewisi*, insectos como las moscas blancas (*Aleurotrixus* sp. y *Trialeurodes* spp.) y pulgones (*Aphis* spp. y *Myzus persicae*); daños en la raíz por nematodos agalladores (*Meloidogyne*) y gusanos de alambre (*Agriotes* sp.). Dentro de las principales enfermedades de la papaya, se encuentran las causadas por hongos y oomicetos, como pudriciones de raíz (*Phytophthora*, *Fusarium* y *Pythium*) y pudriciones en flor y fruto (*Colletotrichum* spp., *Asperisporium* spp., y *Phytophthora*); la virosis o chino de la papaya causada por el *Papaya ringspot virus* (PRSV-P) y pudriciones bacterianas causadas por *Erwinia papayae* y *Pseudomonas* spp. Los fitoplasmas de los grupos 16Srl (subgrupo AF), 16SrX y 16SrXIII y las rickettsias asociadas a la enfermedad del “Bunchy Top” también pueden ser una amenaza para el cultivo. Dada la gran diversidad y prevalencia de las plagas y enfermedades del cultivo de papaya en la Costa de Oaxaca, se considera necesario realizar más estudios de diagnóstico y manejo integrado de plagas y enfermedades.

KEY WORDS: Ácaros, insectos, hongos, virus, *Carica papaya* L.

Introduction

Papaya (*Carica papaya* L.), a member of the Caricaceae family, is a tropical and subtropical crop. Its fruit is widely consumed due to its high nutritional value and the presence of bioactive compounds (Jiao *et al.*, 2023). Papaya ranks as the third most cultivated tropical crop worldwide, with Mexico being the leading exporter of this fruit (Chávez-Pesqueira & Núñez-Farfán, 2017). At the national level, according to SIAP (2023), 1,148,545.61 t were produced; the state of Oaxaca being the main producer (318,322.69 t), followed by Colima (204,924.25 t), Chiapas (160,251.56 t), Michoacán (122,420.73 t) and Veracruz (121,627.57 t). In particular, the Oaxaca Coast region (15°51'43"N 97°04'02"W) accounts for 95 % of the state's total papaya production, contributing significantly to the state's economy (Alfaro *et al.*, 2023; SIAP, 2023). This region is considered to produce the highest-quality papayas in the country, and its fruit is among the most sought-after for export to the United States.

The environmental conditions required for papaya cultivation—namely, high humidity and temperature—favor the proliferation of pests and diseases (Ventura et al., 2004). Among the most significant pests are mites, especially the immature stages of the crystalline mite or crystalline spider (*Eotetranychus lewisi*) and the two-spotted spider mite (*Tetranychus urticae*), which show higher incidence during warmer seasons (Ovando-Cruz et al., 2007; Otero-Colina, 2016). Whiteflies are also of economic importance, with *Aleurotrixus* sp. (Otero-Colina et al., 2016), *Trialeurodes* spp. (Culik & Martins, 2004; Ortega-Arenas & Ruiz, 2020) and *Bemisia tabaci* (Guo et al., 2015), these last two are the most important due to their ability to transmit viruses. Other phytopathogen-vector insects in papaya include aphids such as *Aphis* spp. and *Myzus persicae* (Rivera-Engracia, 2023), which can transmit *Papaya ringspot virus* (PRSV-P) and the papaya leafhopper (*Empoasca* sp.), a potential vector of viruses and phytoplasmas (Pérez et al., 2010; Acosta et al., 2017; García-Cámara et al., 2019).

Plant-parasitic nematodes represent a serious threat to papaya cultivation; species of *Meloidogyne* have been reported in papaya cultivation in the states of Morelos, Michoacán, and Colima (Cid del Prado et al., 2001). Additionally, Martínez-Gallardo et al. (2014) reported the presence of other nematode genera associated with the crop, including *Aphelenchus*, *Ditylenchus*, *Helicotylenchus*, *Paratylenchus*, *Pratylenchus*, *Rotylenchulus*, *Rotylenchus*, *Trophurus*, *Tylenchorrhynchus*, and *Tylenchus*. In addition to nematodes, another harmful root organism is the wireworm (*Agriotes* sp.), which feeds on plant roots and creates entry points for soilborne phytopathogens by causing wounds (Ovando-Cruz et al., 2007).

Diseases caused by fungi and oomycetes pose a significant challenge in papaya production. Among the most devastating fungal diseases is anthracnose, caused by *Colletotrichum* spp., which primarily affects postharvest fruit (Zakaria, 2021). Root, stem, and fruit rots caused by *Phytophthora* spp. (Nelson, 2008), apical rot or peduncle rot caused by *Lasiodiplodia* spp. (Wang et al., 2007; Netto et al., 2014), and leaf spots caused by *Asperisporium* sp. (Shetty et al., 2021) and *Corynespora cassiicola* (Vawdrey et al., 2008) can also seriously impact papaya production. The PRSV-P, commonly known as “chino de la papaya” in Mexico, is one of the most economically important viral diseases affecting papaya worldwide (Castro et al., 2004). This virus affects leaf tissues and compromises fruit quality. Under conditions of high relative humidity, papaya is also highly susceptible to bacterial infections; in this context, *Erwinia papayae* and *Pseudomonas* spp., have been reported as the primary bacterial pathogens of the crop (Gardan et al., 2004). More recently, phytoplasmas from groups 16SrI (subgroup AF), 16SrX, and 16SrXIII have been identified in papaya plants affected by Bunchy Top disease (Valadez-Ramírez et al., 2024). Additionally, *Rickettsia bellii* has been reported to be associated with this disease (Valadez-Ramírez et al., 2025).

Due to the vast diversity of pests and diseases, the adaptive potential of phytopathogens to current climatic variations, the emergence of new, more aggressive pathogen races, and their dispersal either naturally or through human activities, papaya production has been significantly affected in recent years in the Oaxaca Coast region (Ramos et al., 2007). According to SIAP, papaya production in Oaxaca increased steadily from 2017 to 2022. However, in 2023, a decline was observed, with production dropping from 350,195 t in 2022 to 301,009 t in 2023, representing a decrease of 49,186 t.

Hitherto, only one publication specifically addresses papaya production in the Oaxaca Coast region (Ovando-Cruz *et al.*, 2007). Therefore, the present study provides an updated overview of the current state of knowledge regarding the pests and diseases associated with papaya cultivation in this region.

Discussion

Papaya crop conditions

Papaya (*C. papaya* L.) is a Mesoamerican species with wide distribution across tropical and subtropical regions. It belongs to the Caricaceae family, which comprises six genera and 35 species. These genera include: *Carica* (1 species), *Jarilla* (3 species), *Horovitzia* (1 species), *Jacaratia* (7 species), *Vasconcellea* (21 species), and *Cylicomorpha* (2 species) (Fuentes & Santamaría, 2013). Papaya is primarily cultivated in regions with optimal average temperatures between 24 and 30 °C and at altitudes not exceeding 400 msnm. The crop requires deep, fertile loamy soils with consistent moisture levels, a pH range between 6.0 and 7.5, and an average annual rainfall of approximately 1,800 mm. Papaya is highly sensitive to flooding, with soil saturation for more than 48 hours leading to root damage and plant collapse (Ovando-Cruz *et al.*, 2007). The environmental conditions required for papaya cultivation, namely high humidity and temperature, also promote the development of insects, mites, nematodes, fungi, oomycetes, viruses, and bacteria.

Papaya production

The cultivation of *C. papaya* is a highly profitable and socially important activity worldwide, as it is the third-most-consumed tropical fruit globally (Alfaro *et al.*, 2023). Its widespread consumption as a fresh fruit is mainly due to its high nutritional and digestive value (Aguilar-Carpio *et al.*, 2019). Papaya is primarily cultivated in tropical and subtropical regions; the leading papaya-producing countries are: India (5,341,000 t/year), the Dominican Republic (1,281,726 t/year), Mexico (1,139,121 t/year), Brazil (1,107,761 t/year), and Indonesia (1,089,578 t/year) (FAOSTAT, 2022). Mexico is the world's largest exporter of papaya (Aguilar-Carpio *et al.*, 2019). Nationally, the main papaya-producing states are Oaxaca (318,322.69 t/year), Colima (204,924.25 t/year), Chiapas (160,251.56 t/year), Michoacán (122,420.73 t/year), and Veracruz (121,627.57 t/year). Oaxaca is the top papaya-producing state in the country, and its Coast region is the most productive area within the state (Alfaro *et al.*, 2023; SIAP, 2023).

In the Oaxaca Coast region, approximately 2,680.50 ha of papaya are cultivated, with yields ranging from 112.85 to 116.53 t ha⁻¹ and an annual production of 301,009 t (Alfaro *et al.*, 2023; SIAP, 2023). However, in recent years, papaya production in the region has been negatively impacted by various pests and diseases. In 2023, production decreased by 14% compared to 2022 (Figure 1).

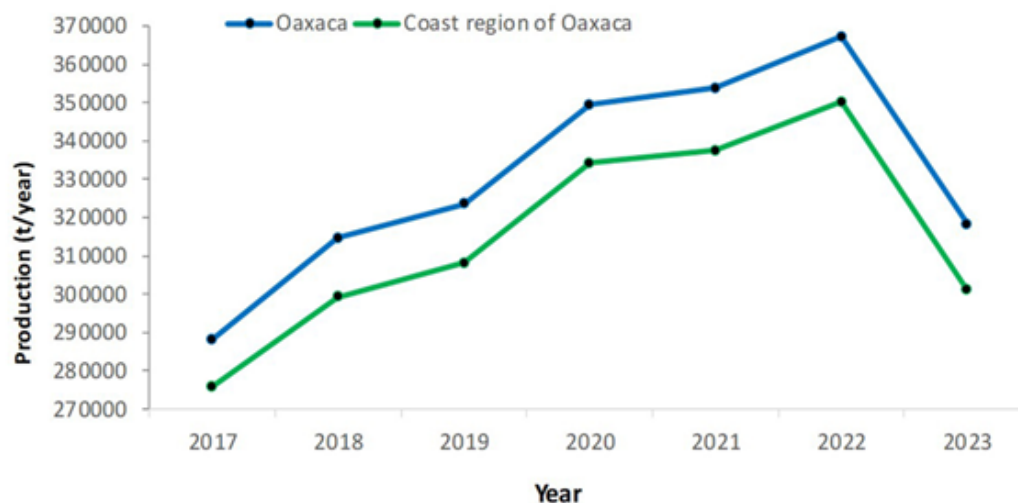


Figure 1. Papaya production in the state of Oaxaca and the Oaxaca Coast region, 2017-2023 cycle.

SIAP, 2023

Major pests and diseases affecting papaya cultivation

Mite damage

Papaya crops can be affected by a wide diversity of phytophagous mites (Abato-Zárate et al., 2014). The main mite species reported on papaya in Mexico include: *Tetranychus urticae*, *T. merganser*, *Eutetranychus banksi*, *Calacarus citrifolii*, *Eotetranychus lewisi*, and *Polyphagotarsonemus latus* (Valencia, 2011; Reyes-Pérez et al., 2013; Abato-Zárate et al., 2014; Otero-Colina, 2016). Papaya producers on the coast of Oaxaca have reported severe damage from the crystal spider mite, mainly during the flowering stage and periods of high temperatures; however, no scientific report has been made on the mite fauna associated with the crop in the region. Phytophagous mites feed on leaves, reducing photosynthesis and transpiration. This physiological stress negatively impacts plant growth, fruit development, and overall yield (Abato-Zárate et al., 2014; Otero-Colina, 2016) (Figure 2). Mite control can be achieved by applying chemical acaricides such as clofentezine, abamectin, fentbutatin oxide, hexythiazox, and vegetable oils (e.g. soybean) (Reyes-Pérez et al., 2015). Since weeds present in papaya crops can serve as reservoirs for mites, proper weed management is essential. Biological control using predatory mites is a viable alternative; species such as *Neoseiulus idaeus*, *Euseius hibisci*, *Galendromus helveolus*, and *Phytoseiulus persimilis* have been used with promising results (Abato-Zárate et al., 2012; Mena et al., 2020). Additionally, entomopathogenic fungi such as *Paecilomyces*

fumosoroseus, *Beauveria bassiana*, and *Metarhizium anisopliae* represent another effective strategy for managing phytophagous mites (Shi & Feng, 2004; El-Sharabasy, 2015; Herrera-Palacios *et al.*, 2018).

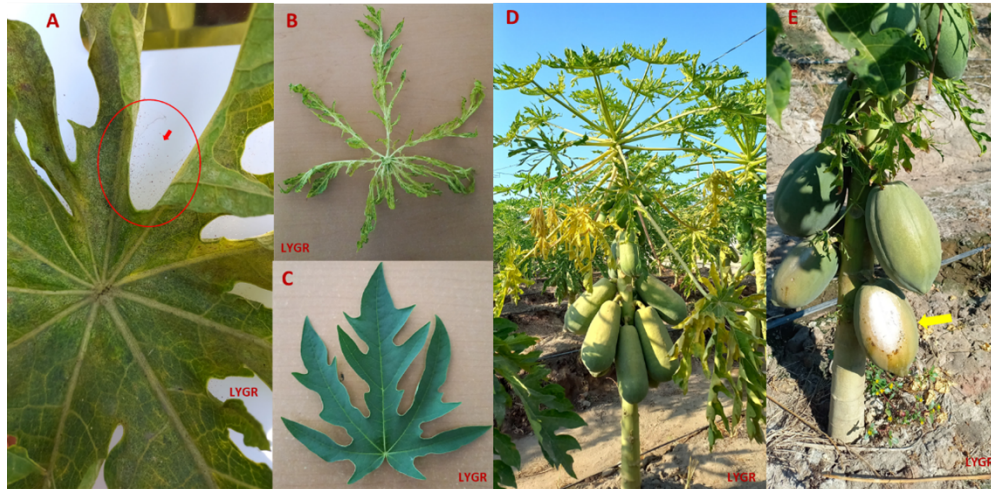


Figure 2. Symptoms of mite damage on *Carica papaya* L. leaves in the Oaxaca Coast region.

A) Red spider mite on papaya leaves (red circle and arrow indicate the presence of red spider mite individuals and webbing), B) papaya leaf damaged by crystalline spider mite, C) papaya leaf without mite damage, D) reduction of leaf area in papaya caused by crystalline spider mite, and E) damage to papaya fruit (yellow arrow) from sunburn.

Whiteflies

Whiteflies (Hemiptera: Aleyrodidae) cause damage to plants both through direct feeding and by transmitting phytopathogenic viruses (Ortega-Arenas & Ruiz, 2020). The main viruses they transmit belong to the geminivirus, carlavirus, closterovirus, and potyvirus groups (Ortega-Arenas & Ruiz, 2020). The most important genera associated with papaya cultivation are *Aleurotrixus* sp. (Otero-Colina *et al.*, 2016), *Trialeurodes* spp. (Culik & Martins, 2004; Ortega-Arenas & Ruiz, 2020) Furthermore, *Bemisia tabaci*, the latter two being of most significance due to their ability to transmit viruses such as *Papaya meleira virus* (PMeV) (Abreu *et al.*, 2015) and *Papaya leaf curl China virus* (PaLCuCNV) (Guo *et al.*, 2015).

Generally, most whiteflies are polyphagous and are known to have over 600 host plant species, both cultivated and wild (Ortega-Arenas & Ruiz, 2020). Papaya producers in the Oaxaca Coast region have observed whitefly damage throughout the crop cycle, particularly from November to May. High whitefly populations excrete large amounts of honeydew on leaves, which promotes the development of fungal diseases such as sooty mold and negatively affects

plant photosynthesis (Otero-Colina *et al.*, 2016). For its control, foliage is sprayed with bifenthrin, imidacloprid, and flupyradifurone (Ovando-Cruz *et al.*, 2007; Sani *et al.*, 2020), as well as the use of entomopathogenic fungi of the genera *Verticillium*, *Isaria*, and *Aschersonia* and parasitoids such as *Encarsia* and *Eretmocerus* (Sani *et al.*, 2020).

Aphids

Aphids (Hemiptera: Aphidoidea), commonly known as “pulgonos” in México, cause significant damage to agriculture worldwide, mainly because they act as vectors of phytopathogenic viruses (Guillén-Sánchez *et al.*, 2018). Approximately 4,700 aphid species have been described globally, with 202 species present in Mexico, of which 53 are considered economically important in Mexican agriculture (Santiago *et al.*, 2023). In papaya, their major importance stems from their role as vectors of PRSV-P. Martins *et al.* (2016) reported 21 aphid species as PRSV-P vectors, with *Aphis gossypii*, *A. coreopsidis*, *Myzus persicae*, and *Toxoptera citricidus* being the most efficient virus transmitters. For control, the use of yellow sticky traps is recommended mainly for pest monitoring (Bravo-Portocarrero *et al.*, 2020), alongside the deployment of natural enemies such as parasitoids (*Aphelinus* spp.) and predators (*Chrysoperla carnea*), as well as entomopathogenic fungi (*Lecanicillium lecanii*, *Metarhizium anisopliae*, and *Beauveria bassiana*) (Vu *et al.*, 2007; Cruz, 2015). For chemical control, according to Kalleshwaraswamy *et al.* (2012) and Osorio-Acosta *et al.* (2016), imidacloprid and deltamethrin can cause up to 100% mortality of aphids, while pymetrozine has the potential to prevent virus transmission in plants. Other control alternatives are the use of plant extracts of rue (*Ruta graveolens*), onion (*Allium cepa*), flower of death (*Tagetes* sp.), mint (*Mentha pulegium*) (Vélez-Ruiz *et al.*, 2022), and neem oil (*Azadirachta indica*) (Kalleshwaraswamy *et al.*, 2012).

Papaya leafhopper (*Empoasca* sp.)

The papaya leafhopper, belonging to the family Cicadellidae, is commonly known as a leafhopper or “chicharritas” (Arroyo *et al.*, 2015). It is an insect that feeds on the sap of papaya leaves, causing small yellowish spots at feeding sites. Leafhoppers have been detected as vectors of phytoplasmas and viruses in papaya plants. *Empoasca papayae* can transmit phytoplasmas and rickettsias responsible for Bunchy Top disease (curled apical growth) (Pérez *et al.*, 2010; Acosta *et al.*, 2017) and is also a vector of the Mexican variant of *Papaya meleira virus* (García-Cámara *et al.*, 2019). For its control, some biorational products such as plant extracts from *Azadirachta indica*, *Allium sativum*, *Phytolacca* spp., *Syzygium aromaticum*, *Spartina* spp., and *Cymbopogon* spp. have been evaluated (Pérez-Cacho *et al.*, 2021). Chemical control involves the use of imidacloprid, thiamethoxam, bifenthrin, deltamethrin, and cypermethrin, among others (Pimentel, 2002), which have shown good efficacy against this pest.

Nematode damage in papaya

Phytoparasitic nematodes cause considerable economic losses in agriculture worldwide, amounting to over \$157 billion dollars annually (Lilley *et al.*, 2024). In Mexico, damage caused by phytopathogenic nematodes has been reported in fruit and vegetable crops (Cid del Prado *et*

al., 2001; Martínez-Gallardo *et al.*, 2014). In papaya crops, species of the genus *Meloidogyne* have been reported in the states of Morelos, Michoacán, and Colima (Cid del Prado *et al.*, 2001). Martínez-Gallardo *et al.* (2014) also reported other genera associated with papaya cultivation, including *Aphelenchus*, *Ditylenchus*, *Helicotylenchus*, *Paratylenchus*, *Pratylenchus*, *Rotylenchulus*, *Rotylenchus*, *Trophurus*, *Tylenchorrhynchus*, and *Tylenchus*. The primary symptoms observed in nematode-infected papaya plants include stunted growth, leaf chlorosis, and leaning plants or uprooted plants due to nematode damage or secondary fungal infections entering through nematode-induced wounds (Gavilánez, 2024). In the case of *Meloidogyne* sp., and *Rotylenchus* sp., root galls and necrosis can be observed (Peraza-Padilla, 2021; Gavilánez, 2024). Nematode control is carried out using chemical nematicides such as fluopyram and fluazaindolizina (Schleker *et al.*, 2022), cultural practices like soil solarization and flooding prior to crop establishment, resistant varieties, and biological control through nematode–antagonistic microorganisms such as *Pochonia chlamydosporia* (Coutinho *et al.*, 2009) and plant extracts (Andrés, 2002).

Wireworm (*Agriotes* spp.)

Agriotes spp., belonging to the family Elateridae, is considered to be present throughout Mexico in all areas planted with host crops (DGSV-CNRF, 2020). The beetle's larval stage causes the damage. These insects generally have long life cycles, ranging from 2 to 5 years depending on environmental conditions (Zurita-García *et al.*, 2014). It has been reported that each adult female lays between 75 and 100 eggs in the soil surface layer. Once the eggs hatch, the larvae begin to search for seeds and roots to feed on. Since wireworms require several years to complete their development cycle and reach the adult beetle stage, many infested fields may harbor high larval populations at various developmental stages and multiple species coexisting if proper control measures are not implemented (DGSV-CNRF, 2020; Furlan *et al.*, 2021). The larvae mainly feed on grasses such as corn; however, in some cases, they can become the primary pest in papaya crops (Ovando-Cruz *et al.*, 2007; DGSV-CNRF, 2020). Recent changes in the distribution of wireworm populations and the availability of effective insecticides have led to the search for alternative management strategies, such as biological control through entomopathogenic fungi (*Beauveria bassiana* and *Metarhizium anisopliae*) (Ritter & Richter, 2013) and entomopathogenic nematodes (*Steinernema* spp., and *Heterorhabditis* spp.) (Morton & Garcia-del-Pino, 2017; Öğretmen *et al.*, 2020; Kabaluk *et al.*, 2024). For chemical control of the wireworm, chlorpyrifos, bifenthrin, and imidacloprid, among other active compounds, have been used (Van Herk *et al.*, 2015).

Anthraxnose (*Colletotrichum* spp.)

Anthraxnose is a disease caused by the fungus *Colletotrichum* spp., which can affect a wide variety of hosts, including legumes, cereals, vegetables, and fruit trees (Torres-Calzada *et al.*, 2013). Papaya is one of the crops most affected by anthracnose, which can manifest in both field-grown plants and postharvest fruits (Figure 3) (García-Mateos *et al.*, 2021). Losses of more than 50% have been reported in affected crops (Torres-Calzada *et al.*, 2013). In Mexico, anthracnose in papaya is caused by *C. gloeosporioides* and *C. capsici*. Recently, *Colletotrichum brevisporum* was reported as the causal agent of anthracnose disease in papaya var. Maradol fruits cultivated

in the Oaxaca Coast region (Pacheco-Steva *et al.*, 2023). Disease management is mainly carried out through chemical fungicides such as chlorothalonil, azoxystrobin, mancozeb, thiabendazole, prochloraz, among others (Santamaría-Basulto *et al.*, 2011).

Biological products have also been evaluated for disease control during flowering and postharvest stages, including plant extracts (García-Mateos *et al.*, 2021) and antagonistic microorganisms such as *Trichoderma* spp., and *Bacillus* spp., (Valenzuela *et al.*, 2015; Nigro *et al.*, 2018), which can act through antibiosis, competition, and mycoparasitism (Aquino-Martínez *et al.*, 2008; Helal & Shamsi, 2019). It has been described that *Trichoderma viride* (Valenzuela *et al.*, 2015) and *Penicillium rolsii* (Lv *et al.*, 2024) reduce infection and colonization by *C. gloeosporioides* in postharvest papaya fruits. García-Mateos *et al.* (2021) they observed that methanolic extract of *Phytolacca icosandra* showed 60-70 % biological effectiveness against anthracnose during the flowering stage in papaya and 71.4% effectiveness in postharvest fruits.

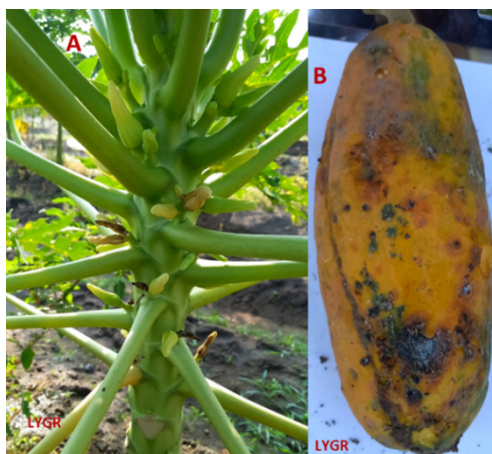


Figure 3. Symptoms associated with anthracnose in *Carica papaya* L. in the Oaxaca Coast region.

A) Flower rot. B) Fruit rot, showing sunken, moist lesions.

Root, stem, and fruit rot caused by *Phytophthora* spp.

The genus *Phytophthora* is capable of infecting all parts of the papaya plant, causing root, stem, and fruit rot, as well as leaf blight and seedling wilting (Nelson, 2008). The main species detected in papaya are *P. palmivora* (Sukhada *et al.*, 2011; Rodríguez-Alvarado *et al.*, 2020), *P. parasitica* (Hunter & Buddenhagen, 1969), and *P. nicotianae* (Roberts & Trujillo, 1998). *Phytophthora* occurs more during the rainy season (Sukhada, 2011). Symptoms in young fruits include lesions with abundant moisture that exude a milky latex; these fruits may eventually

mummify and fall off. In mature fruits, the disease begins as small, circular, moist lesions. Larger lesions may develop, typically starting at the fruit base where it contacts the stem, covered with white mycelium and masses of *Phytophthora* sporangia. Subsequently, the fruits tend to rot and drop prematurely. Stems may develop cankers, making plants more susceptible to wind damage or fruit load (Nelson, 2008). Roots of plants younger than three months, especially in poorly drained soils, are more susceptible to *Phytophthora* rot; roots become dark and begin to decay, causing stunted plant growth, leaf yellowing, and collapse (Roberts & Trujillo, 1998; Nelson, 2008). In severe infections, plants die and tend to fall due to fruit load, and those with rotted roots are more vulnerable to drought (Nelson, 2008).

In the Oaxaca Coast region, papaya fruits with typical *Phytophthora* symptoms have been observed; however, the pathogen has not yet been isolated for identification (Cruz-Vázquez *et al.*, 2016). For control, it is suggested to remove contaminated fruit, avoid overwatering, and maintain good soil drainage in orchards. For chemical and preventative control, applications of potassium phosphites and silicon are used. Curative products include metalaxyl, metiram + pyraclostrobin and chlorothalonil, among others (Vawdrey *et al.*, 2015).

Peduncle rot (*Lasiodiplodia* spp.)

Apical rot or peduncle rot of papaya is caused by the fungus *Lasiodiplodia* spp., a highly destructive disease (Wang *et al.*, 2007; Netto *et al.*, 2014). It can occur during fruit development and after harvest, causing significant production losses. The high incidence of the disease in preharvest fruit may be influenced by high rainfall, temperatures above 30 °C, water stress, and low plant nutrition levels (Netto *et al.*, 2014; Chen *et al.*, 2020). Disease symptoms generally start with rot at the papaya peduncle and progress throughout the fruit. Postharvest, the disease appears on the cut end of the peduncle, affecting the fruit base (Netto *et al.*, 2014). Initial lesions caused by *L. theobromae* are diffuse, watery, and present a wrinkled surface due to the eruption of pycnidia around the peduncle. In some cases, superficial mycelium may appear around the peduncle along with a brown watery exudate (Picos-Muñoz *et al.*, 2015). For the biological control of *L. theobromae* in papaya, microorganisms such as *Bacillus subtilis* Y1336, *Streptomyces candidus* Y21007-2, and *Trichoderma* spp., have been evaluated, which are an alternative for disease management (Wang *et al.*, 2007; Bedine *et al.*, 2022). Chemical control is carried out using fungicides such as tebuconazole, thiabendazole, prochloraz, and imazalil (da Silva *et al.*, 2012).

Black spot or black speck (*Asperisporium caricae*)

Among emerging diseases in papaya, black spot caused by *A. caricae* is considered the most lethal; it was first detected on papaya leaves and fruits in 1992 in Sri Lanka (Adikaram & Wijepala, 1995). The disease is most severe under temperatures between 23 and 27 °C and high rainfall or sprinkler irrigation conditions (Shetty *et al.*, 2021). The primary symptom is the presence of irregular black spots on the abaxial surface of leaves, usually beginning on older leaves and later spreading to younger ones. Fruits may also show symptoms, although the number of black spots is generally lower than on foliage. On the adaxial (upper) leaf surface, early lesions appear

round or somewhat angular, light brown with a yellow halo, dark margins, and abundant moisture (Shetty *et al.*, 2021). Later, lesions become necrotic, turning whitish–gray or dry beige spots (Shantamma *et al.*, 2018; Ventura *et al.*, 2004). Both leaf and fruit lesions may be covered with masses of bicellular black spores of the fungus, appearing as dark dots, and pustules can cover the entire lesion (Shetty *et al.*, 2021). These lesions reduce the photosynthetic area, affecting the commercial value of fruits and causing leaf senescence and defoliation (Ventura *et al.*, 2004; Gabrekiristos & Dagneu, 2020; Shetty *et al.*, 2021).

For disease management, the application of fertilizers and micronutrients based on soil analysis is recommended, along with seedling dip treatments and foliar sprays of *Trichoderma viride* (5 g L⁻¹), sprays with mancozeb, difenoconazole, chlorothalonil, or propiconazole and hexaconazole (Shetty *et al.*, 2021).

Papaya ringspot virus

The main viruses affecting papaya cultivation include: *Papaya leaf distortion mosaic virus* (PLD-MV), *Papaya lethal yellowing virus* (PLYV), *Papaya mosaic virus* (PapMV), *Papaya meleira virus* (PMeV), and *Papaya ringspot virus* (PRSV-P) (Abreu *et al.*, 2015). Papaya ringspot disease ranks among the most economically damaging viral infections affecting papaya cultivation (Castro *et al.*, 2004). It is caused by PRSV-P, which can be non-persistently transmitted by more than 21 aphid species, including *Aphis gossypii*, *A. spiraecola*, *A. nerii*, *Myzus persicae*, and *Macrosiphum euphorbiae* (Castro *et al.*, 2004; Cortez-Madriral & Mora-Aguilera, 2008). PRSV-P belongs to the family Potyviridae, genus Potyvirus. Symptoms caused by the virus include mosaic patterns, chlorosis, leaf distortion, and ring-shaped spots on the fruit (Figure 4). PRSV-P can cause losses ranging from 50 to 90% in the field and 30 to 40% in postharvest fruits (Bermúdez-Guzmán *et al.*, 2018). PRSV-P has been reported to affect papaya cultivation in the Oaxaca Coast region (Noa-Carranza *et al.*, 2006), with the Maradol variety being the most widely cultivated and affected by this pathogen. Control strategies for the virus include biological and chemical control of the vector, use of natural barriers such as maize (*Zea mays*), sorghum (*Sorghum* spp.) and hibiscus (*Hibiscus sabdariffa*) (Rivas-Valencia *et al.*, 2008; Mederos *et al.*, 2013), use of yellow sticky traps (Cortez-Madriral & Mora-Aguilera, 2008; Osorio-Acosta *et al.*, 2016), deployment of virus-resistant varieties (Ordaz-Pérez *et al.*, 2017), weed management, removal of diseased plants and nursery management using anti-aphid mesh (Mederos *et al.*, 2011).



Figure 4. Typical symptoms of *Papaya ringspot virus* in the Oaxaca Coast region.

A) "Chino" or leaf curling symptoms on leaves and shoots. B) Papaya fruits showing characteristic ring-shaped spots.

Sticky disease or meleira of papaya

Papaya meleira virus (PMeV) is the causal agent of meleira, also known as sticky disease of papaya. Reports of PMeV in papaya orchards have been documented in the Oaxaca Coast region (Perez-Brito *et al.*, 2012). Currently, the disease incidence in this area is low; however, it is considered necessary to describe the disease in this work given that there is a risk of higher incidences in the coming years. This virus can cause considerable yield losses in papaya crops in relatively short periods of time. In Brazil, disease incidence can reach 100%, resulting in total yield losses in papaya orchards (Abreu *et al.*, 2015). To date, PMeV has been reported to be transmitted by seed (Tapia-Tussell *et al.*, 2015), mechanical transmission via contaminated latex through agricultural practices, the leafhopper *Empoasca papayae* (García-Cámara *et al.*, 2019) and whiteflies (Abreu *et al.*, 2015). The main symptoms of the disease are the spontaneous exudation of fluid, translucent latex from papaya fruits and the subsequent oxidation of this latex on the fruit surface, which qualitatively affects the commercial value of the fruits (Tapia-Tussell *et al.*, 2015; Magaña-Álvarez *et al.*, 2016). Currently, there is no chemical or genetic control for the disease; the only alternative is cultural practices, which have proven effective (Ventura *et al.*, 2004). These include using pathogen-free planting material, establishing orchards away from infected plots, removing symptomatic plants, effective pest and weed control (which can act as pathogen hosts), disinfecting tools used during cultural practices and harvesting and minimizing plant injuries during crop management (Abreu *et al.*, 2015).

Bacteria and phytoplasmas

During the rainy season, a high incidence of bacteria such as *Erwinia* spp., and *Pseudomonas* spp., may occur. Gardan *et al.* (2004) were the first to describe *E. papayae* as the causal agent of bacterial canker in papaya. Symptoms include oily and water-soaked lesions and spots on leaves that become angular, as well as firm and watery cankers that can cause plant collapse. Other *Erwinia* species infecting papaya include *E. psidii* (Chai *et al.*, 2017) and *E. mallotivora*, which cause regressive death of papaya, typical symptoms of these diseases include greasy and watery lesions on stems and brown spots on leaves without cankers on the stems. Additionally, *Pseudomonas syringae* pv. *tabaci* has been reported to cause foliar spots on papaya seedlings (Beriam *et al.*, 2006).

On the other hand, the “Bunchy Top” disease, which can be associated with the presence of phytoplasmas, rickettsias, or viruses, can significantly affect papaya production (Arocha *et al.*, 2009; Valadez-Ramírez *et al.*, 2024). In plants affected by the disease, internode shortening is observed, causing the apical leaves to curl. In addition, chlorosis, yellowing, deformation, or marginal necrosis of the leaves may occur (Acosta *et al.*, 2013; Valadez-Ramírez *et al.*, 2024). Recently, phytoplasmas of the 16SrI (subgroup AF), 16SrX, and 16SrXIII groups and *Rickettsia bellii* were reported in papaya plants with Bunchy Top symptoms in commercial plantations in Mexico (Valadez-Ramírez *et al.*, 2024; Valadez-Ramírez *et al.*, 2025). The leafhopper *Empoasca papayae* (Hemiptera: Cicadellidae) has been reported to be a simultaneous vector of phytoplasmas and rickettsias associated with the Bunchy Top symptom (Acosta *et al.*, 2017).

For bacterial disease control in papaya, the use of antagonistic microorganisms has been studied. Mohd *et al.* (2019) observed that application of the bacterial consortium *Weissella cibaria* and *Lactococcus lactis* subsp. *lactis* PPSSD39 significantly reduced the severity of papaya regressive death caused by *Erwinia mallotivora*. The use of antibiotics such as oxytetracycline and streptomycin can help control bacterial diseases (Hanagasaki *et al.*, 2023). Since weeds are an important reservoir of phytoplasma and rickettsia inoculum, reasonable control of these, as well as of vector insects (Hemiptera: Cicadellidae), could help reduce the incidence of bacterial diseases in papaya crops (Arocha *et al.*, 2007).

Health of papaya crops on the Oaxaca Coast region

Over the years, farmers and technical advisors have developed skills to detect plant pests and diseases through experience. Various pests and diseases associated with papaya cultivation in the coast region of Oaxaca have been reported through personal communications from producers, technical advisors, regional forums, and technical leaflets (Ovando-Cruz *et al.*, 2007). However, few studies have conducted a robust and scientifically rigorous identification of the causal agents of diseases or damage associated with the crop (Table 1).

Table 1. Diagnoses of phytopathogens associated with papaya cultivation in the Oaxaca Coast region.

Pathogen	Disease	Symptoms	Reference
<i>Gilbertella persicaria</i>	Papaya Soft Rot	Fruits exhibit lesions with a wet appearance, approximately 1 cm in diameter, accompanied by the presence of white mycelium and sporangia. Subsequently, abundant mycelia and sporangia develop, ranging in color from light brown to dark brown and gray to black.	Cruz-Lachica <i>et al.</i> , (2017)
<i>C. brevisporum</i>	Anthrachnose	Sunken, water-soaked lesions with masses of salmon-colored conidia on the surface of the papaya fruit.	Pacheco-Esteva <i>et al.</i> , (2023)
<i>C. chrysophilum</i>	Anthrachnose	Small water-soaked lesions on the fruit surface that later expanded into sunken, circular lesions with translucent light brown margins.	Pacheco-Esteva <i>et al.</i> , (2022b)
<i>C. siamense</i>	Anthrachnose	Sunken necrotic lesions on fruits.	Pacheco-Esteva <i>et al.</i> , (2022a)
<i>C. fructicola</i>	Anthrachnose	Fruits with small lesions have sunken, irregular edges and sporulation ranging from white to gray.	Marquez-Zequera <i>et al.</i> , (2018)
<i>Papaya ringspot virus</i> (PRSV)	Virosis or 'chino' disease of papaya	Yellowing of new leaves and a "cupped" or "rolled" appearance, later becoming thin (leaf thinning) with mottling. Elongated, oily-looking spots on leaf petioles and stems. Fruits showing rings or half-moon-shaped oily spots that later turn gray or silvery.	Noa-Carrazana <i>et al.</i> (2006)
<i>Papaya meleira virus</i> (PMeV)	Sticky or "meleira" disease of papaya	Spontaneous or wound-induced exudation of latex from the fruits, with a greater fluidity compared to the typical milky latex found in healthy plants; this latex oxidizes and turns black, which is the most common symptom of meleira. Necrosis at the tips of young leaves.	Perez-Brito <i>et al.</i> , (2012)

Surveys conducted with papaya growers in the Oaxaca Coast region during 2024-2025, found that mites are currently the most economically significant pest in the crop, generally appearing during hot seasons and at any phenological stage of the plants. Regarding diseases, given the climatic conditions such as high relative humidity and temperature present in the region, rots caused by fungi and oomycetes are recurring problems throughout the crop cycle, as well as a high incidence of the disease regionally known as "chino de la papaya," which is caused by the PRSV-P. It is considered that the main effects caused by pests and diseases associated with

papaya cultivation on the Oaxaca Coast are low production, followed by increases in investment costs and low fruit quality (Figure 5).

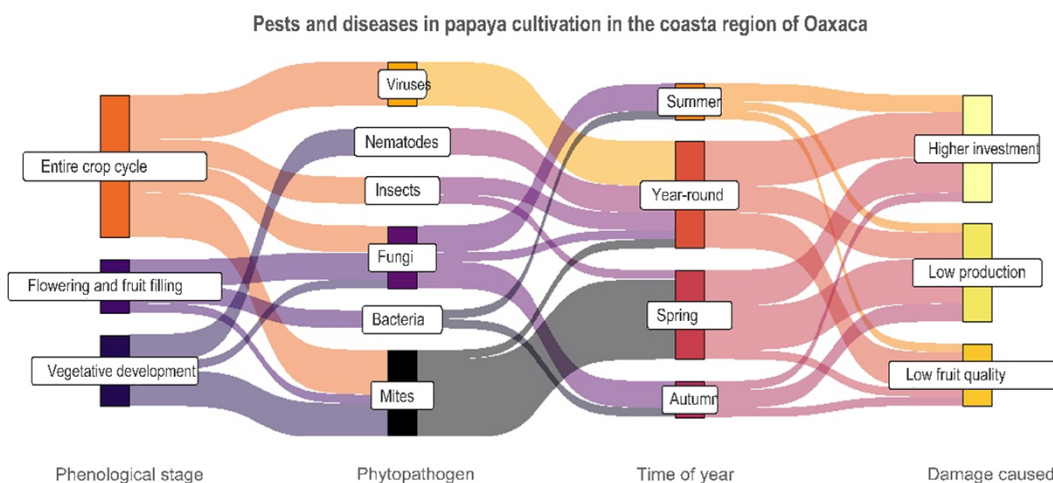


Figure 5. Phytosanitary analysis of papaya cultivation in the Oaxaca Coast region.

Perspectives and conclusions

Papaya cultivation in the Oaxaca Coast region represents an agricultural activity of significant economic and social importance. However, its productivity and fruit quality are severely threatened by various pests and diseases that affect all phenological stages of the crop. Among the most relevant pests are the red spider mite (*Tetranychus urticae*), the crystalline spider mite (*Eotetranychus lewisi*), whiteflies (*Aleurotrixus* sp., and *Trialeurodes* spp.), and aphids (*Aphis* spp., and *Myzus persicae*). The most damaging diseases include root rots caused by *Phytophthora*, *Fusarium*, and *Pythium*, as well as flower and fruit rots caused by *Colletotrichum* spp., *Asperisporium* spp., and *Phytophthora*. Viral infections, such as the PRSV, bacterial rots caused by *Erwinia papayae* and *Pseudomonas* spp., and phytoplasmas and rickettsias associated with the “Bunchy Top” symptom are also significant concerns.

Integrated pest and disease management (MIPE) emerges as the most effective and sustainable strategy to address these challenges. Combining cultural practices, biological control, monitoring, and the rational use of chemical products helps reduce economic losses, minimize environmental impact, and prolong the crop’s productive life.

It is essential to strengthen producer training, encourage local research on pest and phytopathogenic microorganisms population dynamics and promote technologies adapted to the

agroclimatic conditions of the Oaxaca Coast region. Only through a comprehensive approach tailored to regional realities will it be possible to ensure the viability and sustainability of papaya cultivation in this key productive area of Mexico.

Author's contribution

Conceptualization of the study: LYGR; methodology development: LYGR, YCRR, OGB; software management: LYGR, YCRR, OGB; writing and manuscript preparation: LYGR, YCRR, OGB; writing, review, and editing: LYGR, YCRR, OGB.

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Conflict of interest

"The authors declare no conflict of interest."

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