

Review Article

Allspice (*Pimenta dioica*) in Mexico and the use of antagonistic microorganisms for rust and anthracnose control

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Section:
Special Number

Received:
November 20, 2024

Accepted:
July 18, 2025

Published:
August 01, 2025

Citation:
Morales-German MA,
Fajardo-Franco ML and
Aguilar-Tlatelpa M. 2025.
Allspice (*Pimenta dioica*) in
Mexico and the use of
antagonistic microorganisms
for rust and anthracnose
control. Mexican Journal of
Phytopathology 43(4): 79.
<https://doi.org/10.18781/R.MEX.FIT.2024-35>

ABSTRACT

Background/Objective. The allspice (*Pimenta dioica*) has different uses as a spice and potential utility in the pharmaceutical and cosmetic industry, making it a species of economic importance. Mexico is the world's second largest producer of this spice, which is cultivated mainly by indigenous peoples. Allspice has a high potential to increase its production in Mexico, due to favorable agroclimatic conditions. However, the presence of diseases, especially anthracnose and rust, is a limitation. The objective was to document the production of allspice in Mexico and to identify management alternatives using antagonistic microorganisms against the occurrence of anthracnose (*Colletotrichum* sp.) and rust (*Austropuccinia psidii*).

Materials and Methods. An exhaustive search was carried out in digital platforms, particularly in Google Scholar, ResearchGate, SciELO and ScienceDirect, for which different combinations of keywords were used to facilitate the search, which were: *Pimenta dioica*, allspice, diseases, production, cultivation, pimienta and Jamaica pepper in spanish and english. The information was systematized and critically analyzed.

Results. Allspice production in Mexico has increased in recent years, but it is not sufficient to cover the market. Likewise, information regarding the management of anthracnose and rust in pepper is scarce; however, it has been documented that *Bacillus* sp., *Trichoderma* sp., *Fusarium* sp., *Cladosporium* sp., *Simplicillium* sp., *Clonostachys* sp., *Lecanicillium* sp., and *Streptomyces* sp. have antagonistic potential for the management of *Colletotrichum* sp. and *Austropuccinia psidii*.

Conclusion. Research is needed to evaluate the inhibitory capacity of these microorganisms, their mechanisms of action, and their synergistic effect on *Colletotrichum* sp. and *A. psidii* under *in vitro* and field conditions in allspice.

Keywords: *Pimenta dioica*, Antagonism, *Colletotrichum* sp., *Austropuccinia psidii*



INTRODUCTION

Since the 16th century, spices have been of great commercial interest worldwide due to their strong potential as preservatives, flavorings, and aromatic agents, as well as for culinary use (Acosta *et al.*, 2021; Macía, 1998). Among the spices that were commonly traded are clove (*Syzygium aromaticum*), black pepper (*Piper nigrum*), and nutmeg (*Myristica fragans*) (Lenkersdorf, 2009). After the discovery of the Americas, new products unknown to the Old World were introduced—one of them was “Pimienta gorda” (*Pimenta dioica*), used primarily by the Indigenous peoples of the Americas (Acosta *et al.*, 2021), such as the Totonac communities, who used the leaves for seasoning, as medicinal remedies, to scent their homes, and in certain ceremonial rituals. This knowledge has continued to be passed down from generation to generation (Acosta *et al.*, 2021; Jiménez *et al.*, 2015).

“Pimienta gorda” is also known as Jamaican pepper, or in English as “allspice” (Jarquín-Enríquez *et al.*, 2021). In Mexico’s Indigenous languages, it is known as *Moque* (Zoque, Chiapas), *de-tedan* (Cuicatec, Oaxaca), *malagueta*, *papalolote* (Oaxaca), *u’ucum* (Totonac, Veracruz), *xocoxochitl* (Nahuatl), *Cukum* (Tepehua), and *Ixnabacuc* (Maya) (Machuca *et al.*, 2020; Macía, 1998; Vázquez-Yanes *et al.*, 1996).

Allspice is an evergreen tree that grows up to 10 m tall, with a dense, rounded or irregular crown. Its fruits are dark-colored berries measuring 5 to 10 mm, flattened at the tip, warty, and distinctively fragrant (Vázquez-Yanes *et al.*, 1996). This tree is native to Mexico and extends into Central America (Montalvo-Lopez *et al.*, 2021). The dried fruit has various uses, such as for flavoring and scenting; its wood is used as fuel, and its leaves are used to prepare infusions (Vázquez-Yanes *et al.*, 1996). The leaves and fruits have been reported to contain volatile organic compounds responsible for their flavor and aroma, which combine notes of cinnamon (*Cinnamomum verum*), nutmeg (*Myristica* sp.), and clove (*Syzygium aromaticum*) (Montalvo-Lopez *et al.*, 2021). Allspice has anesthetic, analgesic, antimicrobial, antioxidant, antiseptic, and acaricidal properties due to phytoconstituents found in different parts of the tree, including phenylpropanoids, glycosides, tannins, and essential oils. In pharmacology, it is valued for its anticancer, antifungal, antimicrobial, nematocidal, antioxidant, and antidiabetic activity (Rao *et al.*, 2012).

Because of these properties, it is considered a high-value product with applications in cosmetics, food preservatives, perfumes, and pharmaceutical products (Martínez *et al.*, 2013; Montalvo-Lopez *et al.*, 2021). The increase in the price of dried allspice has encouraged the formation of cooperatives and organizations dedicated to processing and marketing allspice, as well as the establishment of various collection centers in Veracruz, Puebla, and Chiapas, with Veracruz and Puebla standing out as the leading producers nationwide (Córdoba, 2016; Martínez *et al.*, 2013; Reyes-Martínez, 2017).

However, allspice production is threatened by diseases such as rust caused by *Austropuccinia psidii* (Beenken, 2017) (formerly *Puccinia psidii*) and anthracnose (*Colletotrichum* sp.), which can cause losses of up to 50% of production during both pre- and post-harvest stages (Rojas-Pérez, 2017; Esperón-Rodríguez *et al.*, 2017; Velázquez-Silva *et al.*, 2018). These fungi are mainly controlled with synthetic fungicides from the triazole, strobilurin, or copper groups (Monroy-Rivera, 2011; Gaviria-Hernández *et al.*, 2013). However, the excessive use of synthetic fungicides can lead to chronic soil toxicity, instability in the microbial balance of the agroecosystem, and health risks for

farmers (Hernández-Flores *et al.*, 2013; Jáquez-Matas *et al.*, 2022; Silveira-Gramont *et al.*, 2018). Based on the above, the aim of this study was to document allspice production in Mexico and to identify management alternatives using antagonistic microorganisms in response to the occurrence of anthracnose (*Colletotrichum* sp.) and rust (*Austropuccinia psidii*).

Allspice Production in Mexico

Allspice (*Pimenta dioica*) belongs to the order Myrtales and the family Myrtaceae (Tropicos, 2024); in Mexico, it is produced under rainfed conditions as a secondary crop, harvested from wild trees in forests, backyard orchards, as well as in pastures, live fences, windbreak barriers, or intercropped with other crops such as coffee (*Coffea arabica*), corn (*Zea mays*), orange (*Citrus × sinensis*), among others (Figure 1).

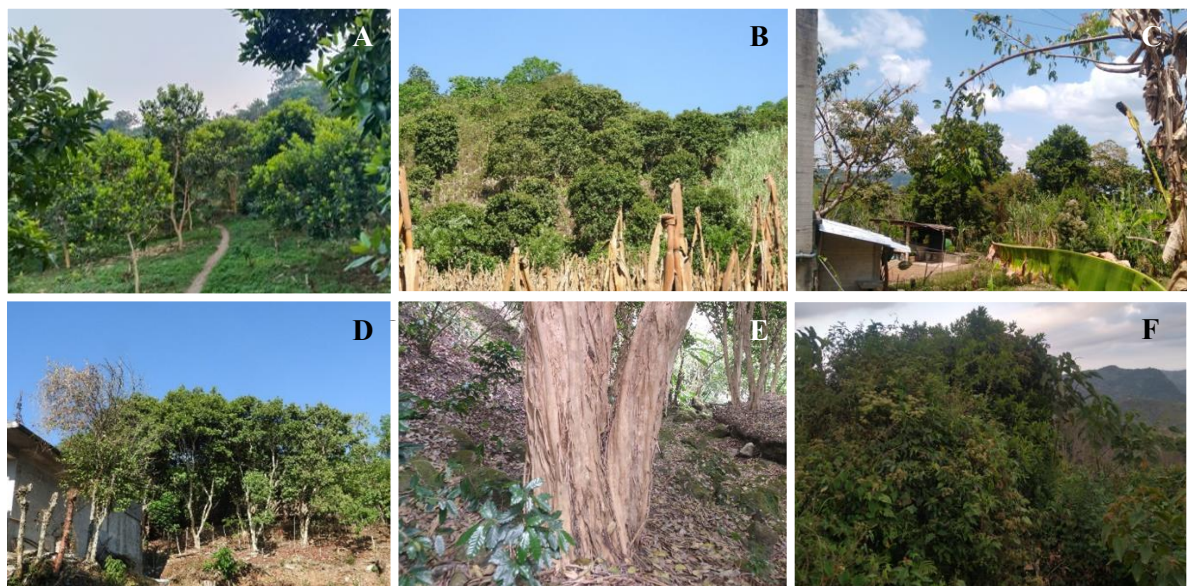


Figure 1. Allspice production systems under traditional Totonac management in Lipuntahuaca, Huehuetla, Puebla. **A)** Monoculture; **B)** Intercropped with corn; **C)** Home garden; **D)** Live fence; **E)** Coffee grown under allspice shade; **F)** *Acahual* (plant associations in areas originally occupied by tropical forests).

Harvesting of the fruit can begin as early as two years after the tree is established and is carried out mainly by hand, climbing the branches to collect the fruits when they are green or yellowish-green, followed by sun-drying (FHIA, 2016). In Mexico, this activity is mainly performed by Indigenous communities or native peoples, harvesting from scattered trees in home gardens, agroforestry systems, and live fences for self-consumption, while the surplus is sold as green allspice (Figure 2) (Machuca *et al.*, 2020; Macía, 1998).

In 1996, in the state of Puebla, the cooperative Tosepan Titataniske set the price of fresh allspice at \$2.50 pesos kg⁻¹ and dried allspice at \$7.50 pesos kg⁻¹, exceeding the price of coffee cherries, which ranged from \$1.70 to \$2.80 pesos kg⁻¹. By 2020, the price

of allspice as a seasoning ranged between \$155.00 and \$540.00 pesos kg⁻¹ (Machuca *et al.*, 2020; Macía, 1998).



Figure 2. Allspice production in Lipuntahuaca, Huehuetla, Puebla. **A)** Harvesting green fruit from allspice trees; **B)** Sun-drying area for dried fruit; **C)** Transport of dried allspice fruit.

In 2022, allspice generated economic revenue of \$161,377,940.00 pesos in Mexico, with a value ranging from \$10,714.00 to \$63,641.00 pesos t⁻¹; in 2023, the revenue was \$153,210,640.00 pesos, with prices ranging from \$10,655.00 to \$66,862.00 pesos t⁻¹ (Table 1) (SIAP, 2024).

Table 1. Allspice (*Pimenta dioica*) production in Mexico during 2022 and 2023.

State	2022			2023	
	Production (t)	Value of production (thousands of pesos)		Production (t)	Value of production (thousands of pesos)
Veracruz	7,799.08	104,427.42	.	7,440.89	101,060.90
Puebla	1,174.10	12,580.03	.	1,147.71	12,229.23
Tabasco	975.05	30,684.49	.	901.64	25,988.78
Campeche	137.50	8,750.77	.	139.90	9,354.13
Chiapas	170.71	4,639.90	.	162.77	4,330.20
Oaxaca	8.90	295.33	.	7.10	247.40
Total	10,265.34	161,377.94	.	9,800.01	153,210.64

Prepared using data from SIAP (2024).

Allspice production in Mexico has increased in recent years; in 2011, 3,452 t were produced, while in 2023, production reached 9,800.01 t, representing a 183.9% increase (SIAP, 2024; Martínez *et al.*, 2013). Currently, the top three producers nationwide are Veracruz, Puebla, and Tabasco, in that order. These states account for approximately 97% of total national production. Most of the production is exported to the United States (Table 1) (Martínez *et al.*, 2013; SIAP, 2024).

The average yield of allspice is 54 kg per tree. In recent years, a small portion of production has been modernized (Macía, 1998; Martínez *et al.*, 2013; Rojas-Pérez, 2017). However, it is estimated that more than 162,566 ha have high potential for cultivation, while 4,379,623 ha have medium productive potential, mainly in the area of the Trans-Mexican Volcanic Belt (INIFAP, 2012).

Martínez *et al.* (2013) note that to increase allspice production, plantations must be established in areas with favourable climatic conditions. The states with areas of high productive potential are Veracruz, Puebla, Hidalgo, San Luis Potosí, Guerrero, and Oaxaca (INIFAP, 2012). It is also necessary to develop pathogen-tolerant varieties; ensure proper tree nutrition; improve fruit harvesting methods, as it is currently done manually and often damages the tree; and modernize fruit drying techniques.

It is also important to develop agricultural technologies adapted to small, rugged plots and highly diversified production systems. In addition, phytosanitary issues must be addressed, as there are pathogens that affect allspice production (Esperón-Rodríguez *et al.*, 2017). Likewise, it is essential to pursue sustainable allspice production, taking into account the three components of Nijkamp's triangle: economic growth, social equity, and environmental sustainability (Zarta-Ávila, 2018).

Phytosanitary issues

Phytosanitary issues are often caused by a combination of environmental, economic, political, and social factors that impact agri-food production (Olvera-Vargas, 2022). In the case of allspice, there are few records of phytosanitary problems, their effects, causal agents, and control measures. However, in Mexico, there are reports of damage caused by *Austropuccinia psidii*, the agent responsible for rust, and *Colletotrichum* sp., which causes anthracnose (López and García, 2014; Morales-German *et al.*, 2024; Velázquez-Silva *et al.*, 2018).

Rust in allspice

Rust is the main phytosanitary problem affecting allspice, caused by *Austropuccinia psidii* (Pucciniales, Basidiomycota). This pathogen belongs to the phylum Basidiomycota, subphylum Pucciniomycotina, class Pucciniomycetes, order Pucciniales, suborder Urediniales, and family Sphaerophragmiaceae (Mycobank, 2024). It is estimated to cause up to 50% crop loss and develops on the upper and lower leaf surfaces, flower buds, and petioles of young allspice leaves (FHIA, 2008; Morales-German *et al.*, 2024; Rojas-Pérez, 2017). It is primarily associated with species of the Myrtaceae family and is commonly known as “guava and eucalyptus rust” because it also affects those species (López and García, 2014). In Brazil, it has been reported on guava (*Psidium guajava*), while in New Zealand it has been found on eucalyptus (*Eucalyptus* spp.) and native species (*Metrosideros* spp., *Lophomyrthus* spp., and *Kunzea* spp.) (Pathan *et al.*, 2020). *A. psidii* poses a risk to agriculture, forestry, and native species in Mexico, as 192 species of the Myrtaceae family have been identified as susceptible to this pathogen (Esperón-Rodríguez *et al.*, 2017).

Symptoms and signs

Symptoms appear on both the upper and lower surfaces of the leaves, on young petioles, and on the fruits of the host, where circular spots develop ranging in color from purple to brown, with powdery pustules (amphigenous, caulicolous uredinia) that range from yellow to orange at the center of the spots, measuring 0.1–0.6 mm in diameter. These symptoms can cause fruit drop or a loss in fruit quality (Figure 3) (FHIA, 2008; López and García, 2014).

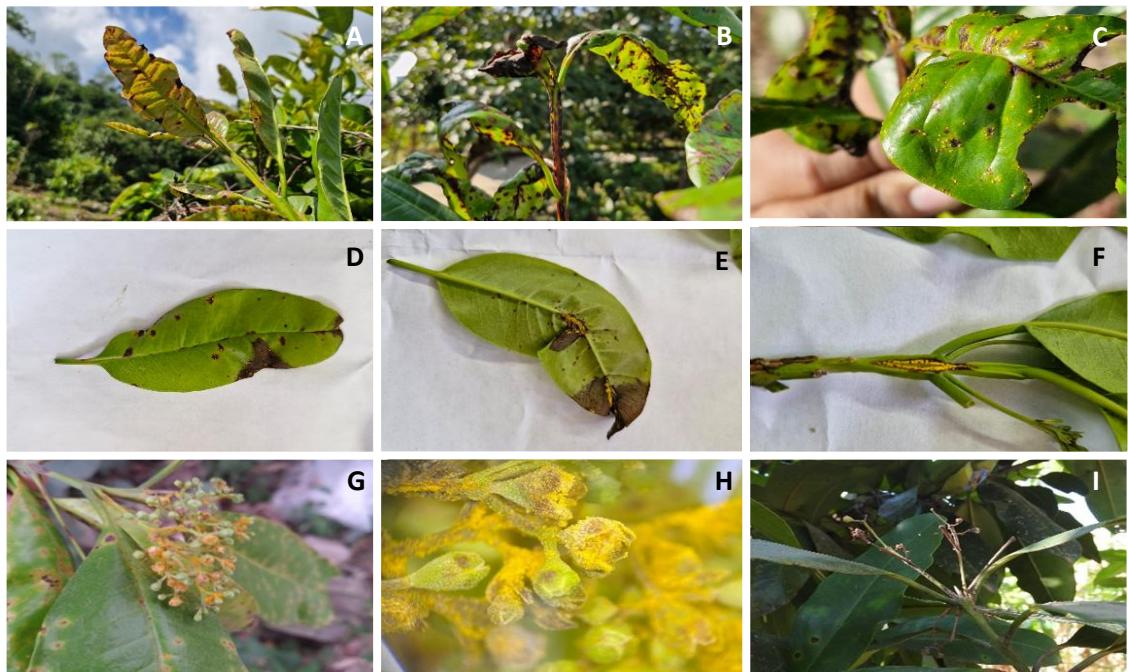


Figure 3. Symptoms and signs of rust (*Austropuccinia psidii*) in allspice cultivated in Huehuetla, Puebla, Mexico. **A and B)** Presence of rust on young leaves; **C and D)** Pustules on the upper side of the leaf; **E)** Pustules on the underside of the leaf; **F)** Pustules on the stem; **G)** Presence of rust on flower buds; **H)** View of flower buds infected with rust; **I)** Necrosis and drop of flower buds caused by rust.

The signs of the pathogen appear as echinulate urediniospores ($22.26 \pm 3.08 \times 16.03 \pm 1.66 \mu\text{m}$), hyaline to yellow, unicellular, and either pyriform, oval, or spherical in shape, with a truncated base (Figure 4) (López and García, 2014; Mohali and Aime, 2016; Morales-German *et al.*, 2024).

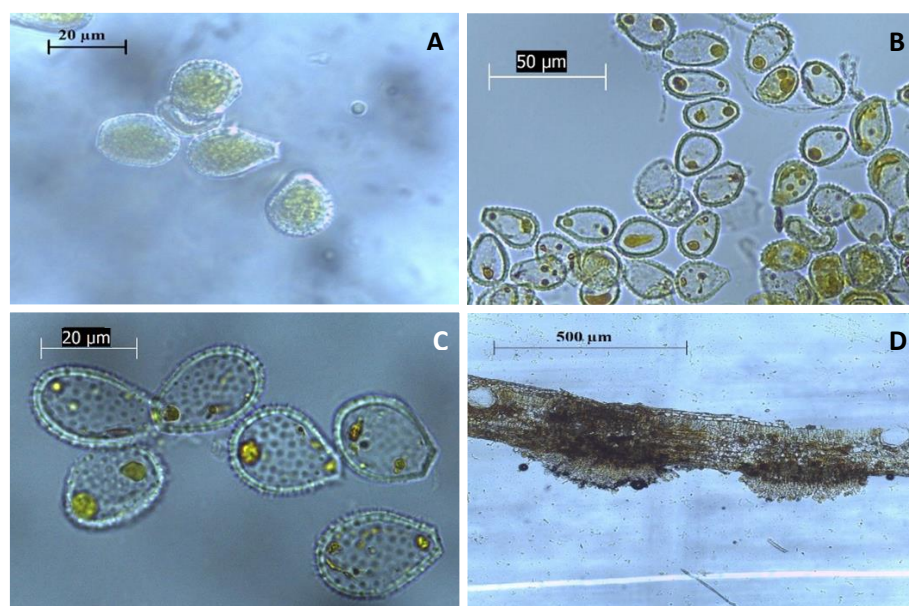


Figure 4. Uredinia and urediniospores of rust (*Austropuccinia psidii*) obtained from plant samples collected in Huehuetla, Puebla. **A–C)** Visualization of echinulate urediniospores with a truncated base; **D)** Visualization of uredinia in a cross-section of an allspice leaf.

Management of *Austropuccinia psidii* using antagonistic microorganisms

Management of rust in allspice is carried out mainly through cultural control (such as proper soil drainage and thinning of wild trees) and chemical control (Table 2) (FHIA, 2008; Martínez *et al.*, 2013; Monroy-Rivera, 2011). However, in Mexico, there are no studies on the effectiveness of synthetic fungicides specifically for managing rust in allspice.

Table 2. Chemical control of *Austropuccinia psidii* in species of the Myrtaceae family.

Active ingredient	Trade name	Dose	Host	Country	Reference
Mancozeb	Dithane® 43 Sc, Manzate® 200	1 Kg/100 L of water	<i>Pimenta gorda</i>	Honduras	FHIA, 2008
Copper sulfate	-	1 kg/100 L of water	<i>Pimenta gorda</i>	Mexico	Martínez <i>et al.</i> , 2013
Copper	Phyton® 24 SC, Sulcox® 50 WP	50 mL per hectare	<i>Pimenta gorda</i>	Honduras	FHIA, 2008
Cuprous oxide	Nordox® 750 WG	0.5 g/500 mL of solution	<i>Lophomyrtus x ralphii</i> y <i>Metrosideros excelsa</i>	Australia	Pathan <i>et al.</i> , 2020
Cyproconazole and Azoxystrobin	Amistar Xtar®	0.5 mL/500 mL of solution	<i>Lophomyrtus x ralphii</i> y <i>Metrosideros excelsa</i>	Australia	Pathan <i>et al.</i> , 2020
Fosetyl aluminum	Aliette® WG	1.25 g/500 mL of solution	<i>Lophomyrtus x ralphii</i> y <i>Metrosideros excelsa</i>	Australia	Pathan <i>et al.</i> , 2020
Copper oxychloride	Cupravit®	2 - 3 g/L of water	<i>Pimenta dioica</i>	Mexico	Monroy-Rivera, 2011
Oxycarboxin	Plantvax® 750 WP	0.65 g/500 mL of solution	<i>Lophomyrtus x ralphii</i> y <i>Metrosideros excelsa</i>	Australia	Pathan <i>et al.</i> , 2020
Tebuconazole	Folicur® 430 SC	0.15 mL/500 mL of solution	<i>Lophomyrtus x ralphii</i> y <i>Metrosideros excelsa</i>	Australia	Pathan <i>et al.</i> , 2020
Triforine	Saporl®	0.5 mL/500 mL	<i>Lophomyrtus x ralphii</i> y	Australia	Pathan <i>et al.</i> ,

Triadimenol	Bayfidan® 250 EC	of solution 0.25 mL/500 mL of solution	<i>Metrosideros excelsa</i> <i>Lophomyrtus x ralphii</i> y <i>Metrosideros excelsa</i>	Australia	2020 Pathan <i>et al.</i> , 2020
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Background information on the use of antagonistic microorganisms against *A. psidii* is limited; however, some microorganisms have been reported to reduce the incidence and act as potential biocontrol agents against rusts of the order Pucciniales, suggesting possible antagonistic effects against *A. psidii* (Table 3).

Table 3. Microorganisms reported as antagonists of rusts belonging to the order Pucciniales.

Biocontrol agent	Phytopathogen	Host	Conditions	Country	Results	Reference
<i>Bacillus megaterium</i> and <i>Paneibacillus xylanexedens</i>	Stripe rust of wheat (<i>Puccinia striiformis</i>)	Wheat (<i>Triticum</i> sp.)	Natural environment (semi-field)	Pakistan	Decrease in severity (65.16 and 61.11 % respectively)	Kiani <i>et al.</i> , 2021
<i>B. subtilis</i> (Serenade® ASO)	Yellow rust (<i>P. striiformis</i>)	Wheat (<i>Triticum</i> sp.)	Field trials	Denmark	Up to 60% control at moderate disease pressure was reported	Reiss y Jørgensen, 2017
<i>Cladosporium</i> sp.	White rust (<i>P. horiana</i>)	Chrysanthemum (<i>Dendranthema grandiflora</i>)	Laboratory and greenhouse	Mexico	Severity was reduced by 41% to 84%	García-Velasco <i>et al.</i> , 2005
<i>Cladosporium angulosum</i> , <i>C. anthropophilum</i> , <i>C. bambusicola</i> and <i>C. benschii</i> , <i>C. guizhouense</i> , and <i>C. macadamiae</i>	Myrtle rust (<i>Austropuccinia psidii</i>)	Myrtaceae family	---	Brazil	Potential biocontrollers	Pereira <i>et al.</i> , 2023
<i>Cladosporium tenuissimum</i>	<i>Uromyces appendiculatus</i>	<i>Phaseolus vulgaris</i>	<i>in vitro</i> <i>in vivo</i>	Italy	Reduction of 17 % of urediniospore germination. Severity decreased to 13 %.	Assante <i>et al.</i> , 2004
<i>Cladosporium</i> sp., <i>Alternaria</i> sp., <i>Aspergillus</i> sp. and <i>Trichoderma</i> spp.	<i>U. transversalis</i>	Gladiolus (<i>Gladiolus</i> sp.)	<i>in vitro</i>	Mexico	Colonization percentages ranged from 41.7 to 60.2 %	Romero-Óran <i>et al.</i> , 2016
<i>Fusarium fujikuroi</i> , <i>Fusarium solani</i>	<i>Austropuccinia psidii</i>	Malay Apple (<i>Syzygium malaccense</i>)	Laboratory	Brazil	Potential hyperparasitism for	Lopes <i>et al.</i> , 2019
<i>Lecanicillium</i> spp., <i>Calcarisporium</i> sp., <i>Sporothrix</i> sp. and <i>Simplicillium</i> spp.	Coffee rust (<i>Hemileia vastatrix</i>)	Coffee (<i>Coffea arabica</i>)	<i>in vitro</i>	Mexico	The percentage of mycoparasitism ranged from 51.6 to 88.8 %	Gómez-De La Cruz <i>et al.</i> , 2017
<i>Simplicillium lanosoniveum</i>	<i>Puccinia graminis</i>	Wheat (<i>Triticum</i> sp.)	Artificial climate chamber	China	Urediniospore germination rate of 17%, compared to 91% for the control.	Si <i>et al.</i> , 2023
<i>Simplicillium lanosoniveum</i> and <i>Phakopsora pachyrhizi</i>	<i>Phakopsora pachyrhizi</i>	Soybean (<i>Glycine max</i>)	Laboratory and field trials	E.U.A.	The mean number of urediniospores produced with the treatment was four times lower compared to the control.	Ward <i>et al.</i> , 2012
<i>Trichoderma barbatum</i> and <i>T. asperellum</i>	<i>P. horiana</i>	Chrysanthemum (<i>Chrysanthemum morifolium</i>)	Plants in styrofoam cups	Mexico	Rust incidence ranged from 17 to 47 %.	García-Velasco <i>et al.</i> , 2022

Recently, a study conducted in Brazil evaluated the effect of *Bionectria ochroleuca*, *Cladosporium* spp., and two isolates of *Clonostachys rosea* obtained from *Metrosideros polymorpha*, *Eugenia reinwardtiana*, and *Syzygium jambos*. However, only one of the *C. rosea* isolates reduced pustule formation by *A. psidii* and diseased tissue in *Eugenia koolauensis* (Chock *et al.*, 2021).

Anthracnose in allspice

Anthracnose caused by *Colletotrichum* sp. was first reported in Veracruz, Mexico, in 2018. It belongs to the phylum Ascomycota, subphylum Pezizomycotina, class Sordariomycetes, order Glomerellales, and family Glomerellaceae (Mycobank, 2024). This disease can cause production losses ranging from 20 to 50% during both pre- and post-harvest stages. Symptoms on the fruit include sunken brown or dark spots that lead to fruit necrosis (Figure 5) (Velázquez-Silva *et al.*, 2018).



Figure 5. Symptoms of anthracnose on allspice fruits collected in Veracruz, Mexico. Source: Velázquez-Silva *et al.* (2018).

In a study conducted by Velázquez-Silva *et al.* (2018) in northern Veracruz, allspice fruits were collected, from which monospore cultures were obtained and later identified morphologically and molecularly as *C. acutatum*, *C. gloeosporioides*, *C. fragariae*, and *C. boninense*.

Control of *Colletotrichum* sp. using antagonistic microorganisms

Currently, there are no control strategies specifically for anthracnose in *Pimenta dioica*; however, there are precedents for the control of *Colletotrichum* sp. in other plant species using biorational products such as plant extracts (*Allium sativum*, *Citrus sinensis* and *C. grandis*, *Swinglea glutinosa*, *Eucalyptus globulus*, *Piper auritum*, *Psidium guajava*, and *Urtica urens*), biofungicides, defense inducers, genetic manipulation

(Baños-Guevara *et al.*, 2004; Gaviria-Hernández *et al.*, 2013; Landero-Valenzuela *et al.*, 2016), and the use of synthetic fungicides (Table 4).

Table 4. Chemical control for the management of *Colletotrichum* sp. in different hosts.

Active ingredient	Trade name	Dose	Host	Country	Reference
Azoxystrobin	Amistar® 50 WG	32 ppm, 250 mg L ⁻¹	<i>Rubus glaucus</i> , <i>Carica papaya</i>	Colombia, Mexico	Gaviria-Hernández <i>et al.</i> , 2013; Santamaria <i>et al.</i> , 2011
Benomyl	Benoagro® 50 WP, Benocor®	125 ppm	<i>Rubus glaucus</i>	Colombia	Gaviria-Hernández <i>et al.</i> , 2013
Carbendazim	Derosal® 500 SC, Rodazim® 500 sc	300 ppm	<i>Rubus glaucus</i>	Colombia	Gaviria-Hernández <i>et al.</i> , 2013
Clorotalonil	Odeon® 720 SC	Recommended on the label	<i>Passiflora edulis</i> , <i>Carica papaya</i>	Ecuador	Carreño <i>et al.</i> , 2021
Difenoconazole	Difecor®	50 ppm	<i>Rubus glaucus</i>	Colombia	Gaviria-Hernández <i>et al.</i> , 2013
Hidróxido de cobre	Kocide® 101	1230 ppm	<i>Rubus glaucus</i>	Colombia	Gaviria-Hernández <i>et al.</i> , 2013
Mancozeb	Dithane M-45	1000 ppm	<i>Mangifera indica</i>	Venezuela	Rondón <i>et al.</i> , 2006
Propiconazole	Bumper® 25 CE	Recommended on the label	<i>Passiflora edulis</i> , <i>Carica papaya</i>	Ecuador	Carreño <i>et al.</i> , 2021
Procloraz	Funclozaz®	1000 ppm, 112 mg L ⁻¹	<i>Carica papaya</i> , <i>Mangifera indica</i>	Venezuela, Mexico	Rondón <i>et al.</i> , 2006; Santamaria <i>et al.</i> , 2011
Pyraclostrobin	---	38.0 and 75.0 mg L ⁻¹ i.a	<i>Citrus sinensis</i>	Costa Rica	Guillén-Carvajal <i>et al.</i> , 2023
Copper pentahydrate sulfate	Phyton®	Recommended on the label	<i>Passiflora edulis</i> , <i>Carica papaya</i>	Ecuador	Carreño <i>et al.</i> , 2021
Tebuconazole	---	7.50 y 75.0 mg L ⁻¹ i.a	<i>Citrus sinensis</i>	Costa Rica	Guillén-Carvajal <i>et al.</i> , 2023
Tebuconazole + Triadimenol EC 300	Silvacur Combi® EC300	---	<i>Selenicereus megalanthus</i>	Peru	Bello <i>et al.</i> , 2022
Ferbam	---	1520 y 3040 mg L ⁻¹ i.a	<i>Citrus sinensis</i>	Costa Rica	Guillén-Carvajal <i>et al.</i> , 2023

For the control of *Colletotrichum* sp., plant extracts from orange (*Citrus sinensis*), grapefruit (*C. grandis*), Swinglea lemon (*Swinglea glutinosa*), eucalyptus (*Eucalyptus globulus*), garlic (*Allium sativum*), and nettle (*Urtica urens*) have also been used (Gaviria-Hernández *et al.*, 2013). Against *Colletotrichum gloeosporioides* in yam (*Dioscorea* spp.), the use of lemongrass (*Cymbopogon citratus*) essential oil has been reported (Pérez-Cordero *et al.*, 2017). Other aqueous and ethanolic extracts used for this purpose include extracts from *Capparis sinaica*, *Crotalaria aegyptiaca*, *Galium sinaica*, *Plantago sinaica*, and *Stachys aegyptiaca* (Zakaria and Mohamed, 2020).

The effectiveness of antagonistic microorganisms (either endemic or from commercial products) for controlling *Colletotrichum* sp. isolated from and affecting various crops has also been reported, with their biocontrol potential evaluated both *in vitro* and in the field (Table 5).

Table 5. Microorganisms reported as antagonists of *Colletotrichum* sp.

Biocontrol agent	Phytopathogen	Host	Conditions	Country	Results	Reference
Actinobacteria	<i>C. capsici</i>	Chili (<i>Capsicum annuum</i>)	Field trials	Indonesia	Decrease in severity and incidence by 100%.	Yanti <i>et al.</i> , 2023
<i>Bacillus amyloliquefaciens</i> (Serenade ASO®)	<i>C. gloeosporioides</i>	Yellow pitaya of Huambo (<i>Selenicereus megalanthus</i>)	<i>in vitro</i>	Peru	Inhibited 100% of mycelial growth.	Bello <i>et al.</i> , 2022
<i>Bacillus amyloliquefaciens</i> (Amylo-X®), <i>T. gamsii</i> y <i>T. asperellum</i> (Remedier®), <i>B. amyloliquefaciens</i> (Serenade® ASO), <i>B. pumilus</i> (Sonata®) and <i>T. harzianum</i> (Trianum-P®)	<i>C. acutatum</i>	Olive (<i>Olea europaea</i>)	<i>in vivo</i>	Greece	Inhibition in the production of conidia greater than 40%.	Varveri <i>et al.</i> , 2024
<i>Bacillus firmus</i>	<i>C. gloeosporioides</i>	Papaya Maradol (<i>Carica papaya</i>)	<i>in vitro</i>	Mexico	Decreased pathogen growth by 75.32 and 69.17%.	Baños-Guevara <i>et al.</i> , 2004
<i>Bacillus subtilis</i> and <i>Rhodotorula minuta</i>	<i>C. gloeosporioides</i>	Mango (<i>Mangifera indica</i>)	Field trial	Mexico	The combination of antagonists reduced the disease (severity of 8.0).	Carrillo <i>et al.</i> , 2005
<i>Bacillus</i> sp., <i>Streptomyces</i> sp., <i>Paenibacillus</i> sp. and <i>Gluconobacter cerinus</i>	<i>Colletotrichum</i> sp.	Strawberry (<i>Fragaria</i> sp.) and blueberry (<i>Vaccinium</i> sp.)	<i>in vitro</i>	Mexico	Inhibition percentage from 67.0 to 97.5%.	Garay-Serrano and Pérez, 2024
<i>Nigrospora</i> spp.	<i>C. gloeosporioides</i>	<i>Solanum betaceum</i>	Bioassays	Ecuador	Decrease in damage and significant differences between treated plants versus control.	Delgado y Vásquez, 2010
<i>Paenibacillus</i> sp.	<i>Colletotrichum</i> sp.	Cocoa (<i>Theobroma cacao</i>)	<i>in vitro</i> y field tests	Mexico	Inhibited fungal growth by 30 to 50%. Decreased the incidence of anthracnose.	Rodríguez-Velázquez <i>et al.</i> , 2025
<i>Trichoderma asperellum</i> , <i>Trichoderma</i> sp., <i>T. virens</i> (G-41®), <i>T. harzianum</i> (T-22®), <i>Trichoderma</i> sp. (Bactiva®) and <i>Trichoderma</i> sp. (Fithan®)	<i>C. gloeosporioides</i>	Passion fruit (<i>Passiflora edulis</i>)	<i>in vitro</i>	Mexico	The percentage of mycelial growth varied between 72.2 and 88.1%. The percentage of sporulation varied between 97.5 and 100%.	Ayvar-Serna <i>et al.</i> , 2024
<i>T. harzianum</i> , <i>T. viride</i> , <i>T. asperellum</i> and <i>Clonostachys rosea</i>	<i>Colletotrichum</i> sp. and <i>C. rosea</i>	Mango (<i>Mangifera indica</i>)	<i>in vitro</i>	Perú	The Percentage Inhibition of Radial Growth Rate (PICR) ranged from 18.2 to 69.4%.	Goñas <i>et al.</i> , 2017
<i>Trichoderma lignorum</i> (Mycobac®), <i>Trichoderma harzianum</i> (Agroguard®) and <i>Bacillus subtilis</i>	<i>C. gloeosporioides</i> and <i>C. acutatum</i>	Blackberry (<i>Rubus glaucus</i>)	<i>in vitro</i>	Colombia	Inhibition percentages between 26 and 79 %.	Gaviria-Hernández <i>et al.</i> , 2013

(Rhapsody®)

<i>Trichoderma</i> spp.	<i>C. gloesporioides</i>	Papaya (<i>Carica papaya</i>)	<i>in vitro</i>	Mexico	Inhibition of 59 and 63%.	Rendón-García <i>et al.</i> , 2020
<i>Streptomyces murinus</i>	<i>C. scovillei</i>	Tomato (<i>Solanum lycopersicum</i>)	<i>in vitro</i>	Vietnam	50% inhibition.	Nguyen <i>et al.</i> , 2025

Modes of action of antagonistic microorganisms

Romero-Orán *et al.* (2016) reported that *Cladosporium* sp., *Alternaria* sp., *Aspergillus* sp., and *Trichoderma* spp. caused dehydration, degradation, and deformation of uredinia and urediniospores of *Uromyces transversalis*. They also observed hyphal invasion of *Trichoderma* sp. into uredinia of *U. transversalis* and did not rule out the production of antibiotics, secondary metabolites, and enzymes.

Assante *et al.* (2004) described the mechanisms of action involved in the mycoparasitism of *Cladosporium tenuissimum* on *Uromyces appendiculatus*, reporting enzymatic degradation of both external and internal layers of the urediniospore walls of *U. appendiculatus*. They documented urediniospore penetration by short, septate, and highly branched hyphae of *Cladosporium tenuissimum*, leading to the disappearance of organelles in the urediniospores of *U. appendiculatus*. They also identified lytic activity during advanced stages of mycoparasitism, resulting in discoloration and thinning of the urediniospore walls, followed by hyphal growth and conidiophore formation on the urediniospores.

Ward *et al.* (2012) evaluated the biocontrol effect of *Simplicillium lanosoniveum* on soybean rust (*Glycine max*) caused by *Phakopsora pachyrhizi*, reporting changes in the color of uredinia, which may indicate a hypersensitive response of the antagonists against the pathogen.

In bacteria of the genus *Bacillus*, the mechanisms of action in the biocontrol of phytopathogens include the production of antimicrobial substances, competition for substrates, emission of volatile organic compounds, secretion of lytic enzymes, and induction of resistance (Pedraza *et al.*, 2020). These mechanisms also involve the production of lipopeptides, siderophores, δ -endotoxins, and the activation of systemic acquired resistance (Villarreal-Delgado *et al.*, 2018). A study conducted in Colombia found that the antibiotic Iturin A, produced by *B. subtilis*, inhibited the growth of *Fusarium* spp., demonstrating its potential as a phytopathogen control agent (Ariza and Sánchez, 2012). In vitro studies of *B. subtilis* against *Fusarium solani* and *Pythium* sp. showed that the bacterium produces biosurfactant compounds that enable it to exert antifungal activity by destabilizing the cell membranes of the phytopathogens (Sarti, 2019). However, *Bacillus* species must be assessed for biosafety. Although *B. subtilis*, *B. licheniformis*, and *B. pumilus* are not considered pathogenic to humans, there have been reported cases of foodborne intoxication associated with some species of the *Bacillus cereus* group (Villarreal-Delgado *et al.*, 2018).

The main modes of action of *Trichoderma* sp. include competition for space and nutrients, mycoparasitism, and antibiosis, as well as the secretion of enzymes and the

production of inhibitory compounds (Infante *et al.*, 2009). Its antimicrobial activity against phytopathogenic fungi is primarily due to a combination of secondary metabolites (terpenes, peptaibols, pyrones, gliovirin, and gliotoxin) and hydrolytic enzymes. *Trichoderma* sp. also releases substances that induce systemic resistance responses and the expression of defense-related genes (Khan *et al.*, 2020).

Perspectives

Worldwide, there are no studies on the use of antagonistic microorganisms to inhibit *A. psidii* and *Colletotrichum* sp. in allspice. Research on native and endophytic microorganisms antagonistic to these phytopathogens represents a promising line of investigation in Mexico, where allspice agroecosystems remain vulnerable to outbreaks of anthracnose and rust.

It is essential to carry out studies that evaluate the effects of antagonistic microorganisms on the growth and development of *Colletotrichum* spp. and *A. psidii*, not only under in vitro conditions but also in terms of their impact on the epidemic development of the diseases under field conditions. These studies must also confirm that the microorganisms are not pathogenic to allspice, which would provide the basis for designing effective management strategies. Some of the microorganisms that could be evaluated include *Bacillus* spp., *Cladosporium* spp., *Fusarium* spp., *Simplicillium* spp., *Trichoderma* spp., *Paenibacillus* spp., *Gluconobacter* spp., *Nigrospora* spp., *Clonostachys* spp., and *Streptomyces* spp., which have been reported in the management of anthracnose and rust in other plant species.

In addition, it is necessary to deepen the investigation of the mechanisms of action that may be involved, conduct histological studies on the behaviour of antagonists in plant tissue, and perform biochemical analyses of potential secondary metabolites. The use of antagonistic microorganisms is proposed as a viable alternative for the sustainable production of allspice, given that its cultivation in Mexico takes place in diversified agroecosystems, where various plant and animal species coexist, including native species and potentially beneficial microorganisms with antagonistic potential.

CONCLUSIONS

Allspice production in Mexico has increased in recent years; however, it remains insufficient to meet both international and domestic market demand, and production remains largely unmechanized across the various production systems. To date, there are no records of in vitro or in situ biocontrol studies targeting *Austropuccinia psidii* and *Colletotrichum* sp., the causal agents of rust and anthracnose in allspice, respectively. Various studies have demonstrated the effectiveness of antagonistic microorganisms in controlling other rusts caused by *Puccinia* spp. in wheat, rose apple, and chrysanthemum, as well as the effectiveness of antagonists in controlling *Colletotrichum* spp. in tomato, papaya, mango, dragon fruit, and blackberry. Among the microorganisms identified are *Bacillus* spp., *Cladosporium* spp., *Fusarium* spp., *Simplicillium* spp., *Trichoderma* spp., *Paenibacillus* spp., *Gluconobacter* spp., *Nigrospora* spp., *Clonostachys* spp., and *Streptomyces* spp., among others. However, their modes of action have not been described, nor has their synergistic effect when combined with other microorganisms, and it is still unknown whether any of them could be pathogenic to allspice or have adverse

health effects on producers, most of whom belong to Indigenous communities. Therefore, further research is necessary. This article provides information on antagonistic microorganisms that could be evaluated for the management of rust and anthracnose in allspice.

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