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Original Article

Diversity and Distribution of Rust Fungi (*Pucciniales*) Infecting Mulberry (*Morus* spp.) in the Philippines: A Scoping Review

Frederick J. Abanes, John Raymund D. Torres

Author Information:

Don Mariano Marcos Memorial State University, La Union, Philippines

Correspondence:
jrtorres@dmmmsu.edu.ph

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Abstract. Mulberries (*Morus* spp.) are cultivated widely in climatic zones and are important in food production, medicine, pollution control, and sericulture. Rust fungi (Pucciniales) are obligate plant pathogens, and some species have been reported to infect mulberries, causing ecological and economic impacts. Despite their potential impact, information on the diversity and distribution of rust fungi infection in *Morus* spp. in the Philippines remains limited. This scoping review aims to map the distribution and diversity of rust fungi (Pucciniales) infecting *Morus* spp. locally. Reliable online resources, including published articles and reviews from Google Scholar, were used to gather relevant information on Pucciniales infecting *Morus* spp. in the Philippines, including their taxonomic identities, host associations, and geographic distributions. Two rust fungi species were documented: *Gymnosporangium mori* and *Cerotelium fici*. Records were concentrated in a few provinces, indicating limited geographic data. This scoping review highlights the presence of rust fungi species in the Philippines. Overall, this scoping review provides a baseline for disease management in *Morus* spp. with regard to rust fungi by identifying the rust species known to infect them locally. Given current knowledge on how to identify and manage them, identical measures could be used to prevent future rust-fungal infections in *Morus* spp. in the Philippines.

Keywords: *Aecidium mori; Cerotelium fici; Gymnosporangiaceae; Gymnosporangium mori; Phakopsoracea.*

Mulberries (*Morus* spp.), which belongs to the genus *Morus* and the family Moraceae, is a fruit-bearing trees that provide edible treats among people over time. They are widely cultivated across climatic zones, but their origin can be traced to the Himalayan foothills of India and China (Rohela et al., 2020). There are approximately 24 mulberry species and more than 1,000 cultivars, predominantly originating in Southeast Asia. Among them, three mulberry species are mainly grown all over the world: black (*M. nigra* L.), red (*M. rubra* L.), and white (*M. alba* L.) mulberries. This plant is popular not only for the nutritional value of its berries but also for its significance in other fields, such as medicine, pollution control, and sericulture (Khalifa et al., 2018; Rohela et al., 2020; Baciu et al., 2023). In sericulture, mulberry leaves are primarily used because they are the sole food for the silkworm *Bombyx mori* (Baciu et al., 2023). However, healthy leaves are essential for optimal silkworm growth; therefore, mulberry trees must be continuously monitored for disease (Bekkamov et al., 2023).

Pucciniales, or simply rust fungi, refer to the order of rust-causing fungi, known to be obligate plant pathogens. Species of about 8000 are globally distributed, and each infects a specific host. As a group, they infect plants and

cause diseases that affect economically and ecologically crucial plant species (Kaishian et al., 2024). From a biological and ecological perspective, Puccinales are strict biotrophic fungi; to complete their life cycle, they require a host (plant). There is a wide range of varieties of rust fungi, depending on the number of hosts and number of spores to produce to finish a species' life cycle (Duplessis et al., 2014). This includes heteroecious macrocyclic rusts, which refer to those that require two hosts, telial and aecial, to produce five different spore types. Other types include autoecious rusts, which infect only one host to complete their life cycle, and demicyclic and microcyclic rusts, which have fewer spore stages (Newcombe, 2004).

Globally, various species of rust fungi have been reported to infect mulberries. In Ibaraki and Saitama Prefectures, Japan, *Morus alba* was found infected by *Gymnosporangium mori* comb. nov., an anamorphic rust fungus forming aecidioid uredinia only (Kasuya et al., 2024). In a separate study by Gonçalves et al. (2022), which focused on pathogenic rust fungi infecting *M. nigra* in Brazil, *M. nigra* leaves exhibited pustules (light brown with a yellowish halo), severe rust, yellowing, and premature leaf drop. The pathogen was identified as *Cerotelium fici* based on morphological characteristics and molecular phylogenetic analysis. Another case occurred in Southwestern Nigeria, in which *Cerotelium fici* also caused leaf rust and leaf withering in *Morus alba*, as revealed by pathogenicity tests. Symptoms follow a distinct pattern of infection, with numerous pinhead-sized, brownish to black spots initially appearing on the leaflets. This is followed by the spread of spots across the entire leaf surface, which subsequently causes the infected leaves to become yellowish and wither (Baiyewu et al., 2005; Goncalves et al., 2023).

In the Philippines, despite growing interest in mulberry cultivation, particularly for sericulture, research on rust fungi in the order Pucciniales remains scarce and is scattered across isolated reports. There is limited discussion of their distribution and ecological and economic impacts. This scoping review aims to map the distribution and diversity of rust fungi (Pucciniales) infecting *Morus* spp. locally. Specifically, it seeks to collect available data from various studies, identify taxonomic and geographic gaps, and provide a baseline for future research and management strategies.

Methodology

Research Design

This study employed a scoping review to synthesize published articles on rust fungi (Pucciniales) infecting *Morus* spp. in the Philippines. The scoping review approach was employed due to the limited number of local studies and the fragmented nature of existing reports on rust fungi. This approach involves incorporating relevant historical and recent studies to generate an overview report on rust fungal infections in *Morus* species and their distribution.

Research Collection and Data Analysis Procedure

Reliable online resources, including published articles and reviews from Google Scholar, were used to gather information on Pucciniales infecting *Morus* spp. in the Philippines. The following keywords were used to identify studies on the web: Pucciniales, *Morus*, and the Philippines. Studies written in English were used exclusively, and, given the scarcity of recent studies on this topic in the Philippine setting, older studies, together with available recent studies, were consulted to provide a comprehensive perspective on the subject. This is also intended to account for older data that recent studies have not followed up on. The content of the collected studies was ensured to include information such as rust species name, host (*Morus* spp.), location, and method of identification. The collected data were organized by fungal species and synthesized to describe diversity and distribution patterns.

Results and Discussion

Characteristics and Traces of *Gymnosporangium mori* (*Aecidium mori*) in the Philippine Archipelago

Gymnosporagium mori refers to the latest, teleomorphic name of *Aecidium mori* (anamorphic name) based on modern phylogenetic evidence in 2024, and belongs to the family Gymnosporangiaceae. It is a rust fungus that infects plant hosts in the genus *Morus* worldwide. Other names used for this species were *Caeoma mori*, given by Barclay in 1890, and later mentioned as *Uredo mori* by Saccardo in 1891, but due to the presence of peridia in the sori, Barclay treated it as the same species as *A. mori* (Kasuya et al., 2024). In 1993, the species was transferred to the genus *Peridiospora* by Prasad et al. (1993). Historically, *Aecidium mori* was considered the correct identification because its asexual stage was the only known stage; therefore, the older species name was used in some studies addressing its presence in different places.

In a study by Kobayashi & de Guzman (1981), titled "Monograph of Tree Diseases in the Philippines with Taxonomic Notes on Their Associated Microorganisms", *Morus alba* was mentioned. It was found infected with *Aecidium mori*, causing rust on the infected hosts from Pacdel Forest Nursery in Baguio City, Benguet Province, in Luzon. The fungus was identified using morphological observations and molecular phylogenetic analyses. As stated in their study, it was the sole species in the genus *Aecidium* that affected *Morus alba*, based on their records of tree diseases from 1977 to 1985. It infects the leaves and young green shoots of *M. alba,* and numerous aecia are produced on diseased leaves, petioles, and green stems, bursting yellowish-orange powdery masses of aeciospores. Regarding the distribution of the pathogen, the authors reported that, among the sites surveyed for tree diseases, it was found only in one location in Luzon. However, across the globe, *A. mori* is widely distributed and has been recorded to infect other *Morus* species like *M. bombycis*, *M. catayana*, *M. indica*, *M. kagayamae,* and *M. mongolica* in countries like Burma, China, India, Indonesia, Japan, Korea, the Philippines, Taiwan, and Thailand (Kobayashi & De Guzman, 1981).

A deeper analysis of *Aecidium mori* in the Philippines, using the Mycology Collections Portal (n.d.-a), indicates that *A. mori* (along with its synonyms) was also found in other regions of the Philippines. These regions include Bontoc in Mountain Province (collected by Reyes, M., in 1920) and the Kalinga Sub-province (collected by Yates, H.S., in 1916), which were also reported to infect *M. alba*.

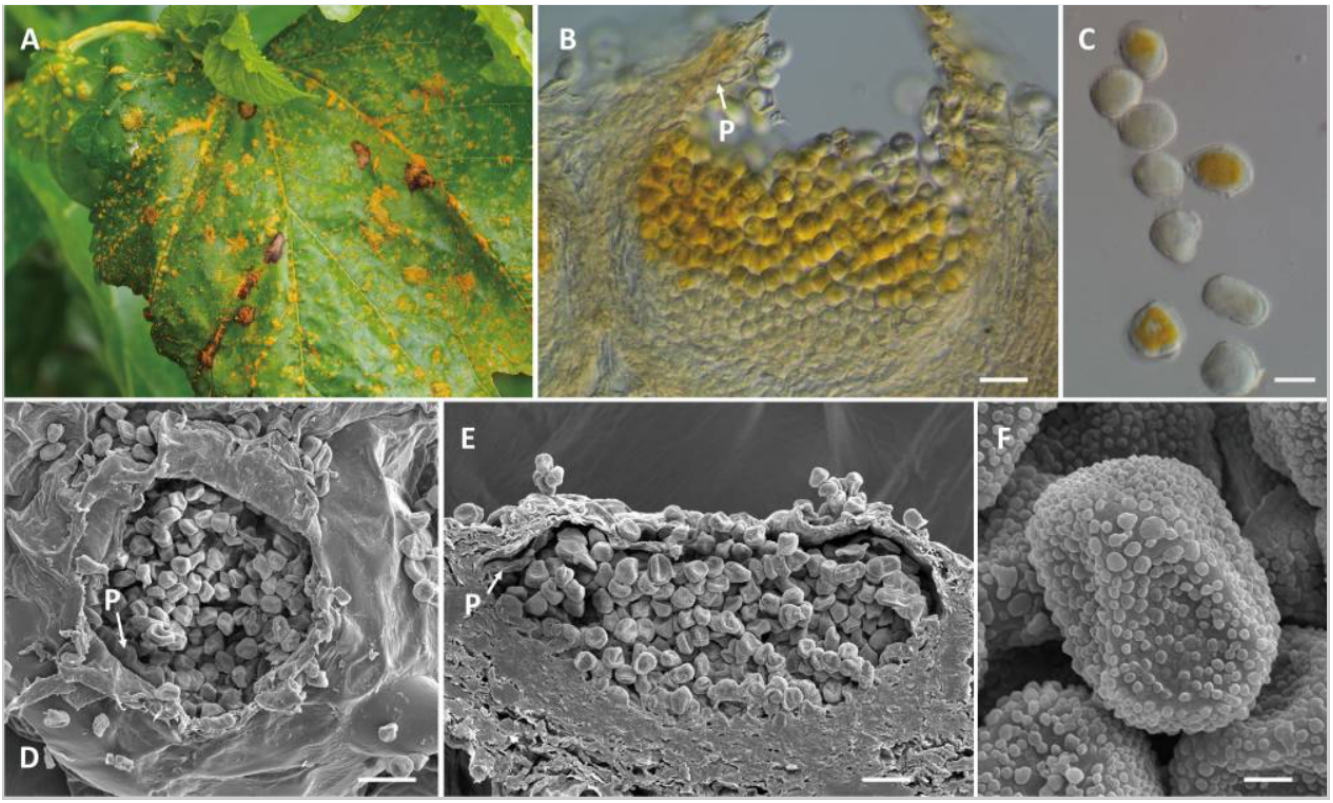

Figure 1. *Gymnosporangium mori on an infected Morus alba leaf. A: Sori on the upper leaf surface. B: Vertical section of sorus. Peridium at the margin of the sori (P). C: Spores with hyaline walls. D: Sorus on the leaf surface observed by scanning electron microscopy (SEM). Peridium at the margin of the sori (P). E: Vertical section of sorus observed by SEM. Peridium at the margin of sori (P). F: Spores with verrucae on the surface observed by SEM. Bars: B, E 20 µm; C 10 µm; D 30 µm; F 2.5 µm. Images by Kasuya et al. (2024).*

In the study by Kasuya et al. (2024), morphological observations were conducted using light microscopy and scanning electron microscopy to identify *Gymnosporangium mori*. They have observed amphigenous, densely formed sori that range from rounded to elliptical and cupulate, and are surrounded by fragile, short peridia. The peridial cells were loosely conjoined, and their inner walls were verrucous. Spores were catenulate, angularly globose to ellipsoid, measuring 11.5–20 × 8–15.5 µm (average 16 × 12 µm; n = 50). Their walls were hyaline, verrucose, and 1–1.5 µm thick.

Characteristics and Prevalence of *Cerotelium fici* on *Morus* spp. in the Philippines

Cerotelium fici is a fungal species that typically infects *Ficus* species worldwide, affecting 18 countries in Africa, 14 in Asia, 10 in North and South America, 8 in Europe, and 7 in Oceania (Avasthi et al., 2023). It belongs to the fungal family Phakopsoraceae and was previously known as *Kuehneola fici* and *Uredo fici*. It had a significant impact on edible fig, causing defoliation and yield loss due to immature fruits failing to ripen. The spread of *C. fici* can happen through short-distance splash from one leaf to another or one plant to another, and wind dispersal. It was also noted that spores require water on the leaf surface for germination and infection (Jackson & McKenzie, n.d.).

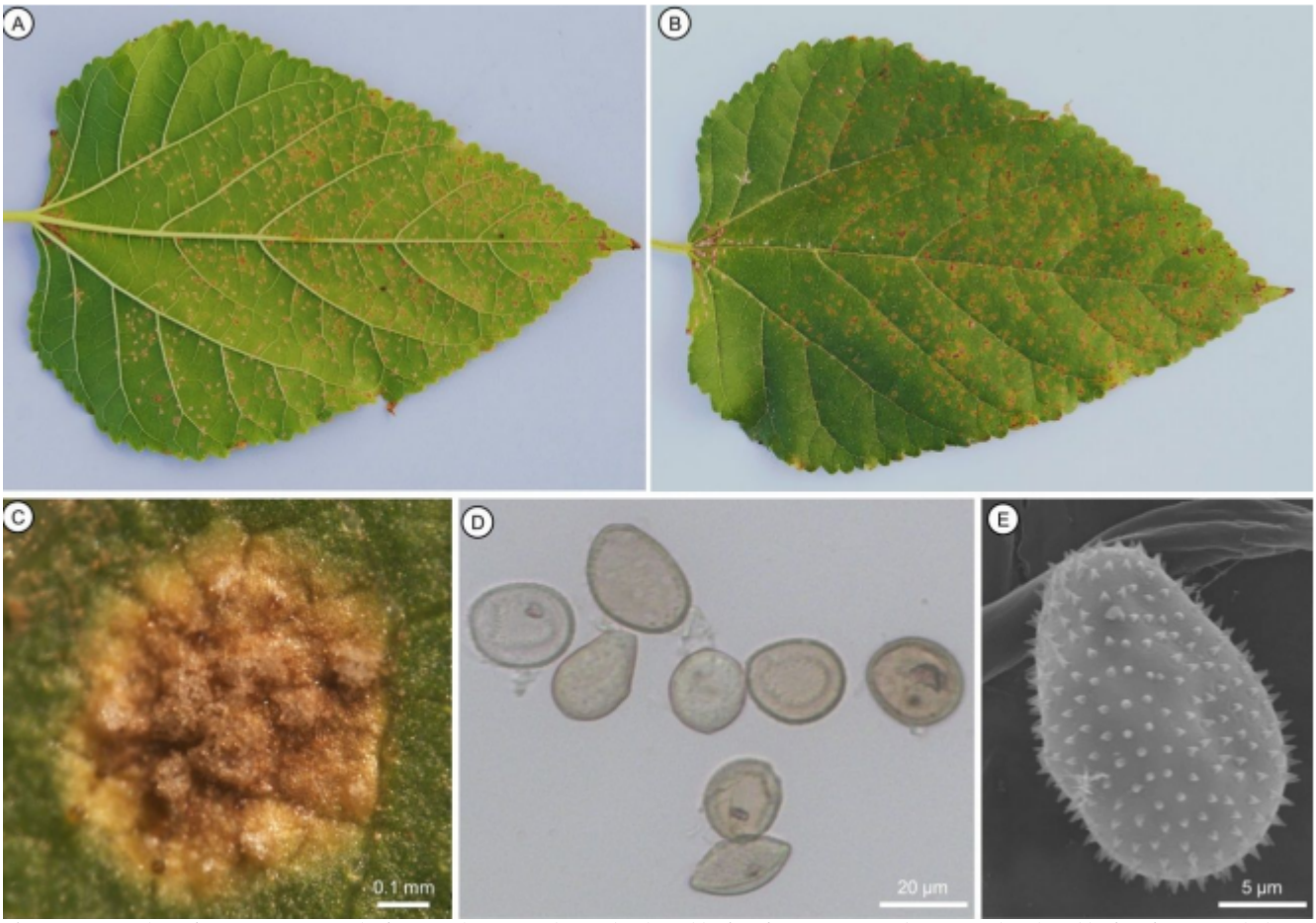

Figure 2. *Cerotelium fici on Morus nigra leaf. A: Uredinia pustules on the abaxial leaf surface. B: Necrotic lesions on the adaxial leaf surface. C: Light brown uredinia with a yellowish halo. D and E: Urediniospores of C. fici under light and scanning electron microscopy, respectively. Images by Gonçalves et al. (2022).*

In a study by Gonçalves et al. (2023), it was noted that *C. fici* affects not only *Ficus* species but also *Morus* species. They specifically studied the infection of *Morus nigra* L. by *C. fici* that happened in an experimental orchard in Piracicaba, SP, Brazil (22°42′28″S, 47°37′42″W) in August 2020. They observed that mulberry leaves with severe rust turned yellow and fell prematurely. The pustules were light brown with a yellowish halo, averaging 0.9 mm² in size. The uredinial paraphyses (n = 50) measured 42.2 ± 0.67 µm in length, with a wall thickness of approximately 0.6-1.1 µm. The urediniospores were brownish, echinulate, globoid to broadly ellipsoid, measuring 27.1 ± 0.29 by 21.0 ± 0.27 µm with a wall thickness of 0.6 ± 0.01 µm (n = 100). To identify the fungal pathogen species, the authors examined urediniospores using light and scanning electron microscopy. The morphological data were complemented by molecular phylogenetic analysis of rRNA gene (18S and 28S) and mitochondrial *COX3* gene sequences, which, using Bayesian inference, confirmed the pathogen's identity as *Cerotelium fici* (Gonçalves et al., 2022).

Cerotelium fici was reported by Spaulding (1961) to be infecting *M. alba* in the Philippines. It reportedly forms powdery cinnamon-brown rust pustules on the leaves of infected hosts, typically species in the family Moraceae (including *M. alba*). However, the exact locations of the infected samples were not specified. In contrast, the records listed in the Mycology Collections Portal (n.d.-b) indicate several occurrences of *Cerotelium fici* infection on Morus

species in specific locations in the Philippines. First is the one collected by Clemens, M. S., in 1928 in Baguio, Benguet, wherein it reportedly caused bright yellow rust on *Morus alba.* The other instance occurred in the Kalinga Subprovince, where the specimen collected by Yates, H. S., in 1916 was reportedly infecting *Morus alba* as well. The next one is from Los Baños; the specimen by Ponce, B., in 1920 was reported to have infected *Morus alba*, and the specimen by Baker, C.F., in 1913 from Mount Makiling, Laguna, near Los Baños, was also reported to have infected *Morus alba*. In other countries, there are already reports on the infection of *Morus* species by *Cerotelium fici* (Goncalves et al., 2023; Kumar et al., 2021; Gangwar & Qadri, 2002).

Conclusion

This scoping review highlights the presence of rust fungi species in the Philippines. Available studies suggest that two major rust fungi species affecting *Morus* species in the Philippines are *Gymnosporangium mori* and *Cerotelium fici*. However, given the limited number of reports on their local distribution, it cannot be ensured that they are limited to the locations included in this scoping review. Further research is needed to confirm the official distribution of each rust fungi species in the Philippines. Moreover, there may be other species from the same families as the rust fungi pathogens mentioned in this review that could infect *Morus* species in the Philippines. Overall, this scoping review provides a baseline for disease management in *Morus* spp. with regard to rust fungi by identifying the rust species known to infect them locally. Given current knowledge on how to identify and manage them, identical measures could be used to prevent future rust-fungal infections in *Morus* spp. in the Philippines.

Contributions of Authors

Author 1: proposal writing, data gathering, data analysis, and writing of the manuscript
Author 2: conceptualization, writing and formatting, and revisions of the manuscript

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Conflict of Interests

The authors declare no conflicts of interest.

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