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Review Article

Rodent-associated fungal zoonoses: Ecology, transmission dynamics, and a one health perspective on public health implications

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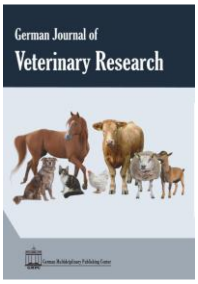

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Abstract

Rodents are among the most widespread and adaptable mammals worldwide and play a central role in the ecology of numerous infectious diseases. While rodent-borne viral, bacterial, and parasitic infections have been extensively studied, fungal zoonoses associated with these animals remain comparatively underrecognized. This review synthesizes current evidence on medically important rodent-associated fungal infections, with emphasis on histoplasmosis, cryptococcosis, dermatophytosis, blastomycosis, and sporotrichosis. We examine the ecological mechanisms by which rodents contribute to fungal persistence and dissemination, including soil modification, organic matter accumulation, and environmental contamination. The main transmission routes, clinical manifestations, and public health implications of these mycoses are discussed, with particular emphasis on their relevance in both endemic and emerging settings. Special attention is given to the influence of climate change, urbanization, deforestation, and other anthropogenic activities that intensify human–rodent–environment interactions and favor disease emergence. The review also analyzes current prevention and control strategies from a One Health perspective, emphasizing the integration of environmental monitoring, wildlife surveillance, rodent management, and health system strengthening. Despite growing recognition of these infections, major challenges persist, including underdiagnosis, limited surveillance, and insufficient interdisciplinary collaboration, particularly in low- and middle-income countries. By consolidating available evidence and identifying knowledge gaps, this article aims to improve understanding of rodent-associated fungal zoonoses and to support the development of coordinated, sustainable interventions. Strengthening integrated surveillance and adopting holistic public health approaches are essential to mitigate the expanding global burden of these neglected fungal diseases.

Keywords: Cryptococcosis, Emerging infectious diseases, Environmental reservoirs, Fungal infections, Histoplasmosis, One Health, Rodent, Zoonotic mycoses

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Introduction

Rodents constitute the most numerous and diverse order within mammals, with an almost cosmopolitan distribution and a remarkable ability to adapt to urban, rural, and wild environments. Their constant proximity to human populations, their high reproductive rate, and their ability to exploit multiple ecological niches make them key reservoirs of numerous infectious agents of public health importance (Shehata et al., 2025). Traditionally, research on rodent-borne diseases has focused primarily on viruses (Muvunyi et al., 2024), bacteria (Basiouni et al., 2025), and parasites (Rodriguez-Morales et al., 2025). However, fungal infections associated with these animals have received considerably less attention, despite their potential clinical impact and increasing epidemiological relevance (Djiman et al., 2024).

Human mycoses are a heterogeneous group of diseases caused by opportunistic or primary fungi that can affect various organs and systems (Table 1). In recent decades, the incidence and severity of fungal infections have increased, driven by factors such as population aging, the rise in immunosuppressed patients, the widespread use of biologic therapies, organ transplantation, and the spread of chronic diseases. In this context, animal and environmental reservoirs are becoming increasingly important in the transmission dynamics of these pathogens (Seyedmousavi et al., 2018).

Rodents play an important role in the ecology of multiple pathogenic fungi, both directly and indirectly. Through their burrowing, nesting, and displacement habits, they contribute to soil modification and the dispersal of fungal spores in the environment (Table 1). Likewise, the accumulation of organic matter in burrows, shelters, and infested areas favors the growth of saprophytic fungi with pathogenic potential. Contamination of the environment with urine, feces, and organic remains creates microenvironments conducive to the development and persistence of various fungal agents (Kitabayashi et al., 2022; Miranda et al., 2019).

From an epidemiological perspective, numerous mycoses of medical importance are associated, directly or indirectly, with habitats frequented by rodents (Table 2). These include histoplasmosis, cryptococcosis, dermatophytosis, blastomycosis, and sporotrichosis, among others (Almeida-Paes et al., 2022; Di Mango et al., 2019; Tirado-Sánchez et al., 2020). These infections can be acquired through inhalation of spores in environmental dust, direct contact with infected animals, or exposure to contaminated surfaces (Table 1). In many cases, transmission occurs inadvertently, making it difficult to identify sources of infection and limiting the timely implementation of preventive measures.

The accelerated process of urbanization, the expansion of informal settlements, deforestation, agricultural intensification, and climate change have profoundly altered the interactions among humans, animals, and ecosystems (Rodriguez-Morales, 2026). These environmental transformations favor increases in rodent populations and expand the areas of contact with human communities. At the same time, phenomena such as floods, droughts, and wildlife displacement alter the geographical distribution of pathogenic fungi, contributing to the emergence or re-emergence of fungal diseases in previously non-endemic regions (Morand et al., 2019; Tazerji et al., 2022).

In low- and middle-income countries, where deficiencies in health infrastructure, pest control, and epidemiological surveillance persist, the impact of rodent-associated mycoses can be particularly significant. The limited availability of specialized diagnostic methods, the low clinical suspicion, and the restricted access to antifungal treatments contribute to underdiagnosis and therapeutic delay, which increases the morbidity and mortality associated with these infections. In addition, in these contexts, occupational activities, such as agriculture, mining, and construction, increase exposure to polluted environments (Ortiz et al., 2024).

From a holistic perspective, rodent-borne fungal infections are a clear example of interdependence among humans, animals, and environmental health (Table 1). The One Health approach provides an adequate conceptual framework for understanding the complexity of these processes and for designing sustainable prevention and control strategies (Nowbuth and Parmar, 2025). The integration of veterinary, environmental, and clinical surveillance, together with community interventions and evidence-based public policies, is essential to mitigate the impact of these diseases (Ahmed et al., 2025b).

In this context, the present article aims to review in an updated way the role of rodents in the transmission of fungal infections, analyzing their ecological mechanisms, transmission routes, clinical manifestations, and repercussions on public health (Zhang et al., 2022), as we previously did for rodent-borne viruses (Muvunyi et al., 2024), bacteria (Basiouni et al., 2025), and parasites (Rodriguez-Morales et al., 2025). It also aims to highlight existing gaps in the current knowledge and to propose priority lines of research and action to strengthen the response to these emerging threats in an increasingly interconnected world.

Histoplasmosis

Histoplasmosis is a systemic mycosis caused by the dimorphic fungus *Histoplasma capsulatum*, which is among the most significant fungal pathogens worldwide from epidemiological and clinical perspectives (Table 1). This microorganism develops in mycelial form in soils rich in organic matter, particularly those contaminated with bird and bat droppings, and transforms into its yeast-like form after being inhaled by the human or animal host (Figure 1) (Al Mheiri et al., 2024; Furuie et al., 2016; Yglesias et al., 2023). The infection is acquired primarily through inhalation of microconidia in aerosols generated by activities that disturb the soil, such as agriculture, construction, or cleaning of enclosed spaces. Although most cases are asymptomatic or mild in immunocompetent individuals, histoplasmosis may progress to chronic or disseminated lung forms in immunosuppressed individuals, young children, and older adults (Ansari et al., 2016). From a clinical point of view, its spectrum of presentation is broad, ranging from self-limited respiratory symptoms to severe multisystem disease with involvement of the reticuloendothelial system. The geographical distribution of *H. capsulatum* is broad, with endemic areas in the Americas, Africa, and Asia, and environmental changes, population mobility, and ecosystem alterations have influenced its incidence. In this context, rodents indirectly help maintain favorable ecological niches for the fungus by modifying the soil and facilitating the accumulation of organic matter, thereby reinforcing their role in the disease's environmental dynamics (Hernández-Alomía et al., 2025).

Various epidemiological and ecological studies have shown that rodents play an important role in maintaining the environment for *Histoplasma capsulatum*, especially in endemic regions of Latin America, Africa, and Asia (Figure 1) (Hernández-Alomía et al., 2025). Research conducted in rural, peri-urban, and wild environments has identified a high frequency of fungal isolation in soils associated with burrows, nests, and rodent shelters, suggesting that these animals actively contribute to creating microhabitats favorable to fungal growth. Microbiological and molecular studies have detected *H. capsulatum* genetic material in lung and lymph node tissues from various species of wild and synanthropic rodents, indicating frequent exposure to the pathogen (Figure 1). These findings reinforce the hypothesis that rodents serve as biological indicators of the fungus's environmental circulation in endemic areas (Figure 1) (Hernández-Alomía et al., 2025).

From an experimental perspective, animal models have enabled characterization of the susceptibility of different rodent species to H. capsulatum infection and their immune responses to the pathogen (Cheemarla and Guerrero-Plata, 2015; Fregonezi et al., 2020). Studies in laboratory mice and rats have shown that inhalation of microconidia results in subclinical or chronic lung infections, with the microorganism persisting in reticuloendothelial system tissues. In many cases, these infections remain latent for long periods, favoring the fungus's survival in the host without causing obvious disease (Ansari et al., 2016). This phenomenon is particularly relevant from an epidemiological perspective, as it facilitates the pathogen's persistence in ecosystems and makes it difficult to detect with conventional surveillance systems.

The importance of rodent-associated histoplasmosis lies not only in their role as incidental hosts, but also in their influence on the environmental dynamics of the disease (Table 2) (Vasconcellos et al., 2019). Through their excavation, displacement, and accumulation of organic debris, rodents facilitate the dispersion of spores and the contamination of soils and enclosed spaces. In addition, close coexistence between rodents and humans in marginal urban contexts, precarious housing, and high-risk work environments increases the likelihood of human exposure to contaminated aerosols. In these scenarios, histoplasmosis outbreaks are usually associated with activities involving dust removal in infested areas where rodent colonies previously existed (Shehata et al., 2025).

From the zoonotic perspective, although histoplasmosis is not transmitted directly from rodents to humans by physical contact, these animals play a key role as environmental amplifiers of infectious risk (Li et al., 2023; Tomori and Oluwayelu, 2023; Zhang et al., 2022). Their presence favors the persistence of the fungus in shared ecosystems, making them indirect reservoirs and facilitators of airborne transmission. This pattern of indirect environmental transmission represents a particular form of zoonosis, in which the animal does not act as a classical vector, but as an ecological modulator of the pathogen.

Consequently, surveillance of rodent populations, environmental monitoring, and integrated pest control are fundamental tools for preventing human histoplasmosis, particularly in endemic regions. The incorporation of these components into One Health strategies is essential to reduce the health impact of this emerging disease (Alawneh et al., 2025).

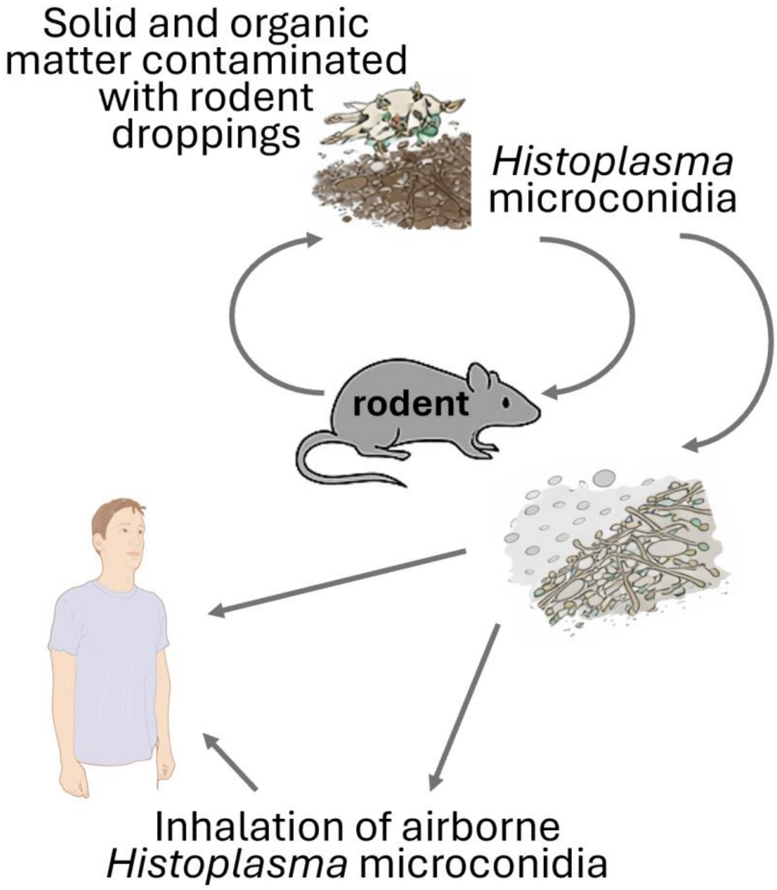

Figure 1: Life cycle of histoplasmosis, involving rodents. *Histoplasma capsulatum* persists in soil and organic matter enriched with rodent excreta, where it grows in its mycelial form and produces infectious microconidia. Rodents become exposed through contact with contaminated substrates and contribute to the maintenance and dissemination of the fungus by modifying the soil and dispersing organic debris. Environmental disturbance caused by natural processes or human activities aerosolizes microconidia, facilitating their inhalation by humans. After inhalation, the fungus transforms into its yeast form within pulmonary macrophages, initiating primary infection that may remain asymptomatic or progress to disseminated disease, particularly in immunocompromised individuals. Humans represent accidental hosts and do not contribute to further environmental contamination. This cycle highlights the central role of rodent–environment interactions in sustaining *H. capsulatum* transmission and underscores the importance of ecological and occupational exposure in the epidemiology of histoplasmosis.

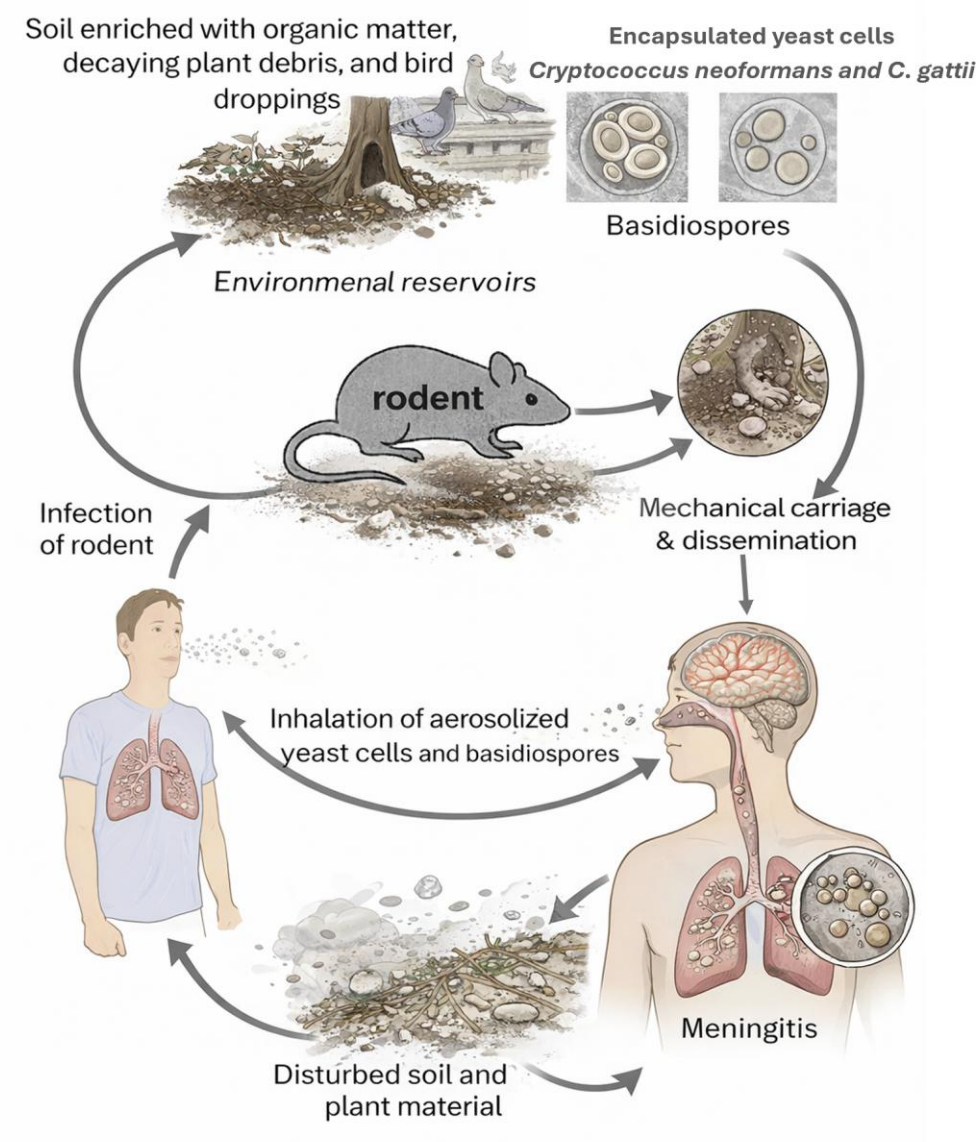

Figure 2: Life cycle of cryptococcosis, involving rodents. *Cryptococcus neoformans* and *Cryptococcus gattii* persist in soil, decaying plant material, and bird droppings, where they survive as encapsulated yeast cells and basidiospores. Rodents become exposed through contact with contaminated environments and contribute to mechanical carriage and environmental dissemination of fungal cells. Disturbance of contaminated substrates leads to aerosolization of infectious particles, thereby facilitating their inhalation by humans. Following inhalation, primary pulmonary infection may occur, with subsequent hematogenous dissemination, particularly to the central nervous system, resulting in meningoencephalitis, especially in immunocompromised individuals. Humans act as accidental dead-end hosts and do not contribute to further transmission. This cycle highlights the central role of environmental reservoirs and rodent–habitat interactions in sustaining cryptococcal circulation and emphasizes the importance of ecological and occupational exposure in disease emergence

Cryptococcosis

Cryptococcosis is a potentially serious systemic mycosis caused primarily by the encapsulated species *Cryptococcus neoformans* and *Cryptococcus gattii*, recognized for their marked ability to cause disease in humans and animals (Table 1) (Andrade et al., 2018; Cano et al., 2020; Kwon-Chung et al., 2017). These fungi are widely distributed in the environment, particularly in soils contaminated with bird droppings, decaying plant material, and other organic debris, where they can persist for extended periods. The infection is acquired mainly by inhalation of yeasts or basidiospores present in environmental aerosols, which initially leads to a primary lung infection that, in many cases, remains subclinical. However, in immunocompromised individuals, particularly in patients with HIV infection, transplant recipients, and people under immunosuppressive treatment, the microorganism can spread hematogenously, with a predilection for the central nervous system, producing cryptococcal meningoencephalitis (Firacative et al., 2018). From a clinical point of view, cryptococcosis has a broad spectrum that includes pulmonary, cutaneous, bone, and disseminated forms, associated with high morbidity and mortality when not diagnosed and treated promptly. Its global geographical distribution is accompanied by variable epidemiological patterns that depend on the species involved, climatic conditions, and environmental factors, underscoring the importance of its continuous surveillance and consideration in emerging mycosis control programs (Firacative et al., 2020).

Various ecological and epidemiological studies have shown that rodents can play a significant role in the environmental dispersal of *Cryptococcus* species, particularly *C. neoformans* and *C. gattii*, in both endemic and non-endemic regions (Table 2) (Hallas-Møller et al., 2024; Jimenez et al., 2024). Research conducted in urban, peri-urban, and wild environments has identified these fungi in soils, rodent burrows and shelters, and on surfaces contaminated with organic material. Microbiological and molecular studies have detected cryptococcal yeasts in respiratory, digestive, and skin samples from various rodent species, suggesting frequent exposure to the pathogen and a possible role as environmental carriers. These findings support the use of rodents as useful ecological indicators for monitoring the circulation of *Cryptococcus* across different ecosystems (Jimenez et al., 2024).

From an experimental perspective, animal models have contributed significantly to understanding the interaction between *Cryptococcus* and rodent hosts (Hansakon and Angkasekwinai, 2024; Mukaremera and Nielsen, 2017). Studies in laboratory mice and rats have shown that inhaling fungal cells leads to initial lung infections that can resolve spontaneously or evolve into latent, chronic forms, depending on the host's immune status. In these models, the fungus can persist in the lung, lymph node, and brain tissues for prolonged periods without obvious clinical manifestations. This persistence capacity favors the pathogen's survival in animal populations and reinforces its potential to persist in the environment, making it difficult to detect with conventional monitoring systems (Wiesner et al., 2016).

The epidemiological importance of rodent-associated cryptococcosis lies mainly in its indirect contribution to environmental pollution and the amplification of the risk of human exposure. Excavation, displacement, and colony establishment activities favour the redistribution of Cryptococcus-contaminated particles in soil and enclosed spaces, such as warehouses and abandoned homes. In contexts of poverty, overcrowding, and poor sanitation, where coexistence between humans and rodents is common, the risk of inhaling contaminated aerosols increases. In addition, the coexistence of birds and rodents in certain environments enhances the availability of highly favorable ecological niches for the fungus's proliferation (Guterres et al., 2021).

From a zoonotic perspective, cryptococcosis represents a model of indirect transmission mediated by the environment, in which rodents do not act as classical vectors or direct transmitters but rather as ecological modulators of infectious risk. Their role as secondary reservoirs and passive disseminators contributes to the persistence of the pathogen in ecosystems shared with humans. This transmission pattern highlights the need to integrate synanthropic wildlife surveillance, rodent control, and environmental monitoring into prevention programs. Within the One Health framework, the systematic study of rodent populations is essential for anticipating outbreaks, identifying risk areas, and designing sustainable interventions to reduce the global burden of cryptococcosis (Mistrick et al., 2024).

Dermatophytosis

Dermatophytosis, commonly known as ringworm, is a superficial fungal infection caused by keratinophilic fungi belonging to the genera *Trichophyton*, *Microsporum*, and *Epidermophyton*, which can invade keratin-rich tissues, such as skin, hair, and nails. These microorganisms are widely distributed in the environment (Table 1). They can be classified according to their primary reservoirs as anthropophilic, zoophilic, and geophilic species; the latter two are particularly relevant for animal-to-human transmission, including from rodents. The infection is acquired primarily through direct contact with infected individuals or animals, as well as through exposure to contaminated fomites and surfaces, thereby facilitating its spread in human communities and domestic environments (Rathi et al., 2025; Thakur and Kalsi, 2020). From a clinical perspective, dermatophytosis presents with a wide spectrum of manifestations, including erythematous, pruritic, and actively edged lesions, with variable localization depending on the affected body area, such as tinea corporis, tinea capitis, tinea pedis, and onychomycosis. Although it is not generally life-threatening, its high prevalence, tendency to recur, and impact on quality of life make it a significant public health concern, particularly in vulnerable populations and in contexts with poor hygienic and sanitary conditions (Zha and Usatine, 2024).

Various epidemiological and microbiological studies have documented the role of rodents as natural reservoirs of zoophilic and geophilic dermatophytes, particularly *Trichophyton mentagrophytes*, *Trichophyton benhamiae,* and *Microsporum gypseum*. Research conducted in wild, synanthropic, and laboratory rodent populations has shown variable prevalence of skin, hair, and nail colonization by these fungi in both symptomatic and asymptomatic animals. The use of culture techniques, microscopy, and molecular methods has enabled confirmation of the active circulation of dermatophytes in urban and rural environments, particularly in settings characterized by high population density, overcrowding, and poor sanitation. These studies suggest that rodents may act as persistent reservoirs, facilitating continued transmission of the pathogen in ecosystems shared with humans and other animals (Bontems et al., 2020; Zha and Usatine, 2024).

From an experimental perspective, animal models have been instrumental in understanding the pathogenesis, immune response, and transmission mechanisms of dermatophytosis. Studies in mice and rats have shown that dermal inoculation with dermatophytes leads to the development of superficial lesions characterized by inflammation, flaking, and hair loss, with variations depending on the fungal strain and the host's immune status. In many cases, the infection can resolve spontaneously, although subclinical forms persist, facilitating the silent spread of the fungus. The ability of dermatophytes to persist on fur and skin scales for prolonged periods underscores their potential for indirect transmission via contact with contaminated surfaces and materials (Tan et al., 2022).

The epidemiological importance of rodent-associated dermatophytosis lies in its high transmissibility and its impact on human and animal health, especially in domestic, school, and occupational environments. In communities with high levels of coexistence between people and rodents, such as informal settlements, markets, warehouses, and precarious housing, the risk of transmission increases considerably. In addition, rodents can introduce dermatophytes into hatcheries, laboratories, pet stores, and zoos, favoring outbreaks in animals and humans. These infections, although generally benign, incur substantial economic costs from treatment, loss of productivity, and health control measures, underscoring their relevance from a public health perspective (Thakur and Kalsi, 2019).

From a zoonotic perspective, dermatophytosis is among the mycoses most clearly associated with direct transmission between animals and humans. Rodents act as primary or secondary reservoirs, capable of transmitting dermatophytes through direct contact, animal handling, bites, or through contaminated fomites, such as cages, clothing, and cleaning materials. This pattern of transmission facilitates the occurrence of family, school, and occupational outbreaks, particularly in children, animal keepers, and laboratory personnel. Under the One Health approach, controlling dermatophytosis requires integrated strategies, including veterinary surveillance, community education, rodent control, and strengthening hygiene practices, to sustainably reduce the global burden of this fungal zoonosis (Martín-Vaquero et al., 2021).

The genus *Microsporum* comprises keratinophilic filamentous fungi in the family *Arthrodermataceae*, widely recognized as etiological agents of dermatophytosis in humans and animals (Table 1). These species are characterized by their affinity for keratin-rich structures, especially hair and skin, where they cause superficial infections by secreting keratinolytic enzymes that facilitate tissue invasion (Martinez-Rossi et al., 2017). From an ecological perspective, members of the genus *Microsporum* are classified as anthropophilic, zoophilic, and geophilic; the latter two are particularly relevant to animal-associated transmission, including that involving rodents. Its distribution is global and closely related to environmental factors, including humidity, temperature, and organic soil matter. The infection is acquired primarily through direct contact with infected hosts or via contaminated fomites and surfaces, thereby facilitating its spread in domestic, school, and occupational environments. Clinically, *Micros Porum* infections manifest with well-defined erythematous squamous lesions, areas of alopecia, and fragility of the hair shaft, with *Microsporum canis* and *Microsporum gypseum* being some of the most relevant species from the epidemiological point of view, which makes this genus a central component in the dynamics of superficial mycoses of public health importance (Jańczak et al., 2023).

Various epidemiological and mycological studies have shown that species of the genus *Microsporum* are present in wild, synanthropic, and laboratory rodent populations, particularly in rural and peri-urban environments. Research conducted across different geographic regions has reported frequent isolation of Microsporum gypseum, *M. canis*, and related species from skin, fur, and soil samples collected from burrows and rodent shelters (Bescrovaine et al., 2023). The application of mycological culture techniques, microscopy, and molecular methods has confirmed the genetic diversity and wide distribution of these dermatophytes in ecosystems shared with humans and animals. These findings support the role of rodents as natural reservoirs and epidemiological sentinels for monitoring the environmental circulation of *Microsporum* (Fratti et al., 2023).

From an experimental perspective, animal models have been fundamental for understanding the pathogenesis of Microsporum infections and their interactions with the host immune system. Studies in mice and rats have shown that skin inoculation leads to the development of superficial lesions characterized by desquamation, erythema, focal alopecia, and hair shaft fragility, with variations in intensity depending on the fungal species and the animal's immune status. In many cases, the infection can be self-limited; however, subclinical forms persist, promoting prolonged colonization and silent dissemination of the fungus. The ability of *Microsporum* to survive on skin scales and hair fragments for prolonged periods increases its potential for indirect transmission (Shi et al., 2024).

The epidemiological importance of *rodent-associated Microsporum* infections lies in their contribution to the emergence and maintenance of endemic foci of dermatophytosis in human communities. In contexts characterized by close coexistence among people, domestic animals, and rodents, such as informal settlements, schools, farms, and research centers, the risk of transmission is considerably higher. Likewise, rodents can introduce and spread these fungi in breeders, animal shelters, and veterinary facilities, thereby facilitating outbreaks that affect both humans and animals. These infections have significant impacts on quality of life, school and work performance, and health system costs, underscoring their relevance from a public health perspective (Nikaein et al., 2023).

From a zoonotic perspective, dermatophytoses caused by *Microsporum* represent a classic example of direct and indirect transmission between animals and humans, in which rodents serve as secondary reservoirs and passive disseminators of the pathogen. Transmission can occur through direct contact with colonized animals, handling contaminated cages and materials, or exposure to infested surfaces and soils. This pattern facilitates the occurrence of family, school, and occupational outbreaks, especially in children, animal keepers, laboratory personnel, and rural workers. Within the framework of the One Health approach, effective control of these infections requires integrated strategies that include veterinary surveillance, community education, strengthening hygiene practices, rodent control, and environmental monitoring to reduce the burden of these fungal zoonoses sustainably (Jahan et al., 2021).

The genus *Trichophyton* comprises keratinophilic filamentous fungi in the family *Arthrodermataceae*, which are responsible for a significant proportion of dermatophytoses in humans and animals worldwide (Table 1). These species are characterized by their ability to invade and degrade keratin-rich tissues, such as skin, hair, and nails, by producing specialized proteolytic enzymes (Łagowski et al., 2021; Lahmer et al., 2024). From an ecological perspective, members of the genus Trichophyton can be classified into anthropophilic, zoophilic, and geophilic species; the latter two are particularly relevant for animal-associated transmission, including that involving rodent. Its distribution is global and closely related to environmental, climatic, and socioeconomic factors, such as overcrowding, humidity, and hygienic-sanitary deficiencies. Infection is acquired primarily through direct contact with infected hosts or through exposure to contaminated surfaces and objects, facilitating its spread in human communities, the home, and occupational settings (Rodríguez-Cerdeira et al., 2021). From a clinical perspective, Trichophyton infections encompass a broad spectrum that includes tinea corporis, tinea capitis, tinea pedis, and onychomycosis, with manifestations characterized by erythematous, pruritic, and chronically evolving lesions, making this genus a central component of the epidemiology of superficial mycoses (Cai et al., 2016).

Various epidemiological and mycological

studies have documented the frequent presence of Trichophyton species in wild, synanthropic, and laboratory rodent populations, particularly in urban and peri-urban environments. Research conducted on different continents has identified recurrent isolates of Trichophyton mentagrophytes, *T. benhamiae*, and related species in the skin, fur, and keratin material of rodents, both with visible lesions and in asymptomatic carriers. The use of traditional cultural techniques, microscopy, and, more recently, molecular methods has enabled more precise characterization of the genetic diversity and geographical distribution of these fungi. These findings confirm that rodents constitute important natural reservoirs for environmental persistence and transmission of *Trichophyton* in shared ecosystems (Fratti et al., 2023).

From an experimental perspective, animal models have been fundamental for understanding the mechanisms of infection and the immune response to dermatophytoses caused by *Trichophyton*. Studies in mice and rats have shown that skin inoculation leads to the development of superficial lesions characterized by hyperkeratosis, local inflammation, and desquamation, with variations depending on the fungal species and the host's immune status. In many cases, the infection can resolve spontaneously; however, subclinical forms persist, facilitating the silent dissemination of the pathogen. The ability of these fungi to survive on fur and skin scales for prolonged periods increases their potential for direct and indirect transmission (Fratti et al., 2023).

The epidemiological importance of *rodent-associated Trichophyton* infections lies in their high prevalence, ease of spread, and impact on human and animal health. In environments characterized by overcrowding, poor hygiene, and close coexistence of humans and rodents, such as informal settlements, markets, warehouses, and laboratories, the risk of transmission increases significantly. In addition, rodents can serve as vectors for introducing dermatophytes into breeding sites, research facilities, and pet stores, thereby facilitating outbreaks that affect animals, workers, and visitors. These infections incur significant health and social costs, including prolonged treatment, recurrence, and absenteeism from work or school (Tekin et al., 2019).

From a zoonotic perspective, dermatophytoses caused by *Trichophyton* represent one of the clearest examples of direct animal-to-human transmission within superficial mycoses. Rodents act as primary or secondary reservoirs that can transmit the fungus through direct contact, handling, bites, or contaminated fomites, such as cages, clothing, tools, and surfaces. This pattern facilitates the occurrence of family, community, and occupational outbreaks, especially in children, animal keepers, laboratory personnel, and agricultural workers. Under the One Health approach, effective control of these infections requires integrated strategies that include veterinary surveillance, community education, rodent control, strengthening hygiene practices, and timely access to diagnosis and treatment, to reduce their impact on public health sustainably (Bontems et al., 2020).

Blastomycosis

Blastomycosis is a systemic mycosis caused by the dimorphic fungus *Blastomyces dermatitidis* and related species of the *Blastomyces* complex, recognized for its potential to cause lung and disseminated disease in humans and animals (Table 1). This microorganism primarily inhabits moist soils rich in organic matter, particularly in areas near rivers, lakes, forests, and sites with abundant decomposing plant material, where it can persist for extended periods. The infection is acquired primarily through inhalation of aerosolized conidia after soil disturbance, leading to a primary lung infection that may be asymptomatic or manifest as an acute or chronic respiratory condition. In certain cases, the fungus can spread hematogenously to the skin, bones, genitourinary system, and central nervous system, producing potentially serious extrapulmonary forms (Hashim and Barrios, 2020; Linder et al., 2023; Mak et al., 2018). From a clinical point of view, blastomycosis presents a wide spectrum of manifestations that vary from self-limiting disease to severe systemic conditions, particularly in immunocompromised individuals. Its geographical distribution is relatively focal, with a predominance in regions of North America, although cases have been documented in other parts of the world, which highlights the importance of its epidemiological surveillance and its consideration within the group of emerging mycoses associated with environmental and ecological factors (Najdawi et al., 2023).

Various ecological and epidemiological studies have shown that rodents play a relevant role in the environmental maintenance of *Blastomyces dermatitidis* and related species, particularly in endemic regions of North America.

Research conducted in river, forest, and riparian ecosystems has identified the fungus in soils associated with burrows, natural refuges, and areas frequented by wild and synanthropic rodents. The use of advanced molecular techniques has enabled the detection of Blastomyces genetic material in environmental samples and small mammalian tissues, suggesting frequent exposure to the pathogen. These findings support the hypothesis that rodents act as incidental hosts and as biological indicators of fungal circulation in risk areas (Jackson et al., 2021).

From an experimental perspective, rodent models have been fundamental to understanding the pathogenesis and immune responses to *Blastomyces* infection. Studies in laboratory mice have shown that inhalation of conidia results in an initial lung infection characterized by granulomatous inflammation and activation of the cellular immune system. In many cases, the infection remains subclinical or is partially controlled, allowing the fungus to persist in the lungs and lymphatic tissues. This capacity for intracellular survival and dormancy contributes to the maintenance of the pathogen in animal populations, favoring its permanence in ecosystems (Ferling et al., 2020).

The epidemiological importance of rodent-associated blastomycosis lies in its indirect contribution to environmental risk amplification and to the identification of endemic foci. The digging and territorial behavior of these animals facilitate the redistribution of contaminated soils and the generation of aerosols containing infectious spores, particularly during natural events or human activities that alter the environment. In rural communities, recreational areas, and forests, interactions among humans, rodents, and contaminated environments increase the likelihood of exposure. Likewise, outbreaks of blastomycosis in humans and domestic animals often coincide with documented rodent presence in affected areas (Diaz, 2021).

From a zoonotic perspective, blastomycosis represents a model of indirect environmental transmission, in which rodents do not act as vectors or directly transmit the infection to humans, but as ecological modulators of infectious risk. Their role as secondary hosts and passive dispersers contributes to the persistence of the fungus in shared habitats. This pattern highlights the need to integrate wildlife surveillance, environmental monitoring, and rodent population control into prevention programs. Within the framework of the One Health approach, the systematic study of these animals makes it possible to anticipate outbreaks, delimit endemic areas, and design sustainable strategies aimed at reducing the global burden of blastomycosis (Brennan et al., 2024).

Sporothrix

The genus *Sporothrix* comprises dimorphic fungi in the family Sporotrichaceae, widely recognized as the etiological agents of sporotrichosis, a subcutaneous mycosis of worldwide distribution, with particular predominance in tropical and subtropical regions (Table 1). These species primarily inhabit soils, decomposing plant matter, moss, wood, and other organic remains, where they develop in mycelial form at room temperature and transform into yeasts within host tissues after infection. Transmission occurs primarily through traumatic inoculation of the fungus via skin wounds caused by animal thorns, splinters, bites, or scratches, which facilitates its introduction into the subcutaneous tissue (Lemes et al., 2021; Xavier et al., 2025). Clinically, sporotrichosis is characterized by subcutaneous nodules that may ulcerate and spread along lymphatic vessels, giving rise to the classic lymphocutaneous form; however, fixed, pulmonary, and disseminated forms can also occur, particularly in immunocompromised individuals. The geographical distribution and incidence of the disease are influenced by environmental, occupational, and socioeconomic factors, such as agricultural activity, gardening, and contact with animals, which highlights the importance of Sporothrix within the group of emerging mycoses associated with the interaction between humans, animals, and ecosystems (Celiker and Lin, 2024; Fischman Gompertz et al., 2016; Shah et al., 2021).

Various ecological and mycological studies have documented the presence of *Sporothrix* species in environments frequented by rodents, particularly in soils rich in organic matter, burrows, natural refuges, and areas with abundant decomposing vegetation. Research conducted in endemic regions of Latin America, Africa, and Asia has detected environmental isolates and genetic material of *Sporothrix* in soil samples and on contaminated surfaces associated with rodent colonies. Likewise, serological and microbiological studies have identified prior exposure among small mammals, suggesting their indirect involvement in the pathogen's ecological dynamics. These findings support the role of rodents as environmental facilitators in the persistence and dispersal of the fungus in shared ecosystems (Chow et al., 2021).

From an experimental perspective, animal models have significantly contributed to understanding the pathogenesis and immune responses to *Sporothrix* infection. Studies in mice have shown that skin inoculation with the fungus produces nodular, ulcerated, and granulomatous lesions that reproduce the clinical manifestations observed in humans. In many cases, the infection remains localized; however, in immunosuppressed animals, it can progress to disseminated forms with systemic involvement. The fungus's ability to survive in subcutaneous tissues and partially evade the immune response promotes persistence and facilitates its maintenance in animal reservoirs (Patel et al., 2016).

The epidemiological importance of rodent-associated sporotrichosis lies mainly in its indirect contribution to environmental pollution and increased risk of human exposure. The activities of digging, moving, and nesting rodents favor the removal of contaminated soil and the redistribution of infected plant material, thereby increasing the likelihood of contact with *Sporothrix* during agricultural, forestry, and domestic activities. In rural and peri-urban contexts, where there is close interaction between humans, domestic animals, and wildlife, these processes facilitate the emergence of endemic foci and localized outbreaks (Santos et al., 2024).

From a zoonotic perspective, sporotrichosis exhibits a mixed pattern of environmental and animal transmission, in which rodents do not act as primary direct transmitters but rather as ecological modulators of infectious risk. Their role as secondary reservoirs and passive dispersers contributes to the persistence of the fungus in habitats shared with humans. This pattern highlights the need to integrate rodent control, environmental monitoring, and community education into prevention programs. Within the One Health framework, the systematic study of rodent populations is essential to anticipate new outbreaks, strengthen early detection, and design sustainable strategies to reduce the global burden of sporotrichosis (Williams et al., 2021).

Climate change and anthropogenic activities leading to the emergence of rodent-borne fungal zoonoses

Climate change is a major environmental determinant of ecosystem reconfiguration and the dynamics of emerging infectious diseases, including rodent-associated mycoses. The sustained increase in global temperature, alterations in precipitation patterns, the greater frequency of droughts, floods, and storms, and the modification of seasonal cycles directly influence the distribution, density, and behavior of rodent populations. These variations favor the expansion of synanthropic species into new geographic areas, prolonging reproductive periods and increasing their survival in previously unfavorable environments. At the same time, hot, humid climatic conditions promote the growth, sporulation, and persistence of pathogenic fungi in soil and organic matter, increasing the likelihood of human exposure to agents such as *Histoplasma*, *Cryptococcus*, *Blastomyces*, and *Sporothrix* (Lockhart et al., 2021).

Table 1: Main rodent-associated fungal infections and their characteristics.

Pathogen	Mycological Characteristics	Clinical Impact	Transmission Routes	Preventive Measures
Histoplasma capsulatum	Dimorphic fungus; mycelial form in soil and yeast form in tissues; grows in organic-rich soils	Pulmonary, chronic, and disseminated histoplasmosis; systemic involvement	Inhalation of microconidia in contaminated dust	Rodent control, respiratory protection, ventilation, and proper soil management
Cryptococcus neoformans / C. gattii	Encapsulated yeast; environmentally resistant; persists in organic soils	Cryptococcal meningitis; pulmonary and systemic disease	Inhalation of yeasts or basidiospores	Environmental hygiene; dust control; sanitation
Dermatophytes *(Trichophyton, Microsporum, Epidermophyton)*	Superficial keratinophilic fungi; zoophilic and geophilic species	Dermatophytosis: tinea corporis, capitis, pedis, unguium	Direct, indirect, and environmental contact	Health education; hygiene; reservoir control
Trichophyton mentagrophytes	Zoophilic keratinophilic fungus; colonizes skin, hair, and nails	Dermatophytosis: cutaneous tinea, alopecia, pruritus	Direct contact with rodents; contaminated fomites	Hygiene; disinfection; veterinary control

Microsporum gypseum	Geophilic fungus; present in keratin-rich soil	Inflammatory dermatophytosis; extensive skin lesions	Contact with contaminated soil	Personal protection; environmental cleaning
Blastomyces dermatitidis	Dimorphic fungus; moist soils rich in organic matter	Pulmonary and disseminated blastomycosis	Inhalation of conidia	Environmental monitoring; respiratory protection
Sporothrix schenckii complex	Environmental dimorphic fungus; associated with plant material	Lymphocutaneous and systemic sporotrichosis	Traumatic inoculation; environmental contact	Use of gloves; environmental control

Table 2: Rodent species associated with medically important fungal pathogens and their geographical distribution.

Rodent Genus and Species	**Reported Fungal Species of Medical Importance**	**Geographical Distribution (Continent)**
Rattus norvegicus (Norway rat)	*Histoplasma capsulatum; Cryptococcus neoformans; Trichophyton mentagrophytes; Microsporum gypseum*	North America, South America, Europe, Asia, Africa, Oceania
Rattus rattus (Black rat)	*Histoplasma capsulatum; Cryptococcus neoformans; Trichophyton spp.; Sporothrix schenckii*	Africa, Asia, Europe, the Americas, Oceania
Mus musculus (House mouse)	*Histoplasma capsulatum; Cryptococcus neoformans; Trichophyton spp.; Microsporum spp.*	Worldwide (except Antarctica)
Peromyscus maniculatus (Deer mouse)	*Histoplasma capsulatum; Blastomyces dermatitidis*	North America
Sigmodon hispidus (Cotton rat)	*Histoplasma capsulatum; Blastomyces dermatitidis*	North America
Oligoryzomys spp.	*Histoplasma capsulatum; Sporothrix spp.*	South America
Akodon spp.	*Histoplasma capsulatum; Microsporum spp.*	South America
Bandicota indica (Greater Bandicoot rat)	*Cryptococcus neoformans; Trichophyton spp.*	Asia
Mastomys natalensis (Multimammate rat)	*Histoplasma capsulatum; Cryptococcus spp.*	Africa
Apodemus sylvaticus (Wood mouse)	*Trichophyton spp.; Microsporum spp.*	Europe
Microtus arvalis (Common vole)	*Trichophyton spp.; Microsporum gypseum*	Europe, Asia
Meriones spp. (Gerbils)	*Histoplasma capsulatum; Trichophyton spp.*	Africa, Asia

Anthropogenic activities play a central role in modifying natural landscapes and generating ecological interfaces that facilitate the transmission of fungal zoonoses. Processes such as deforestation, unplanned urbanization, agricultural expansion, mining, infrastructure construction, and habitat fragmentation disrupt traditional wildlife refuges, forcing rodents to move into peri-urban and urban environments. These transformations increase the spatial overlap among humans, domestic animals, and rodents, thereby facilitating contact with soils, dust, and contaminated surfaces. Likewise, the accumulation of solid waste, inadequate wastewater management, and precarious housing favor the proliferation of rodents and the creation of favorable microenvironments for the development of pathogenic fungi (Hassell et al., 2017).

The synergistic interaction between climate change and anthropogenic pressures intensifies the epidemiological complexity of rodent-associated zoonotic mycoses and complicates their control. Human migrations, population growth, the occupation of previously wild areas, and the increase in recreational and work activities in natural environments amplify opportunities for exposure. In addition, health systems, particularly in low- and middle-income countries, face limitations in their ability to respond promptly to emerging scenarios. In this context, it is essential to adopt integrated approaches grounded in the One Health paradigm that incorporate climate, environmental, veterinary, and clinical surveillance, as well as public policies aimed at mitigating climate change, promoting sustainable land management, and strengthening community resilience to emerging fungal zoonoses (Shehata et al., 2025).

Prevention and control strategies based on the One Health approach

Prevention and control strategies for rodent-borne fungal zoonoses should be based on the One Health approach, which recognizes the interdependence between human, animal, and environmental health. From this perspective, it is essential to strengthen integrated epidemiological surveillance systems that enable simultaneous monitoring of the circulation of pathogenic fungi across human, animal, and environmental populations. This includes implementing systematic sampling programs in soils, burrows, and rodent refuges; monitoring infections in wildlife and domestic animals; and strengthening diagnostic capacity within health services. The integration of climate, ecological, and health data facilitates early identification of risk areas and the prediction of outbreaks, enabling timely, evidence-based interventions (Ahmed et al., 2025a; Sangkachai et al., 2024).

Effective control of fungal zoonoses also requires coordinated interventions targeting environmental management and sustainable rodent population management. These actions include improving sanitation infrastructure, managing solid waste and wastewater effectively, reducing food sources and shelter for rodents, and designing infestation-resistant housing and public spaces. It is also essential to promote safe practices in high-risk occupational and recreational activities, such as agriculture, mining, construction, and cleaning of enclosed spaces, by using personal protective equipment and biosafety protocols. The active participation of environmental, veterinary, and municipal authorities is key to ensuring the sustainability of these measures (Sangkachai et al., 2024).

Finally, community education and the strengthening of intersectoral cooperation are fundamental pillars of the One Health approach to preventing fungal zoonoses. It is essential to develop awareness programs for vulnerable communities, exposed workers, and health professionals that promote early recognition of symptoms, timely access to medical care, and the adoption of appropriate hygiene practices. At the same time, collaboration among academic institutions, government agencies, non-governmental organizations, and international organizations should be encouraged to advance research, facilitate information exchange, and support the development of comprehensive public policies. This multidimensional approach enables the holistic management of fungal zoonoses, thereby reducing their long-term health, social, and economic impacts (Heo et al., 2020; Nyokabi et al., 2023).

Limitations

Despite providing a comprehensive overview of rodent-associated fungal zoonoses, this review has several limitations that should be acknowledged. First, much of the available evidence derives from observational studies, case reports, and localized ecological investigations, which limit the generalizability of findings across geographic and socioeconomic contexts. In many regions, particularly in low- and middle-income countries, systematic surveillance of fungal pathogens in rodent populations and environmental reservoirs remains limited, potentially underestimating disease burden and transmission dynamics. In addition, variability in diagnostic capacity and reporting practices may contribute to inconsistencies in epidemiological data.

Second, the indirect nature of transmission for several fungal pathogens complicates establishing clear causal links between rodent exposure and human infection. In many cases, environmental contamination is the primary pathway of transmission, making it difficult to disentangle the specific contribution of rodents from other ecological and climatic factors. Furthermore, experimental models, while valuable for understanding pathogenesis and host responses, may not fully replicate natural transmission scenarios or the complex interactions observed in real-world ecosystems.

Finally, this review is limited by the heterogeneity of study designs, methodologies, and outcome measures across the existing literature. Differences in sampling strategies, laboratory techniques, and molecular tools hinder direct comparisons among studies and restrict the synthesis of robust conclusions. The scarcity of longitudinal, multidisciplinary, and population-based investigations also limits the understanding of long-term trends and the impact of environmental change. Future research should prioritize standardized surveillance protocols, integrated One Health approaches, and collaborative multicenter studies to address these gaps and strengthen the evidence base for prevention and control strategies.

Conclusions

Rodent-borne fungal infections represent an emerging and underrecognized threat to global public health, particularly amid the profound environmental, climatic, and social changes that characterize the contemporary world. This work shows that medically important fungi, such as *Histoplasma*, *Cryptococcus*, *Trichophyton*, *Microsporum*, *Blastomyces*, and *Sporothrix*, maintain complex ecological interactions with rodent populations, thereby favoring their persistence in the environment and eventual transmission to humans. These pathogens, although they differ in their mechanisms of infection and clinical manifestations, share determinants related to environmental degradation, accelerated urbanization, and limited health surveillance that contribute to their emergence and re-emergence across regions (Gonçalves et al., 2019; Muvunyi et al., 2024).

From an epidemiological and clinical perspective, rodent-associated fungal zoonoses pose significant challenges to health systems, particularly in low- and middle-income countries. Underdiagnosis, low clinical suspicion, limited access to specialized diagnostic methods, and the restricted availability of timely antifungal treatments remain significant barriers to the effective control of these diseases. Likewise, heterogeneity in geographic distribution, variability in transmission patterns, and the influence of sociocultural factors complicate the implementation of uniform prevention strategies. In this context, it is essential to strengthen health personnel training, promote interdisciplinary research, and consolidate surveillance networks to enable a faster and more efficient response to emerging pathogens (Xiques-Molina et al., 2025).

Finally, a sustainable approach to rodent-borne fungal zoonoses requires the full adoption of the One Health approach, which systematically integrates human, animal, and environmental components. The articulation among governmental, academic, and community sectors, together with public policies aimed at mitigating climate change, responsible management of the territory, and integrated rodent control, constitutes a fundamental axis for reducing future risk. Likewise, the development of early warning systems, the strengthening of community education, and the promotion of safe practices in high-risk environments will facilitate progress toward more effective control of these diseases. In an increasingly interconnected world, understanding and addressing these threats from a holistic perspective represents a strategic priority for protecting global health (Awaidy and Al Hashami, 2020).

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