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Neglected and Dangerous: A Systematic Review of Fungal Pathogens as Public Health Threats

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Abstract

Fungal pathogens cause over 1.7 million deaths annually, comparable to tuberculosis and malaria, yet they remain critically neglected in public health priorities, research funding, and surveillance systems. This comprehensive review synthesizes evidence from 130 studies (2010-2025) examining the global burden, emerging threats, and systemic neglect of fungal diseases. Major fungal pathogens including *Candida*, *Aspergillus*, *Cryptococcus*, *Pneumocystis*, and emerging fungi such as *Candida auris* and drug resistant dermatophytes cause life threatening infections, particularly among immunocompromised populations (HIV, cancer, transplant, ICU patients). Climate change is driving geographic expansion and novel emergence, including *Coccidioides* (Valley fever) and *Histoplasma*. Antifungal resistance is rising, with multidrug resistant *C. auris* spreading globally and azole resistant *Aspergillus fumigatus* linked to agricultural fungicide use. Despite the burden, fungal diseases receive less than 1.5% of infectious disease research funding, are absent from many national disease surveillance systems, and lack rapid diagnostics and affordable treatments in low resource settings. The COVID-19 pandemic exacerbated fungal threats, with COVID-19 associated aspergillosis and candidiasis contributing to excess mortality. We recommend integrating fungal pathogens into WHO priority pathogen lists, establishing global surveillance networks, investing in diagnostics and antifungal development, and including fungal threats in pandemic preparedness frameworks. Fungal neglect is a preventable public health failure.

Keywords: Fungal pathogens; neglected diseases; antifungal resistance; *Candida auris*; climate change; emerging infectious diseases; global health security

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1. Introduction

Fungal pathogens kill an estimated 1.7 million people each year, more than malaria and comparable to tuberculosis, yet they remain largely invisible in global public health discourse (Denning, 2024). The annual mortality from fungal diseases exceeds that of breast cancer or prostate cancer, and the global burden of severe fungal infections is estimated at over 150 million cases annually (Bongomin *et al.*, 2017; Brown *et al.*, 2022). Despite these staggering numbers, fungal diseases receive a fraction of the research funding, policy attention, and public awareness allocated to bacterial, viral, and parasitic infections (Rodrigues and Nosanchuk, 2023). This neglect is not due to a lack of clinical need. Immunosuppressed populations are expanding: HIV/AIDS, cancer chemotherapy, organ transplantation, stem cell transplantation, advanced age, intensive care unit admissions, and immunomodulatory biologics all increase susceptibility to fungal infections (Armstrong James *et al.*, 2024). The COVID-19 pandemic added millions of critically ill patients who developed secondary fungal infections, COVID-19 associated pulmonary aspergillosis (CAPA) and COVID-19 associated candidiasis (CAC), with attributable mortality exceeding 30-50% (Hoenigl *et al.*, 2022).

The fungal threat is growing and evolving. Climate change is expanding the geographic range of endemic fungi such as *Coccidioides* (Valley fever) and *Histoplasma*, exposing previously unexposed populations (Benedict and Jackson, 2025). Novel fungal pathogens have emerged, most dramatically *Candida auris*, a multidrug resistant yeast that spreads in healthcare settings and caused outbreaks on six continents within a decade (Lockhart *et al.*, 2023). Antifungal resistance is accelerating, driven by agricultural fungicide use that selects for cross resistance to clinical azoles, and by extensive antifungal use in healthcare (Fisher *et al.*, 2022). The World Health Organization responded in 2022 with its first ever Fungal Priority Pathogens List (WHO FPPL), classifying 19 fungi into critical, high, and medium priority categories, acknowledging that fungal threats have been systematically neglected (WHO, 2022). However, listing is not action; implementation of surveillance, diagnostics, treatment access, and research funding lags far behind (Rodrigues and Nosanchuk, 2025).

This comprehensive review aims to synthesize the evidence on fungal pathogens as neglected public health threats. We address eight key questions: (1) What is the global burden of fungal diseases, and which populations are most affected? (2) What are the major fungal pathogens, including emerging threats? (3) How is climate change driving fungal emergence and geographic expansion? (4) What is the state of antifungal resistance, and what are its drivers? (5) How did the COVID- 19 pandemic exacerbate fungal threats? (6) What are the diagnostic and treatment gaps, particularly in low resource settings? (7) Why are fungal diseases neglected in research funding and surveillance? (8) What policy and research priorities are needed? We argue that fungal pathogens are not niche tropical diseases but global public health threats requiring urgent integration into mainstream infectious disease frameworks.

2. General Review

2.1 Global Burden of Fungal Diseases

Estimating the global burden of fungal diseases is challenging due to underdiagnosis, lack of surveillance, and limited diagnostic capacity in low resource settings. The most comprehensive estimates from the Global Action Fund for Fungal Infections (GAFFI) and the LIFE program (Leading International Fungal Education) provide the following annual figures: over 1.7 million deaths attributed to fungal diseases, over 150 million serious fungal infections, and over 1 billion people affected by superficial fungal infections (Denning, 2024). The leading causes of fungal mortality are: chronic pulmonary aspergillosis (CPA) (~450,000 deaths), invasive candidiasis (~350,000 deaths), *Pneumocystis* pneumonia (~200,000 deaths, primarily in HIV positive individuals), cryptococcal meningitis (~150,000 deaths, primarily HIV associated), and invasive aspergillosis (~100,000 deaths) (Bongomin *et al.*, 2017; Brown *et al.*, 2022).

Geographic variation is substantial. Cryptococcal meningitis is the leading cause of adult meningitis in sub- Saharan Africa, causing an estimated 150,000 deaths annually, largely among people living with HIV (Rajasingham *et al.*, 2024). Histoplasmosis and talaromycosis are hyperendemic in Southeast Asia and the Americas but rarely diagnosed (Baker *et al.*, 2023).

Coccidioidomycosis (Valley fever) is endemic in the southwestern United States and parts of Central and South America, with over 20,000 reported cases annually in the US alone, though true incidence is likely 10-fold higher (Benedict and Jackson, 2025). Burden in immunocompromised populations is concentrated: 25-30% of HIV/AIDS deaths are attributable to fungal infections; 10-15% of cancer patients develop invasive fungal infections; 5-10% of solid organ transplant recipients develop invasive fungal disease (Armstrong James *et al.*, 2024).

Underdiagnosis is the norm. A systematic review estimated that 75% of fungal diseases are never diagnosed, particularly in low and middle income countries (LMICs). Fungal meningitis is misdiagnosed as bacterial meningitis; fungal pneumonia is misdiagnosed as tuberculosis; chronic pulmonary aspergillosis is misdiagnosed as TB or COPD (Denning, 2024). The true burden is almost certainly higher than current estimates, and the gap between burden and policy attention is a public health scandal (Rodrigues and Nosanchuk, 2023).

2.2 Major Fungal Pathogens and Emerging Threats

2.2.1 WHO Fungal Priority Pathogens List

The WHO Fungal Priority Pathogens List (2022) classified 19 fungi into three priority categories.

Critical priority group (highest public health threat): *Cryptococcus neoformans*, *Candida auris*, *Aspergillus fumigatus*, and *Candida albicans*. *C. neoformans* causes cryptococcal meningitis, killing 150,000 annually, primarily in HIV endemic regions (WHO, 2022). *C. auris* is an emerging multidrug resistant yeast causing healthcare associated outbreaks with mortality rates of 30-60% (Lockhart *et al.*, 2023). *A. fumigatus* causes invasive aspergillosis in immunocompromised patients; azole resistance is rising globally (Fisher *et al.*, 2022). *C. albicans* remains the most common cause of invasive candidiasis, though resistance is emerging (Armstrong James *et al.*, 2024).

High priority group: *Candida glabrata* (now *Nakaseomyces glabratus*), *Histoplasma* spp., *Emmonsia* (now *Emergomyces*) spp., Mucorales (causing mucormycosis), *Fusarium* spp., *Seedosp orium* spp., and *Lomentospora* *prolificans*. These fungi cause severe infections with high mortality and are often drug resistant (WHO, 2022).

Medium priority group: *Coccidioides* spp. (Valley fever), *Paracoccidioides* spp., *Pneumocystis jirovecii*, *Talaromyces marneffei*, dermatophytes, and several others (WHO, 2022).

2.2.2 Emerging Threats Beyond the WHO List

Candida auris is the most dramatic recent emergence. First described in 2009 from Japan, within a decade it spread to over 50 countries. Unique features: persistent environmental contamination (survives on surfaces for weeks), misidentification by conventional lab methods (often identified as *Candida haemulonii* or other yeasts), multidrug resistance (some isolates resistant to all three major antifungal classes), and healthcare transmission (Lockhart *et al.*, 2023). US cases increased 300% between 2019 and 2022, with clinical cases exceeding 10,000 (CDC, 2024).

Azole resistant *Aspergillus fumigatus* is another emerging crisis. Azole resistance is driven by agricultural use of azole fungicides (demethylase inhibitors, DMIs) on crops, which selects for resistance mutations that also confer resistance to clinical azoles (itraconazole, voriconazole, posaconazole). In some European countries, azole resistance rates exceed 10% in clinical isolates; in parts of the Netherlands and India, rates exceed 30% (Fisher *et al.*, 2022). Patients with azole resistant aspergillosis have mortality rates 50-80% compared to 20-40% for azole susceptible infections (Verweij *et al.*, 2024).

Mucormycetes (the fungi causing mucormycosis) gained global attention during COVID-19 due to the "black fungus" epidemic in India, with over 50,000 cases reported during the Delta wave. COVID-19 associated mucormycosis had mortality exceeding 50% (Hoenigl *et al.*, 2022). *Emergomyces* (formerly *Emmonsia*) species have emerged as causes of disseminated fungal infections in immunocompromised persons, particularly in South Africa (Baker *et al.*, 2023).

2.3 Climate Change and Fungal Emergence

Climate change is driving the geographic expansion, increased incidence, and novel emergence of fungal pathogens. Coccidioidomycosis (Valley fever) incidence in the United States increased 10-fold between 1998 and 2025, with geographic expansion northward into Washington State and Canada. The fungus *Coccidioides* lives in soil and becomes airborne when soil is disturbed; warming temperatures and drought followed by rainfall (climate whiplash) promote spore release. Models predict Valley fever incidence will increase 50-100% by 2050 under moderate warming scenarios (Benedict and Jackson, 2025; Gorris *et al.*, 2023).

Histoplasmosis (*Histoplasma capsulatum*) is expanding beyond traditional endemic areas (Ohio and Mississippi River valleys in the US, parts of Central and South America) into northern US states and Canada. Climate change may be expanding the geographic range of bat and bird habitats that support *Histoplasma* (Baker *et al.*, 2023). *Candida auris* emergence has been linked to climate change: the fungus may have adapted to higher temperatures (thermotolerance), allowing it to survive in mammalian hosts. One hypothesis is that *C. auris* emerged from wetlands in response to warming (Casadevall *et al.*, 2023).

Fungal adaptation to warming: most fungal pathogens cannot grow at mammalian body temperature (37°C), which is a primary host defense. Climate change may select for thermotolerant fungi capable of crossing the thermal barrier, potentially expanding the pool of potential human pathogens. This "thermal adaptation hypothesis" suggests future emergence of novel fungal pathogens (Casadevall *et al.*, 2023). Extreme weather events (wildfires, floods, hurricanes) increase exposure to fungal spores. After the 2023 Maui wildfires, cases of coccidioidomycosis increased in residents exposed to windblown dust (Benedict and Jackson, 2025).

Antifungal resistance and climate are linked through agricultural fungicide use. Warmer, wetter climates increase crop fungal diseases, leading to increased fungicide application, which selects for azole resistant *A. fumigatus* in soil and compost. These resistant strains then infect humans (Fisher *et al.*, 2022). Climate change is not only expanding fungal geography but also shaping fungal evolution toward greater virulence and resistance (Casadevall *et al.*, 2023).

2.4 Antifungal Resistance: Drivers and Epidemiology

Antifungal resistance is a growing global crisis. The three major classes of antifungals, azoles, echinocandins, and polyenes, are all compromised by resistance.

2.4.1 Azole resistance is most concerning. In *A. fumigatus*, resistance is primarily driven by agricultural fungicide use (environmental route) rather than clinical exposure. TR34/L98H and TR46/Y121F/T289A mutations are widespread in the environment; patients acquire resistant strains directly from soil, compost, and agriculture (Verweij *et al.*, 2024). In some countries, 50% of *A. fumigatus* isolates from compost contain resistance mutations. Clinical azole resistance rates in Europe range from 5-30%; in India, 25-40% (Fisher *et al.*, 2022).

2.4.2 Echinocandin resistance is emerging in *Candida* species, particularly *C. glabrata* and *C. auris*. Echinocandins are first line therapy for candidemia; resistance is associated with *FKS* gene mutations. In the US, echinocandin resistance in *C. glabrata* increased from 4% to 12% between 2010 and 2024 (CDC, 2024).

2.4.3 Multidrug resistance (MDR) is characteristic of *C. auris*: some isolates are resistant to all three major classes (azoles, echinocandins, amphotericin B). Pan resistant *C. auris* has been reported in the US and India (Lockhart *et al.*, 2023).

Drivers of resistance include: agricultural fungicide use (azoles, leading to cross resistance to clinical azoles); extensive antifungal use in healthcare (prophylaxis in hematology patients, empiric therapy in ICUs); long courses of antifungal therapy (chronic pulmonary aspergillosis patients treated for years); lack of antifungal stewardship (many hospitals have no antifungal stewardship programs); and global travel and trade transporting resistant strains (Fisher *et al.*, 2022).

Resistance burden is underestimated due to lack of susceptibility testing. Most fungal infections are treated empirically; cultures are not routinely tested for antifungal susceptibility. In LMICs, susceptibility testing is rarely available. The true global burden of antifungal resistance is unknown but likely substantial (Rodrigues and Nosanchuk, 2025). The WHO FPPL explicitly identifies antifungal resistance as a core priority (WHO, 2022).

2.5 COVID-19 and Fungal Co-infections

The COVID-19 pandemic dramatically exposed the neglected status of fungal threats.

COVID-19-associated pulmonary aspergillosis (CAPA) occurred in 10-20% of critically ill COVID-19 patients requiring ICU admission and mechanical ventilation. Mortality in CAPA patients was 40-60%, compared to 20-30% in COVID-19 patients without fungal co-infection (Hoenigl *et al.*, 2022). CAPA was often underdiagnosed because fungal coinfections were not initially considered; many deaths attributed to COVID-19 alone were likely due to CAPA (Armstrong James *et al.*, 2024).

COVID-19 associated candidiasis (CAC) occurred in 5-15% of critically ill COVID-19 patients, particularly those with central lines, broad spectrum antibiotics, and prolonged ICU stays. *C. auris* outbreaks in COVID-19 units were reported in multiple countries, including the US, India, Brazil, and South Africa (Lockhart *et al.*, 2023).

COVID-19 associated mucormycosis (CAM) reached epidemic proportions in India during the Delta wave, with over 50,000 reported cases and mortality exceeding 50%. CAM was linked to uncontrolled diabetes, corticosteroid use, and ICU care (Hoenigl *et al.*, 2022).

Lessons learned: the pandemic revealed that fungal co-infections are common in respiratory viral illnesses but are systematically underdiagnosed; that diagnostic tests for fungal infections are not routinely available in ICUs; that antifungal prophylaxis and stewardship were inadequate; and that fungal threats are not considered in pandemic preparedness plans (Rodrigues and Nosanchuk, 2025). Most national and global pandemic plans list bacteria and viruses but not fungi. This must change (Armstrong James *et al.*, 2024).

2.6 Diagnostic and Treatment Gaps

Fungal diseases are treatable if diagnosed early, but diagnostic capacity is severely limited, especially in LMICs.

Diagnostic gaps: microscopy (requires expertise, low sensitivity for many fungi), culture (slow, 2-10 days, poor sensitivity for bloodstream infections), antigen testing (cryptococcal antigen, galactomannan, beta-D-glucan, sensitive but not universally available), molecular diagnostics (PCR, metagenomics, highly sensitive but expensive, requires laboratory infrastructure), and histopathology (requires tissue biopsy and pathology expertise) (Denning, 2024).

In high income countries, diagnosis is possible but delayed; in LMICs, diagnosis is often impossible. A GAFFI survey found that 90% of LMICs lack diagnostic capacity for invasive fungal infections. Cryptococcal antigen testing is available in only 30% of African district hospitals; galactomannan testing in <10%; PCR for *Pneumocystis* in <5% (Bongomin *et al.*, 2017). Point of care tests are urgently needed: lateral flow assays for cryptococcus and histoplasma exist but are not widely deployed; low cost PCR is emerging (Denning, 2024).

Treatment gaps: the major antifungal classes have significant limitations. Amphotericin B (polyene) is effective but requires intravenous administration, has significant nephrotoxicity, and requires cold chain storage. Liposomal amphotericin B is less toxic but expensive ($100-500 per dose). In LMICs, deoxycholate amphotericin B (nephrotoxic) is often the only option (Rodrigues and Nosanchuk, 2023). Azoles (fluconazole, itraconazole, voriconazole, posaconazole, isavuconazole) are oral, affordable for fluconazole but expensive for newer azoles. Drug interactions (with rifampin, antiretrovirals, immunosuppressants), hepatotoxicity, and resistance limit use (Fisher *et al.*, 2022).

Echinocandins (caspofungin, micafungin, anidulafungin) are effective against *Candida* and *Aspergillus*, have excellent safety profiles, but are intravenous only, expensive, and unavailable in many LMICs (Armstrong James *et al.*, 2024). Flucytosine (5-FC) is used for cryptococcal meningitis but is unavailable in most LMICs, despite WHO guidelines recommending its use. The combination of amphotericin B and flucytosine for cryptococcal meningitis reduces mortality by 30% compared to amphotericin alone, but flucytosine is not registered or available in most African countries (Rajasingham *et al.*, 2024).

Treatment access: many essential antifungals are not on national essential medicines lists. A GAFFI analysis found that amphotericin B is on only 60% of essential medicines lists in LMICs; flucytosine on 15%; voriconazole on 40%; echinocandins on 25% (Denning, 2024). Even when drugs are listed, they may not be available in hospitals. The result is preventable deaths from treatable fungal infections (Rodrigues and Nosanchuk, 2025).

2.7 Research Funding and Policy Neglect

Fungal diseases receive a fraction of the research funding allocated to other infectious diseases. Analysis of funding from the US National Institutes of Health (NIH), UK Medical Research Council (MRC), Wellcome Trust, and European Commission (2015-2025) shows that fungal diseases receive 1.2-1.5% of infectious disease research funding, despite causing 10-15% of infectious disease deaths (Brown *et al.*, 2022; Rodrigues and Nosanchuk, 2023). In comparison, HIV/AIDS receives approximately 30% of infectious disease funding (though deaths are lower than fungal mortality); tuberculosis receives 15%; malaria receives 10% (Denning, 2024).

Funding per death dramatically illustrates neglect: HIV/AIDS research receives approximately $30,000 perdeathannually; tuberculosisreceives$ 15,000 per death; malaria receives $20,000 perdeath; fungaldiseasesreceivelessthan$ 500 per death (Brown *et al.*, 2022). Industry investment is similarly skewed. The antifungal pipeline is thin: only 5 new antifungal classes have been approved in the past 20 years, compared to over 50 new antibacterial classes. Major pharmaceutical companies have largely exited antifungal development due to perceived low returns (Fisher *et al.*, 2022).

Surveillance neglect: most national infectious disease surveillance systems do not include fungal diseases. In the US, only coccidioidomycosis (Valley fever) and *Candida auris* are reportable nationally; other fungal diseases are not. In Europe, only a few countries report aspergillosis or candidemia. In LMICs, fungal surveillance is essentially absent (WHO, 2022).

Policy neglect: the WHO FPPL (2022) was a landmark but has not yet translated into national action. Few countries have national fungal disease control programs; most have no fungal disease strategy embedded in antimicrobial resistance action plans (Rodrigues and Nosanchuk, 2025).

Reasons for neglect: fungi are not considered "emergent" in the same way as viruses (despite *C. auris* and climate driven emergence); fungal diseases are associated with immunocompromised populations, who have less advocacy power than pediatric or maternal health constituencies; diagnostic challenges lead to undercounting, making fungal diseases invisible in burden estimates; and "fungus" carries stigma (misunderstood, associated with poor hygiene) (Denning, 2024). Addressing neglect requires advocacy, burden data, diagnostic scale up, and integration into mainstream infectious disease programs (Rodrigues and Nosanchuk, 2025).

2.8 Low and Middle Income Country Burden

The burden of fungal diseases falls disproportionately on LMICs, where HIV prevalence is highest, cancer care is expanding, and ICU capacity is limited but growing (Bongomin *et al.*, 2017). Cryptococcal meningitis is the leading cause of adult meningitis in sub- Saharan Africa, with an estimated 150,000 cases and 100,000 deaths annually. Cryptococcal antigen (CrAg) screening in HIV positive individuals with CD4 <100 can prevent cryptococcal meningitis, but implementation is incomplete (Rajasingham *et al.*, 2024).

Chronic pulmonary aspergillosis (CPA) complicates tuberculosis. An estimated 1.2 million people have CPA following TB, causing cough, hemoptysis, respiratory failure, and death. CPA is almost never diagnosed in TB endemic countries; patients are treated for recurrent TB (which they do not have) with multiple courses of anti- TB drugs (which do not work) (Denning, 2024). Histoplasmosis and talaromycosis are highly endemic in Southeast Asia and parts of the Americas but almost never diagnosed due to lack of diagnostic tests. Mortality exceeds 50% in diagnosed cases; true mortality is likely higher (Baker *et al.*, 2023).

HIV associated *Pneumocystis jirovecii* pneumonia (PCP) was a leading cause of death in the pre- antiretroviral therapy (ART) era. With ART scale up, PCP has declined in high income countries, but in LMICs where ART access is incomplete and diagnostic testing for PCP is absent, PCP remains a major killer (Armstrong James *et al.*, 2024). *Candida auris* is increasingly reported from LMIC hospitals, particularly India, South Africa, and Brazil, where infection control resources are limited and outbreaks are harder to contain (Lockhart *et al.*, 2023).

Neglect in LMICs is multidimensional: lack of diagnostic tests, lack of affordable antifungals, lack of trained personnel, lack of surveillance, and lack of research funding. Global health initiatives (Global Fund, PEPFAR, WHO) have historically focused on HIV, TB, and malaria, with minimal attention to fungal coinfections. Integration of fungal disease diagnosis and treatment into existing disease programs (e.g., HIV care, TB programs) is the most feasible path forward (Rodrigues and Nosanchuk, 2025).

2.9 The WHO Fungal Priority Pathogens List and Its Impact

The WHO FPPL (2022) was a watershed moment, formally acknowledging that fungal pathogens are neglected public health threats requiring global action. The list was developed through a multi-step process including a systematic review of fungal burden, resistance, and impact, followed by expert voting (WHO, 2022). The FPPL has three tiers:

Critical (4 pathogens): *Cryptococcus neoformans*, *Candida auris*, *Aspergillus fumigatus*, *Candida albicans*.

High (7 pathogens): *Candida glabrata*, *Histoplasma* spp., *Emmonsia (Emergomyces)* spp., Mucorales, *Fusarium* spp., *Seedosporiu m* spp., *Lomentospora prolificans*.

Medium (8pathogens): *Coccidioides* spp., *Paraco ccidioides* spp., *Pneumocystis jirovecii*, *Talaromyces marneffei*.

Impact of FPPL to date: increased awareness among policymakers and funders; some countries (UK, Netherlands, Canada) have developed national fungal action plans; WHO has developed a fungal diagnostics and treatment access roadmap; research funding has increased modestly (from 1.2% to 2.5% of infectious disease funding in some agencies) (Rodrigues and Nosanchuk, 2025).

Limitations: FPPL is not legally binding; countries are not required to act; the list does not come with dedicated funding; implementation remains at country discretion. The FPPL is a necessary first step, not a solution (WHO, 2022).

Next steps include: integrating FPPL into national AMR action plans; developing global fungal surveillance networks; establishing diagnostic and treatment access targets; and creating accountability mechanisms for funding and implementation (Rodrigues and Nosanchuk, 2025). The analogy to the WHO Bacterial Priority Pathogens List (which drove antibacterial research and development) suggests that FPPL could drive antifungal development, but only if accompanied by push and pull incentives (Fisher *et al.*, 2022).

2.10 Future Directions and Research Priorities

Several priorities for research, policy, and practice emerge.

Surveillance: establish global sentinel surveillance for priority fungal pathogens, using standardized case definitions and diagnostics. Integrate fungal surveillance into existing respiratory, meningitis, and bloodstream infection surveillance systems (WHO, 2022).

Diagnostics: develop and deploy low cost, rapid, point of care tests for common fungal pathogens (cryptococcus, histoplasma, aspergillus, *Pneumocystis*, *C. auris*). Use lateral flow, loop-mediated isothermal amplification (LAMP), and portable PCR (Denning, 2024).

Antifungal development: incentivize development of new antifungal classes with novel mechanisms of action. Models include pull incentives (market entry rewards, subscription models) and push incentives (grants for early stage research). The antibacterial pipeline has benefited from CARB-X, GARDP, and AMR Action Fund; similar mechanisms are needed for antifungals (Fisher *et al.*, 2022).

Antifungal stewardship: implement antifungal stewardship programs in hospitals to reduce unnecessary use, slow resistance emergence, and improve outcomes (Armstrong James *et al.*, 2024).

Climate change adaptation: monitor fungal geographic expansion, model future risk under climate scenarios, and prepare healthcare systems in currently non-endemic areas for emerging endemic fungi (coccidioidomycosis in the Pacific Northwest, histoplasmosis in Canada) (Benedict and Jackson, 2025).

One Health approaches: address agricultural fungicide use as a driver of clinical resistance; regulate azole use in agriculture to preserve clinical azole efficacy (Verweij *et al.*, 2024).

Integration into pandemic preparedness: include fungal pathogens in pandemic plans; ensure ICUs have diagnostic capacity for CAPA and CAC; stockpile antifungals for emergency use; train healthcare workers to recognize fungal coinfections (Hoenigl *et al.*, 2022).

Research funding: increase funding for fungal disease research to levels commensurate with burden (target 5-10% of infectious disease research funding). Prioritize translational research, implementation science, and LMIC-relevant interventions (Brown *et al.*, 2022).

3. Conclusion

Fungal pathogens cause 1.7 million deaths annually, more than malaria and comparable to tuberculosis, yet remain critically neglected in public health priorities, research funding, diagnostics, treatment access, and surveillance. This neglect falls disproportionately on immunocompromised populations and low-income countries, while climate change expands fungal ranges and drives emergence of novel threats like *Candida auris*. Rising antifungal resistance, exacerbated by agricultural fungicide use, further compounds the crisis. The WHO Fungal Priority Pathogens List was a critical first step, but must be followed by national action plans, dedicated funding, surveillance systems, diagnostic scale-up, and antifungal stewardship. Fungal neglect is a preventable public health failure; the tools exist, but political and financial barriers remain.

4. Recommendations

Based on the evidence synthesized in this review, the following recommendations are offered for governments, WHO, research funders, healthcare systems, and pharmaceutical developers:

1. Integrate fungal pathogens into national infectious disease surveillance systems as reportable diseases. Establish sentinel surveillance for priority fungi (WHO FPPL) in all WHO regions.

2. Include fungal diseases in national AMR action plans with specific targets (e.g., reduce diagnostic delay, increase antifungal stewardship coverage, reduce agricultural azole use).

3. Increase research funding for fungal diseases to 5-10% of infectious disease research budgets, proportionate to burden. Fund translational research, diagnostics, antifungals, vaccines, and implementation science.

4. Scale up diagnostic capacity for fungal diseases, particularly in LMICs. Deploy point of care tests (cryptococcal antigen, histoplasma antigen, galactomannan, beta-D-glucan, PCR). Include fungal diagnostics on WHO essential diagnostics list.

5. Improve access to essential antifungals by adding amphotericin B, flucytosine, voriconazole, and echinocandins to national essential medicines lists and WHO essential medicines list. Reduce prices through volume guarantees and generic production.

6. Implement antifungal stewardship programs in all hospitals with ICUs, hematology units, and transplant programs. Track antifungal use and resistance. Train infectious diseases physicians and pharmacists.

7. Regulate agricultural azole use to preserve clinical azole efficacy. Implement resistance surveillance in the environment. Phase out high risk azole uses where alternatives exist.

8. Include fungal threats in pandemic preparedness plans. Ensure ICUs have diagnostic capacity for CAPA, CAC, and other fungal coinfections. Stockpile antifungals. Train healthcare workers.

9. Monitor climate driven fungal emergence through environmental surveillance, ecological modeling, and health system preparedness in currently non-endemic regions. Fund research on thermal adaptation.

10. Develop new antifungals through push (grants for early research)

and pull (market entry rewards, subscription models) incentives. Create an antifungal parallel to CARB-X or GARDP.

11. Launch global awareness campaigns targeting clinicians, policymakers, and the public about fungal disease burden, risk factors, and treatability. Reduce stigma.

12. Establish a WHO Global Fungal Pathogens Program with dedicated staff, budget, and technical assistance capacity to support national implementation of FPPL

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