Review Article
ISSN: 2583-7419
Journal homepage: biologyforum.actabotanica.org

Emerging Insights into Antifungal Resistance Mechanisms and the Search for Next Generation Therapeutics

Boyini Sirisha*[1], and Ch. Venkataramana Dev[2]

[1]*Telangana Social Welfare Residential Degree College for Women, Mahendrahills, Hyderabad, TS-India*
[2]*Department of Biochemistry, UCS, Osmania University, Hyderabad, TS-India*

Citation: Boyini Sirisha, and Ch. Venkataramana Dev (2026). Emerging Insights into Antifungal Resistance Mechanisms and the Search for Next Generation Therapeutics. *Acta Biology Forum*. **DOI: https://doi.org/10.51470/ABF.2026.5.3.11**

Corresponding Author: **Boyini Sirisha** | E-Mail: **(boyinisirisha24@gmail.com)**

Received 13 July 2026 | Revised 11 August 2026 | Accepted 10 September 2026 | Available Online 16 October 2026

ABSTRACT

Fungal infections represent a growing global health challenge, driven by rising incidence, limited therapeutic options, and increasing drug resistance. Antifungal resistance, once considered rare, is now recognized as a major clinical threat, particularly in immunocompromised populations. Resistance mechanisms include target-site alterations, efflux pump overexpression, biofilm formation, and stress-response pathways that collectively diminish antifungal efficacy. This review synthesizes recent advances in understanding molecular drivers of antifungal resistance, with a focus on clinically important fungi such as Candida, Aspergillus, and emerging multidrug-resistant pathogens including Candida auris. An innovative therapeutic strategies under development, including novel drug targets, immune-based interventions, natural products, nanotechnology-enabled delivery systems, and drug repurposing. Finally, translational and regulatory challenges in antifungal development and propose future research directions to address the urgent need for safe, effective, and scalable antifungal therapeutics.

Keywords: *Antifungal resistance, Candida auris, efflux pumps, biofilms, azole resistance, next-generation antifungals, host–pathogen interactions.*

1. Introduction

Fungal infections are increasingly recognized as a major global health concern, affecting over 1.5 billion individuals worldwide and causing significant morbidity and mortality, particularly in immunocompromised populations. Invasive fungal infections, such as candidemia and invasive aspergillosis, are associated with mortality rates ranging from 20% to over 50%, underscoring the urgent need for effective therapeutic interventions [1]. The substantial health burden, fungal infections have historically received less attention compared to bacterial and viral diseases, contributing to limited resources for research, diagnostics, and treatment development. The current antifungal armamentarium is restricted to a small number of drug classes, including azoles, polyenes, echinocandins, and pyrimidine analogs. Each of these classes targets specific fungal pathways or structures, such as ergosterol synthesis or cell wall biosynthesis. However, the emergence and spread of antifungal resistance increasingly compromise the effectiveness of these agents. Unlike bacterial resistance, which can evolve rapidly under selective pressure, antifungal resistance develops more slowly due to the eukaryotic complexity of fungi and the conserved nature of their cellular targets. Nevertheless, the clinical impact of antifungal resistance is profound, as there are few alternative therapies available when resistance arises [2].

Treatment failures can lead to prolonged hospitalizations, increased healthcare costs, and higher mortality rates. The World Health Organization (WHO) has recently highlighted antifungal resistance as a critical global health priority, emphasizing the urgent need to address multidrug-resistant fungal pathogens. Among these, *Candida auris* has emerged as a particularly concerning species due to its rapid spread in healthcare settings, multidrug resistance, and difficulty in detection using conventional laboratory methods. Azole-resistant *Aspergillus fumigatus* also represents a significant threat, particularly for immunocompromised patients, such as those undergoing chemotherapy, organ transplantation, or long-term corticosteroid therapy [3]. The global rise of these resistant pathogens reflects both the selective pressures imposed by widespread antifungal use in medicine and agriculture and the adaptive capacity of fungi to survive in diverse environments, antifungal resistance arises through multiple pathways, including target-site mutations that reduce drug binding, overexpression of efflux pumps that expel antifungal agents, biofilm formation that provides a protective niche, and activation of stress-response pathways that enhance fungal survival under drug exposure. These mechanisms often act in concert, rendering standard treatments less effective or entirely ineffective.

Copyright: *This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.*

Understanding the molecular basis of resistance is therefore critical for designing new therapeutic strategies capable of overcoming these adaptive responses [4]. These include novel small-molecule agents targeting previously unexplored fungal pathways, immune-based therapies that enhance host defenses, natural products with antifungal activity, and advanced drug delivery systems such as nanotechnology-based formulations that improve bioavailability and reduce toxicity. Additionally, drug repurposing—leveraging existing pharmaceuticals with known safety profiles—offers a promising avenue for rapid deployment against resistant fungal infections [5]. This review aims to provide an integrated overview of the current understanding of antifungal resistance, highlight emerging therapeutic strategies under investigation, and identify critical knowledge gaps that must be addressed to guide the development of safe, effective, and scalable antifungal therapies. The recent advances in molecular insights, clinical epidemiology, and translational research, we aim to provide a comprehensive framework for tackling the escalating challenge of antifungal resistance on a global scale.

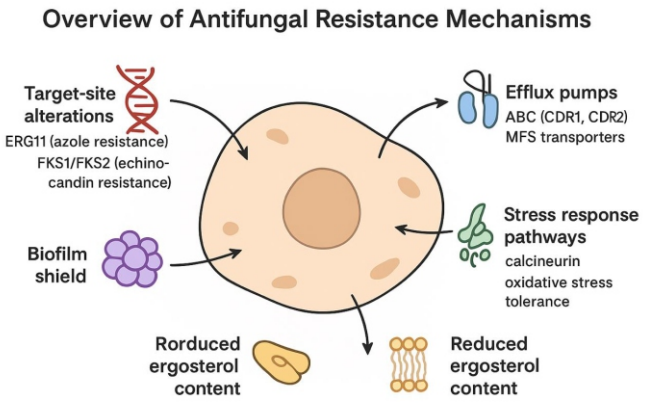


Figure 1. Overview of Antifungal Resistance Mechanisms

2. Antifungal Resistance: Mechanisms and Molecular Insights

Antifungal resistance arises from a combination of genetic, biochemical, and environmental factors that collectively reduce drug efficacy and complicate clinical management. Understanding the molecular underpinnings of resistance is critical for developing new therapeutic strategies and predicting emerging threats. Resistance mechanisms can be broadly categorized into target-site alterations, efflux pump activation, biofilm formation, stress-response pathway activation, and horizontal gene transfer facilitated by environmental reservoirs [6].

2.1 Target Site Alterations

One of the most common mechanisms of antifungal resistance involves mutations in the molecular targets of antifungal drugs. In azole-resistant fungi, point mutations in the ERG11 gene, which encodes lanosterol 14α-demethylase, reduce the binding affinity of azoles, thereby decreasing drug efficacy. Similarly, resistance to echinocandins, which inhibit β-1,3-glucan synthase essential for cell wall biosynthesis, is mediated by mutations in the FKS1 and FKS2 genes. These alterations reduce drug susceptibility without compromising enzyme function. Although polyene resistance is comparatively rare, it can occur through modifications in membrane sterol composition, such as a reduction in ergosterol content, which diminishes the binding of polyenes like amphotericin B. Target-site alterations represent a direct, genetically encoded mechanism of resistance that can emerge under selective drug pressure [7].

2.2 Efflux Pump Activation

Efflux pumps are membrane transporters that actively expel antifungal agents from fungal cells, reducing intracellular drug concentrations. Two major classes are involved: ATP-binding cassette (ABC) transporters and major facilitator superfamily (MFS) pumps. In *Candida* species, overexpression of genes such as CDR1, CDR2, and MDR1 contributes to multidrug resistance by promoting rapid drug efflux. These pumps are often upregulated in response to drug exposure, representing a dynamic mechanism that allows fungi to survive transient antifungal pressure. Efflux-mediated resistance is particularly problematic because it can simultaneously reduce susceptibility to multiple classes of antifungal agents [8].

2.3 Biofilm Formation

Biofilms are structured communities of fungal cells encased in an extracellular matrix that confers protection from environmental stresses, including antifungal therapy. Within biofilms, cells exhibit reduced metabolic activity and altered gene expression, which limit drug penetration and efficacy. Persister cells—a subpopulation within biofilms—display extreme tolerance to antifungal agents and immune-mediated clearance, contributing to chronic and recurrent infections. Biofilm-associated resistance is a multifactorial process, involving both physical barriers and adaptive cellular responses that collectively enhance survival under therapeutic pressure [9].

2.4 Stress Response Pathways

Fungal stress-response pathways play a pivotal role in adaptive resistance. Heat shock proteins, particularly Hsp90, stabilize key regulatory proteins that govern cell growth and survival under drug-induced stress. Calcineurin signaling mediates cellular responses to environmental challenges, including cell wall stress, while oxidative stress-response pathways protect against reactive oxygen species generated during antifungal treatment [10]. These pathways frequently act in synergy with genetic resistance mechanisms, amplifying survival under drug pressure and promoting the evolution of stable resistance phenotypes.

2.5 Horizontal Gene Transfer and Environmental Reservoirs

Environmental reservoirs contribute to the emergence and dissemination of antifungal resistance. The widespread use of azole fungicides in agriculture has driven the selection of resistant *Aspergillus fumigatus* strains in soil and plant matter, which can infect humans through inhalation. Additionally, fungi exhibit remarkable genomic plasticity, enabling horizontal transfer of resistance-associated traits across strains and species. This environmental linkage underscores the complex interplay between clinical antifungal use and ecological factors in shaping resistance evolution, these mechanisms highlight the multifaceted nature of antifungal resistance and emphasize the need for integrated strategies that address both intrinsic and adaptive pathways [11]. A detailed understanding of these molecular insights provides the foundation for the development of next-generation antifungal therapies capable of overcoming existing and emerging resistance challenges.

Table 1: Key Mechanisms of Antifungal Resistance

Mechanism	Description	Key Genes/Proteins	Examples of Resistant Pathogens
Target-site alterations	Mutations in drug-binding sites reduce efficacy	ERG11 (azoles), FKS1/FKS2 (echinocandins)	*Candida albicans*, *Aspergillus fumigatus*
Efflux pump activation	Active expulsion of drugs from fungal cells	CDR1, CDR2, MDR1	*Candida spp.*
Biofilm formation	Structured communities protect cells from drugs and immune attack	Multiple ECM-associated genes	*Candida spp.*, *Aspergillus spp.*
Stress response pathways	Adaptive survival under drug or environmental stress	Hsp90, Calcineurin, Oxidative stress pathways	*Candida*, *Aspergillus*
Horizontal gene transfer / environmental reservoirs	Acquisition of resistance traits from environment	Genomic plasticity mechanisms	*Aspergillus fumigatus* (azole-resistant)

Table 2: Clinical Implications of Antifungal Resistance

Pathogen	Resistance Type	Clinical Impact	Challenges
Aspergillus fumigatus	Azole resistance	Breakthrough infections in immunocompromised patients	Limited alternative therapies
Candida auris	Multidrug resistance	Outbreaks in healthcare facilities; high mortality	Infection control and containment difficult
Candida spp.	Pan-resistance (all three frontline classes)	Therapeutic dead-ends	No effective standard treatment
All resistant fungi	General	Delayed diagnosis	Limited rapid diagnostic tools

Table 3: Emerging Therapeutic Strategies Against Resistant Fungi

Strategy	Mechanism / Approach	Examples / Agents	Potential Advantages
Novel drug targets	Target essential fungal pathways not used by current drugs	Chitin synthase inhibitors (nikkomycin Z), GPI-anchor inhibitors, mitochondrial disruptors	Overcome existing resistance; novel mechanisms
Host-directed therapies	Enhance host immune response	Cytokines (GM-CSF, IFN-γ), monoclonal antibodies against fungal antigens	Boosts innate immunity; synergistic with antifungals
Natural products / secondary metabolites	Exploit plant- or fungal-derived bioactive compounds	Polyphenols, terpenoids, alkaloids	Synergistic with azoles; new chemical scaffolds
Nanotechnology / drug delivery	Improve solubility, bioavailability, targeted delivery	Lipid nanoparticles, polymeric nanocarriers, antifungal-coated devices	Reduced toxicity; prevent biofilm formation
Drug repurposing	Use existing drugs with antifungal potential	Statins, calcineurin inhibitors, NSAIDs	Faster translation; lower development cost

3. Clinical Implications of Antifungal Resistance

The clinical impact of antifungal resistance is profound, particularly among immunocompromised patients, and presents significant challenges for patient management, infection control, and public health. Rising resistance limits the efficacy of standard therapies, often leading to treatment failure, prolonged hospital stays, and increased mortality [12]. One of the most concerning trends is the emergence of azole-resistant *Aspergillus fumigatus*. These strains have been associated with breakthrough infections in patients with hematological malignancies, including those undergoing chemotherapy or hematopoietic stem cell transplantation. Azole resistance compromises first-line prophylactic and therapeutic strategies, often necessitating the use of more toxic or less effective alternatives, which can exacerbate patient morbidity. Multidrug-resistant *Candida auris* represents another major clinical challenge. This pathogen is capable of causing outbreaks in healthcare facilities due to its persistence on surfaces, resistance to standard disinfection, and high transmissibility among vulnerable patients. Infections caused by *C. auris* are frequently resistant to multiple antifungal classes—including azoles, echinocandins, and polyenes—limiting treatment options and complicating infection control measures. The presence of multidrug resistance not only increases the difficulty of therapy but also poses significant public health risks, requiring enhanced surveillance and strict adherence to infection control protocols. The challenges is the limited availability of rapid and reliable diagnostic tools for detecting antifungal resistance. Conventional culture-based methods are often slow, and susceptibility testing may not be routinely available in all clinical settings.

Delays in identifying resistant infections can result in inappropriate empiric therapy, allowing infections to progress unchecked and leading to poorer clinical outcomes. The lack of timely diagnostics underscores the urgent need for molecular and point-of-care testing methods that can guide targeted therapy and improve prognosis [13], therapeutic dead-ends occur when patients harbor infections resistant to all three frontline antifungal classes—azoles, echinocandins, and polyenes. Such pan-resistant infections are increasingly reported in *C. auris* and other emerging pathogens, leaving clinicians with few or no effective treatment options. These scenarios are associated with high morbidity and mortality, highlighting the critical need for novel antifungal agents and alternative therapeutic approaches, antifungal resistance transforms previously manageable infections into life-threatening conditions, especially in high-risk populations such as immunocompromised patients and those with prolonged hospitalization [14]. The crisis requires a multifaceted strategy, including the development of new antifungal therapies, enhanced diagnostic capabilities, rigorous infection control measures, and global surveillance systems to monitor emerging resistance patterns.

4. Emerging Strategies for Next-Generation Therapeutics

The rise of antifungal resistance has prompted intensive research into next-generation therapeutic strategies that extend beyond conventional drug classes. These approaches aim to overcome existing resistance mechanisms, enhance drug efficacy, and reduce toxicity [15]. Emerging strategies can be broadly categorized into novel drug targets, host-directed therapies, natural products and secondary metabolites, nanotechnology-enabled drug delivery systems, and drug repurposing.

4.1 Novel Drug Targets

Targeting essential fungal pathways not exploited by current therapies offers a promising avenue to overcome resistance. Chitin synthase inhibitors, such as nikkomycin Z, disrupt fungal cell wall biosynthesis, compromising structural integrity and fungal viability. Inhibitors of glycosylphosphatidylinositol (GPI)-anchor biosynthesis interfere with the proper localization of cell surface proteins critical for virulence and survival [16]. The compounds that disrupt mitochondrial function impair energy production and metabolic regulation, leading to fungal cell death. These novel targets provide opportunities to develop drugs with unique mechanisms of action, potentially circumventing resistance to existing antifungal classes.

4.2 Host-Directed Therapies

Augmenting host immune defenses represents a complementary strategy to direct antifungal therapy. Cytokine-based interventions, such as granulocyte-macrophage colony-stimulating factor (GM-CSF) and interferon-gamma (IFN-γ), can enhance the fungicidal activity of neutrophils and macrophages. Monoclonal antibodies targeting specific fungal cell wall antigens offer another avenue to boost host immunity, neutralize virulence factors, and facilitate clearance of fungal pathogens. These host-directed approaches are particularly valuable in immunocompromised patients, where conventional antifungal drugs alone may be insufficient [17].

4.3 Natural Products and Secondary Metabolites

Natural products continue to be a rich source of antifungal scaffolds. Plant-derived polyphenols, terpenoids, and alkaloids have demonstrated synergistic activity with azoles, enhancing antifungal potency and reducing the likelihood of resistance. The fungal-derived secondary metabolites possess unique chemical structures that can serve as templates for novel antifungal agents. Harnessing these natural compounds offers the potential to expand the antifungal repertoire with molecules that exploit previously untargeted pathways [18].

4.4 Nanotechnology and Drug Delivery Systems

Advanced drug delivery technologies can improve the pharmacokinetic and pharmacodynamic profiles of antifungal agents. Lipid nanoparticles and polymeric nanocarriers enhance solubility, bioavailability, and targeted delivery, potentially reducing systemic toxicity. Nanotechnology also enables the development of antifungal-coated medical devices, which prevent biofilm formation on indwelling catheters and prosthetic implants, thereby reducing device-associated infections [19]. These strategies integrate material science with pharmacology to address both therapeutic efficacy and infection control.

4.5 Drug Repurposing

Repurposing existing drugs with established safety profiles provides a rapid approach to identify new antifungal options. Statins, calcineurin inhibitors, and nonsteroidal anti-inflammatory drugs (NSAIDs) have demonstrated antifungal potentiation in preclinical models, either by direct inhibition of fungal growth or by synergizing with conventional antifungal agents [20]. Drug repurposing not only accelerates the translational pipeline but also reduces the costs and regulatory hurdles associated with de novo drug development, these emerging strategies reflect a multifaceted approach to tackling antifungal resistance, host-directed interventions, natural product scaffolds, advanced delivery systems, and innovative repurposing approaches, next-generation therapeutics aim to provide safe, effective, and scalable solutions to the growing global burden of resistant fungal infections.

5. Translational and Regulatory Challenges

The development and clinical implementation of next-generation antifungal therapies face multiple translational and regulatory hurdles that impede progress. Despite advances in molecular understanding and therapeutic innovation, challenges related to safety, economics, surveillance, and clinical trials continue to limit the availability of effective antifungal agents [21]. Host toxicity remains a primary concern in antifungal drug development. Because fungi are eukaryotic organisms, their cellular machinery closely resembles that of human cells, making selective targeting difficult. Many promising antifungal candidates demonstrate potent activity in vitro but fail in preclinical or early clinical testing due to unacceptable toxicity profiles. Ensuring an adequate therapeutic window while maintaining antifungal efficacy is a persistent challenge, particularly for novel targets that have not been extensively characterized in humans. Compared to antibiotics or oncology therapeutics, antifungal drugs represent a smaller market with lower projected returns on investment. This economic reality discourages large pharmaceutical companies from investing heavily in antifungal research, slowing the translation of promising compounds from the laboratory to the clinic. The financial risk associated with long development timelines and stringent regulatory requirements exacerbates the scarcity of new antifungal agents. Effective management of antifungal resistance requires robust global surveillance systems. However, existing monitoring programs are limited, particularly in low- and middle-income countries where diagnostic resources may be scarce. The lack of standardized, comprehensive, and timely resistance data hinders early detection of emerging resistant strains and delays the implementation of containment strategies. Without adequate surveillance, resistant infections may spread undetected, undermining both clinical and public health efforts. Conducting clinical trials for invasive fungal infections presents unique challenges. Recruiting sufficient numbers of patients with rare or opportunistic infections is difficult, particularly in immunocompromised populations. Variability in disease presentation, comorbidities, and prior antifungal exposure complicates study design and endpoints. These factors contribute to delays in advancing antifungal candidates through phase II and III trials, prolonging the timeline for regulatory approval and clinical availability. Collectively, these translational and regulatory challenges underscore the complexity of antifungal drug development. Addressing safety concerns, incentivizing pharmaceutical investment, strengthening global surveillance networks, and facilitating clinical trial recruitment are essential steps to accelerate the introduction of novel antifungal therapies. Collaborative efforts among academic institutions, industry stakeholders, regulatory agencies, and global health organizations will be critical to overcome these barriers and ensure that effective antifungal solutions reach the patients who need them most.

6. Conclusions

Antifungal resistance has emerged as a critical and rapidly escalating global health challenge, threatening the efficacy of existing therapies and the management of life-threatening infections. The increasing prevalence of multidrug-resistant pathogens, including *Candida auris* and azole-resistant *Aspergillus fumigatus*, underscores the convergence of genetic adaptations, stress-response mechanisms, and environmental pressures that drive fungal survival under therapeutic and ecological stress. Resistance not only compromises patient outcomes but also complicates infection control measures and public health interventions, particularly in vulnerable populations such as immunocompromised individuals and hospitalized patients, the antifungal drug pipeline remains relatively limited, highlighting the urgent need for innovative approaches to combat resistant infections. Emerging strategies offer promise for next-generation therapeutics by targeting previously unexplored molecular pathways, enhancing host immune responses, leveraging natural product scaffolds, and improving drug delivery through nanotechnology-based platforms. The drug repurposing provides a practical and cost-effective route to accelerate the translation of compounds with established safety profiles into antifungal applications, multidisciplinary effort that integrates molecular mycology, clinical medicine, pharmacology, and public health policy. Robust surveillance systems, rapid diagnostics, and improved clinical trial frameworks are essential to guide effective therapeutic interventions and monitor the emergence of resistance.

References

1. Fuentefria, A. M., Pippi, B., Dalla Lana, D. F., Donato, K. K., & de Andrade, S. F. (2018). Antifungals discovery: an insight into new strategies to combat antifungal resistance. *Letters in applied microbiology*, *66*(1), 2-13.
2. Zheng, Y. H., Ma, Y. Y., Ding, Y., Chen, X. Q., & Gao, G. X. (2018). An insight into new strategies to combat antifungal drug resistance. *Drug design, development and therapy*, 3807-3816.
3. Ivanov, M., Ćirić, A., & Stojković, D. (2022). Emerging antifungal targets and strategies. *International Journal of Molecular Sciences*, *23*(5), 2756.
4. Geddes-McAlister, J., & Shapiro, R. S. (2019). New pathogens, new tricks: emerging, drug-resistant fungal pathogens and future prospects for antifungal therapeutics. *Annals of the New York Academy of Sciences*, *1435*(1), 57-78.
5. Niño-Vega, G. A., Padró-Villegas, L., & López-Romero, E. (2024). New ground in antifungal discovery and therapy for invasive fungal infections: Innovations, challenges, and future directions. *Journal of Fungi*, *10*(12), 871.
6. Ball, B., Langille, M., & Geddes-McAlister, J. (2020). Fun (gi) omics: Advanced and diverse technologies to explore emerging fungal pathogens and define mechanisms of antifungal resistance. *MBio*, *11*(5), 10-1128.
7. Logan, A., Wolfe, A., & Williamson, J. C. (2022). Antifungal resistance and the role of new therapeutic agents. *Current Infectious Disease Reports*, *24*(9), 105-116.
8. Scorzoni, Liliana, Ana CA de Paula e Silva, Caroline M. Marcos, Patrícia A. Assato, Wanessa CMA de Melo, Haroldo C. de Oliveira, Caroline B. Costa-Orlandi, Maria JS Mendes-Giannini, and Ana M. Fusco-Almeida. "Antifungal therapy: new advances in the understanding and treatment of mycosis." *Frontiers in microbiology* 8 (2017): 36.
9. Liu, N., Tu, J., Dong, G., Wang, Y., & Sheng, C. (2018). Emerging new targets for the treatment of resistant fungal infections. *Journal of medicinal chemistry*, *61*(13), 5484-5511.
10. Sanglard, D. (2016). Emerging threats in antifungal-resistant fungal pathogens. *Frontiers in medicine*, *3*, 11.
11. Jha, A., & Kumar, A. (2019). Anticandidal agent for multiple targets: the next paradigm in the discovery of proficient therapeutics/overcoming drug resistance. *Future Medicinal Chemistry*, *11*(22), 2955-2974.
12. Hetta, Helal F., Tameem Melhem, Hashim M. Aljohani, Ayman Salama, Rehab Ahmed, Hassabelrasoul Elfadil, Fawaz E. Alanazi et al. "Beyond Conventional Antifungals: Combating Resistance Through Novel Therapeutic Pathways." *Pharmaceuticals* 18, no. 3 (2025): 364.
13. Su, Yanyu, Yi Li, Qiaolian Yi, Yingchun Xu, Tianshu Sun, and Yingxing Li. "Insight into the mechanisms and clinical relevance of antifungal heteroresistance." *Journal of Fungi* 11, no. 2 (2025): 143.
14. Peraman, Ramalingam, Sathish Kumar Sure, VN Azger Dusthackeer, Naresh Babu Chilamakuru, Padmanabha Reddy Yiragamreddy, Chiranjeevi Pokuri, Vinay Kumar Kutagulla, and Santhivardhan Chinni. "Insights on recent approaches in drug discovery strategies and untapped drug targets against drug resistance." *Future Journal of Pharmaceutical Sciences* 7, no. 1 (2021): 56.
15. Wall, G., & Lopez-Ribot, J. L. (2020). Current antimycotics, new prospects, and future approaches to antifungal therapy. *Antibiotics*, *9*(8), 445.
16. Ostrosky-Zeichner, L., Casadevall, A., Galgiani, J. N., Odds, F. C., & Rex, J. H. (2010). An insight into the antifungal pipeline: selected new molecules and beyond. *Nature reviews Drug discovery*, *9*(9), 719-727.
17. Revie, N. M., Iyer, K. R., Robbins, N., & Cowen, L. E. (2018). Antifungal drug resistance: evolution, mechanisms and impact. *Current opinion in microbiology*, *45*, 70-76.
18. Vanzolini, T., & Magnani, M. (2024). Old and new strategies in therapy and diagnosis against fungal infections. *Applied Microbiology and Biotechnology*, *108*(1), 147.
19. Achilonu, C. C., Davies, A., Kanu, O. O., Noel, C. B., & Oladele, R. (2024). Recent advances and future perspectives in mitigating invasive antifungal-resistant pathogen Aspergillus fumigatus in Africa. *Current Treatment Options in Infectious Diseases*, *16*(1), 14-33.
20. Arastehfar, Amir, Toni Gabaldón, Rocio Garcia-Rubio, Jeffrey D. Jenks, Martin Hoenigl, Helmut JF Salzer, Macit Ilkit, Cornelia Lass-Flörl, and David S. Perlin. "Drug-resistant fungi: an emerging challenge threatening our limited antifungal armamentarium." *Antibiotics* 9, no. 12 (2020): 877.
21. Liu, S., Hou, Y., Chen, X., Gao, Y., Li, H., & Sun, S. (2014). Combination of fluconazole with non-antifungal agents: a promising approach to cope with resistant Candida albicans infections and insight into new antifungal agent discovery. *International journal of antimicrobial agents*, *43*(5), 395-402.