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REVIEW ARTICLE

Fungal Therapeutic Enzymes as Emerging Strategies for Pancreatic Lipase Inhibition and the Management of Obesity and Metabolic Disorders

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ABSTRACT

Obesity and its metabolic complications are a growing global health burden, pushing the search for safer, more effective treatments. This review looks at fungal-derived therapeutic enzymes and endophytic fungi as sustainable resources for new treatments, particularly pancreatic lipase inhibitors for metabolic disease. It covers the pharmaceutical relevance of fungi like *Aspergillus niger, A. oryzae, A. flavus*, and *Saccharomyces cerevisiae*, which produce enzymes used in oncology, metabolic and digestive disorders, inflammation, thrombosis, and enzyme replacement therapy. Particular attention goes to pancreatic lipase inhibitors and fungal bioactive metabolites as anti-obesity agents that reduce dietary fat absorption with fewer side effects than current synthetic drugs. The review also examines how fungal secondary metabolites are biosynthesized and regulated, including biosynthetic gene clusters, metabolic engineering, heterologous expression, and protein engineering used to boost enzyme production and stability. Enzymes like L-asparaginase, uricase, lactase, lipase, β-glucosidase, superoxide dismutase, cytosine deaminase, and fibrinolytic enzymes are discussed by mechanism, application, and clinical status. Manufacturing topics fermentation, downstream processing, GMP, immunogenicity, and regulation round out the picture. Despite ongoing challenges in stability and scale-up, advances in synthetic biology and precision fermentation continue to position fungal biotechnology as a sustainable platform for treating obesity, cancer, and other chronic diseases.

KEYWORDS

• Fungal Therapeutic Enzymes • Endophytic Fungi • Pancreatic Lipase Inhibitors • Secondary Metabolites • Metabolic Disorders • Pharmaceutical Biotechnology

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INTRODUCTION

Microbes are everywhere, and their pharmaceutical potential is enormous. Pharmaceutical microbiology looks at bacteria, yeasts, molds, viruses, and toxins in raw materials, products, and manufacturing environments to protect human health. Microbes treat infectious diseases, manage metabolic disorders, and support drug discovery and safety testing. The field now covers new anti-infectives, using microbes to screen for mutagenic and carcinogenic compounds, and producing therapeutics like insulin and human growth hormone through microbial fermentation. Bioactive compounds derived from microbes give pharmaceutical and biotech companies a faster, cheaper way to make active ingredients than growing plants or raising animals (Kapoor *et al.*, 2020).

Microbial specialized secondary metabolites are low-molecular-weight compounds made outside the main growth phase. Their structures are unusual and their activities wide-ranging: antibiotics, antivirals, antioxidants, antitumor agents, immunomodulatory, enzyme inhibitors, toxins, pigments, hormones. Some also work as colorants, pesticides, or growth promoters. About 53% of FDA-approved natural-product drugs come from microorganisms. Nutrient availability, growth conditions, feedback mechanisms, and enzyme induction or inactivation all regulate how much of these metabolites gets made, often through small signalling molecules, transfer RNAs, sigma (σ) factors, and developmentally expressed gene products. Recent work shows most biosynthetic pathways sit on chromosomal gene clusters rather than plasmids, but plenty of pathway detail is still unresolved leaving open questions in enzymology, regulatory biology, and microbial differentiation (Fouillaud *et al.*, 2022).

Microbial sources are key to producing novel bioactive compounds that improve human health and medicine. The common commercial fungal enzymes are glycosyl hydrolases (cellulases, xylanases, mannanases, amylases, pectinases, β-fructofuranosidase), with cellulases and amylases used in the bioethanol, textile, and detergent industries. Fungal proteases and keratinases serve detergent, food, leather, pharmaceutical, and waste-management applications. Acidic pectinases improve the clarity and taste of fruit juices; phytases are being explored to boost nutrition in poultry feed. L-asparaginases from molds are under investigation for cancer therapy and for reducing acrylamide in food. Heterologous expression, enzyme immobilization, and protein engineering are improving the production, stability, and specificity of fungal enzymes for wider use (Roy *et al.*, 2026).

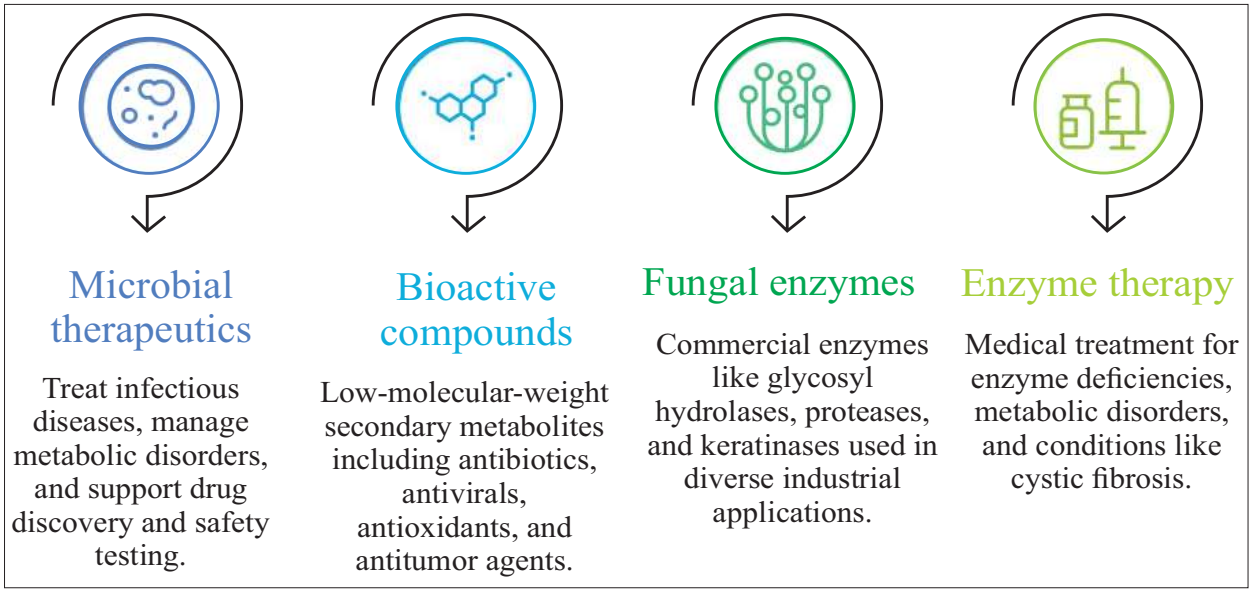
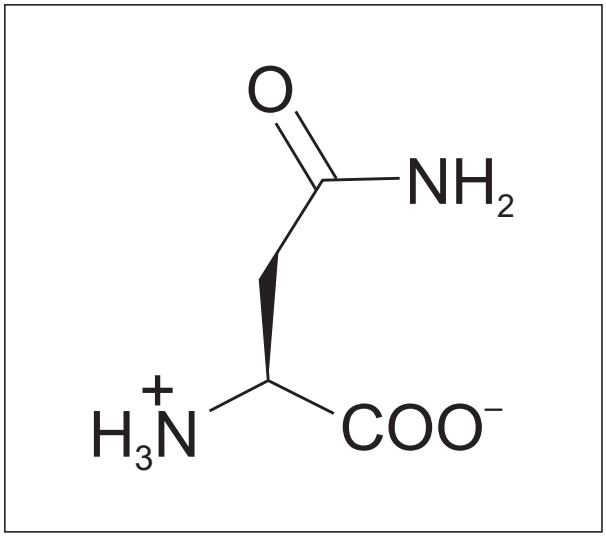


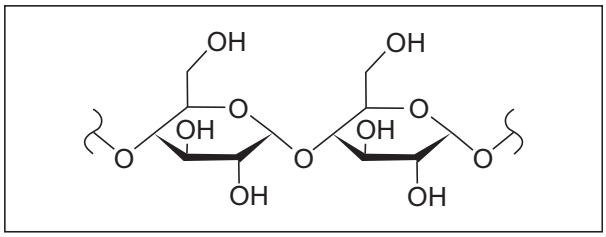
Figure 1: Schematic representation of the pharmaceutical importance of microorganisms, illustrating their role in therapeutic applications, production of bioactive secondary metabolites, industrially important fungal enzymes, and therapeutic enzymes used in the treatment of enzyme deficiencies, metabolic disorders, infectious diseases, and other human health conditions.

BIOTECHNOLOGICAL AND THERAPEUTIC APPLICATIONS OF FUNGAL ENZYMES

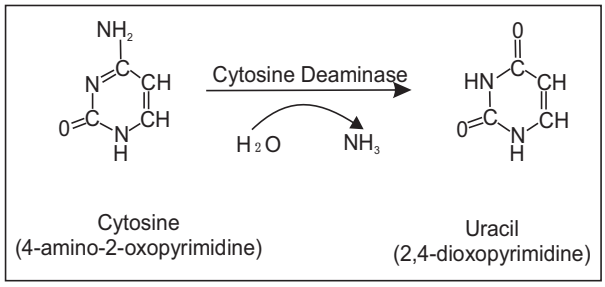
1. L-Asparaginase (EC 3.5.1.1) present in plants, fungi, and microbes, is utilized for leukemia treatment by depriving tumor cells of L asparagine. Fungi like Aspergillus terreus and Penicillium species offer a cost-effective, purifiable source of LA with notable antitumor properties, including PEGylated forms. And fungal LA has various applications in the food industry, biosensors, and biopharmaceutical production, although most commercial LA drugs are derived from bacteria.



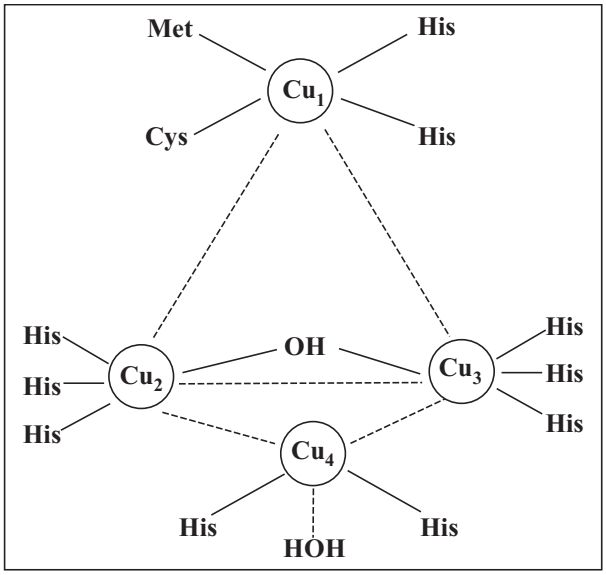
2. α-Amylase (EC 3.2.1.1) are fungal-derived glycoside hydrolases (notably Aspergillus) that digest starch into sugars and dextrins; since commercial use began in 1984 they've been applied in pharmaceuticals, fine chemicals, medical diagnostics (serum 23-85 IU/L; elevated in pancreatitis and other conditions), enzyme replacement for pancreatic insufficiency, wound healing and anti-infective roles, drug delivery/theranostics, and research on pancreatitis, diabetes, and cancer.



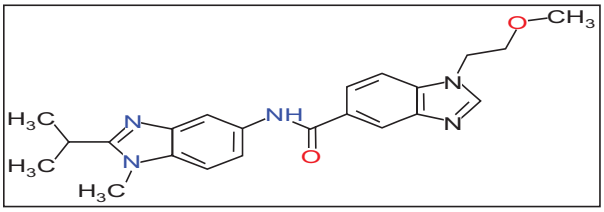
3. Cytosine deaminases (EC 3.5.4.1), found in fungi and prokaryotes, deaminate cytosine to uracil and convert the prodrug 5-fluorocytosine into the chemotherapeutic 5-fluorouracil; this enzyme/prodrug pair is used in suicide gene therapy and has been explored against endometrial, colon, prostate, breast cancers and gliomas, and 5-fluorouracil also serves as an antifungal agent **(waldorf and polak 1983)**.



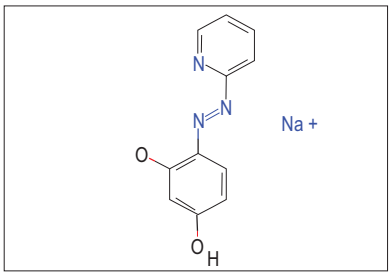
4. Proteases (EC3.4.21–24) are protein-degrading enzymes produced by many fungi (e.g., Trichoderma, Beauveria) and are used therapeutically for wound healing, scar and callus removal, skin regeneration, acne and psoriasis treatment, thrombolysis and surgical hemostasis (e.g., *Urokinase, thrombin*), and as digestive enzyme replacement for pancreatic insufficiency **(Craik page and Madison 2011)**.



5. Lipases (EC 3.1.1.3), produced by Candida, Aspergillus and Rhizopus spp., hydrolyse fats and catalyse esterification/ trans-esterification at interfaces; they're used in drug synthesis (e.g., lovastatin), cancer therapies (colorectal, pancreatic), enzyme replacement for pancreatic insufficiency and fat malabsorption, combined enzyme therapeutics (e.g., TheraCLEC), and as diagnostic markers for pancreatic injury and acute pancreatitis **(Lott and Lu 1991; Gurung *et al.*, 2013)**.



6. Laccases (EC 1.10.3.2), extracellular multicopper oxidases from white-rot fungi (produced by submerged or solid-state fermentation), oxidize phenolic and non-phenolic compounds with O2 and water; they have therapeutic potential anti proliferative activity against breast and liver cancers and antiviral effects (e.g., inhibiting HIV-1 reverse transcriptase and blocking hepatitis C virus entry) **(El-Gendi *et al.*, 2021)**.



Fungal therapeutic enzymes are a safe, effective, and scalable source of biocatalysts for treating a wide range of clinical conditions, with applications in food biotechnology, pharmaceutical biotechnology, and clinical medicine. Fungi such as Aspergillus niger, *A. oryzae, and Saccharomyces cerevisiae* produce clinically important enzymes including L-asparaginase, uricase, lactase, protease, lipase, amylase, superoxide dismutase (SOD), and β-glucosidase, used to treat cancer, metabolic disorders, digestive diseases, thrombotic disorders, genetic deficiencies, and inflammatory conditions. These enzymes are valuable partly because fungi secrete them extracellular, which makes purification simple and cheap, and partly because the enzymes themselves are acid-stable, tolerant of a wide pH range, and highly active under mild conditions (El-Gendi., 2021; Singh *et al.*, 2021). This makes fungal enzyme preparations well suited to clinical use: they resist degradation by stomach acid, they can hydrolyze important substrates across a wide pH range, and in some cases they outperform animal-derived enzymes (Sing *et al.*, 2025).

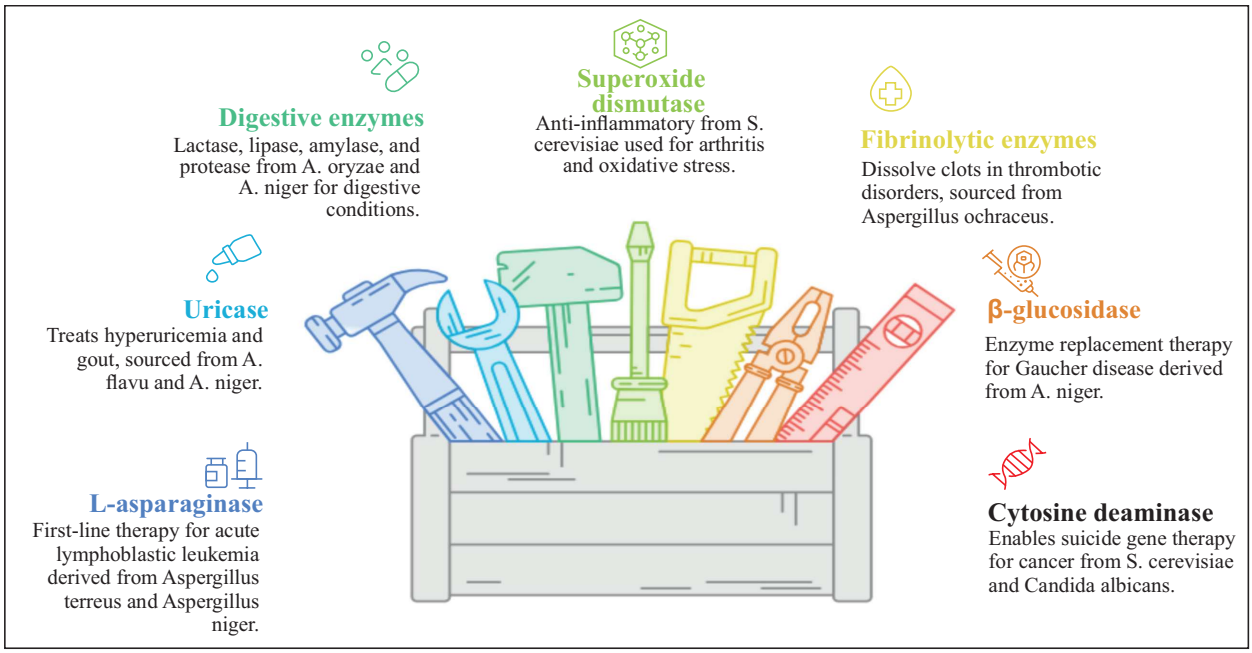


Figure 2: Illustration of major fungal-derived therapeutic enzymes and their biomedical applications, demonstrating their roles in enzyme replacement therapy, antioxidant defense, fibrinolysis, cancer treatment, and digestive health

L-asparaginase from *Aspergillus terreus* and *Aspirgillus niger* is first-line therapy for acute lymphoblastic leukemia, while uricase from *A. flavus* and *A. niger* treats hyperuricemia and gout (Dutta & Kumar, 2023). Digestive enzymes lactase, lipase, amylase, and protease from A. oryzae and *A. niger* are taken orally for lactose intolerance, pancreatic insufficiency, mal digestion, and malabsorption (Resnick, 2016). SOD from *S. cerevisiae* works as an

anti-inflammatory for arthritis and oxidative stress, and fibrinolytic enzymes from *Aspergillus ochraceus* dissolve clots in thrombotic disorders (Singh *et al.,* 2021). β-glucosidase from *A. niger* serves as enzyme replacement therapy for Gaucher disease, and cytosine deaminase from S. cerevisiae and Candida albicans enables suicide gene therapy for cancer (Dhankhar., R. *et all.,* 2020). Beyond therapeutics, these fungal enzymes turn up across pharmaceutical synthesis, industrial processing, agriculture, bioremediation, food processing, diagnostics, molecular biology, Nano biotechnology, cosmetics, and marine biotechnology (Dutta & Kumar, 2023; Singh *et al.,* 2021). They are produced at GMP quality in large volumes using various fermentation techniques and host organisms production choices that help address immunogenicity, shelf-life, therapeutic efficiency, and cost barriers (Dutta & Kumar, 2021).

FUNGAL SECONDARY METABOLITES AND THE BIOSYNTHETIC MACHINERY

Microbial specialized secondary metabolites are low-molecular-weight compounds synthesized outside the main growth phase (Killedar and Ramalingappa 2024). Their structures are unusual and their biological activities wide-ranging, encompassing antibiotics, antivirals, antioxidants, antitumor agents, immunomodulatory, enzyme inhibitors, toxins, pigments, and hormones; some also function as colorants, pesticides, or growth promoters. Roughly 53% of FDA-approved natural-product drugs originate from microorganisms. Production of these metabolites is tightly regulated by nutrient availability, growth conditions, feedback mechanisms, and enzyme induction or inactivation, often through small signalling molecules, transfer RNAs, sigma (σ) factors, and developmentally expressed gene products. Most of the underlying biosynthetic pathways are encoded on chromosomal gene clusters rather than plasmids, although many pathway details remain unresolved (Fouillaud *et al.,* 2022). At the cellular level, this regulatory cascade culminates in a physical production line. Nutrient and growth signals are converted into small signalling molecules, which activate sigma factors, which in turn switch on the relevant biosynthetic gene cluster (Sowmya, K., L. *et al.,* 2025). The resulting enzymes are assembled in the rough endoplasmic reticulum, processed through the Golgi apparatus, and packaged into vesicles that carry the finished compounds to the cell membrane for secretion, while the vacuole serves as an intermediate storage site. As metabolite concentration rises, feedback inhibition dampens the earlier signalling step, which is why secondary metabolite output is tied to growth phase rather than running continuously.

PRODUCTION OF FUNGAL THERAPEUTIC ENZYMES

Fungal sources are central to the production of novel bioactive compounds that support human health (Hani *et al.,* 2025). Common commercial fungal enzymes are glycosyl hydrolases cellulases, xylanases, mannanases, amylases, pectinases, and β-fructofuranosidase with cellulases and amylases widely used in the bioethanol, textile, and detergent industries. Fungal proteases and keratinases serve detergent, food, leather, pharmaceutical, and waste-management applications; acidic pectinases improve the clarity and taste of fruit juices; and phytases are being explored to improve nutrition in poultry feed. Heterologous expression, enzyme immobilization, and protein engineering continue to improve the production, stability, and specificity of fungal enzymes for broader use (Stajich *et al.,* 2009).

At industrial scale, moving from a laboratory strain to a finished therapeutic product follows a consistent sequence an engineered microbial strain is selected, grown under controlled conditions in a bioreactor (fermentation), the target compound is isolated and purified (downstream processing), and the resulting material is stabilized for delivery (formulation) before release as a finished product such as insulin or a therapeutic enzyme preparation (Ramalingappa e*t al.,* 2024).

Fungal enzymes are especially well suited to this pipeline for two reasons. First, fungi secrete many of their enzymes extra cellular, which simplifies purification and lowers production cost relative to enzymes that must be extracted from inside cells or from animal tissue. Second, the enzymes themselves tend to be acid-stable, tolerant of a wide pH range, and catalytically active under mild conditions (Killedar. M, 2024; Singh *et al.,* 2025). These properties carry directly into clinical use: fungal enzyme preparations resist degradation by stomach acid, can hydrolyze physiologically and pathologically relevant substrates across a wide pH range, and in some cases outperform animal-derived enzymes.

CLINICAL APPLICATIONS OF FUNGAL THERAPEUTIC ENZYMES

Fungi such as Aspergillus niger, A. oryzae, and Saccharomyces cerevisiae produce a set of clinically important enzymes that are already in therapeutic use or under active investigation. Table 1 summarizes the principal examples discussed in this review.

Table 1: Therapeutically important fungal enzymes, their major fungal sources, and corresponding clinical applications in the treatment of metabolic, cardiovascular, digestive, inflammatory, and oncological disorders

Enzyme	Fungal Source (S)	Clinical Application
L-asparaginase	*Aspergillus terreus, A. niger*	First-line therapy for acute lymphoblastic leukemia
Uricase	*Aspergillus flavus, Aspergillus niger*	Hyperuricemia and gout
Lactase, lipase, amylase, protease	*Aspergillus oryzae, Aspergillus niger*	Lactose intolerance, pancreatic insufficiency, maldigestion and malabsorption
Superoxide dismutase (SOD)	*Saccharomyces cerevisiae*	Anti-inflammatory agent for arthritis and oxidative stress
Fibrinolytic enzymes	*Aspergillus ochraceus*	Dissolution of blood clots in thrombotic disorders
β-glucosidase	*Aspergillus niger*	Enzyme replacement therapy for Gaucher disease
Cytosine deaminase	*S. cerevisiae, Candida albicans*	Suicide gene therapy for cancer

1. Oncology and Gene Therapy

L-asparaginase is the clearest example of a fungal enzyme with an established place in cancer treatment. The enzyme catalyzes the hydrolysis of circulating L-asparagine to aspartic acid and ammonia. Normal cells synthesize their own asparagine via asparagine synthetase and are largely unaffected by its depletion, but many leukemic lymphoblasts lack sufficient asparagine synthetase activity and depend on the extracellular amino acid pool to survive. Depleting that pool selectively starves the malignant cells, driving apoptosis, and asparaginase is accordingly built into multi-agent induction regimens for acute lymphoblastic leukemia (ALL). The asparaginase products currently approved for this purpose are of bacterial origin (Escherichia coli and Erwinia chrysanthemi), and hypersensitivity or silent inactivation by anti-drug antibodies remains a recognized limitation of long-term use. L-asparaginases from *Aspergillus terreus* and *Aspergillus niger* are under active investigation as potential lower-immunogenicity alternatives, on the premise that a structurally distinct fungal enzyme may provoke a different antibody response and permit re-treatment after a patient develops hypersensitivity to the bacterial forms (Gupta *et al.,* 2025).

A second, mechanistically distinct application is gene-directed enzyme pro-drug therapy (GDEPT), in which cytosine deaminase from Saccharomyces cerevisiae or Candida albicans is delivered to tumor cells by a viral or non-viral vector. Once expressed locally, the enzyme converts the relatively non-toxic pro-drug 5-fluorocytosine (5-FC) into the potent chemotherapeutic 5-fluorouracil (5-FU) inside and around the tumor, concentrating cytotoxicity at the tumor site while limiting systemic exposure. This suicide-gene strategy has been explored in clinical trials for glioma and several solid tumors; it remains an investigational approach rather than routine standard of care, and its clinical success depends heavily on vector delivery efficiency and the bystander effect by which the toxic metabolite spreads to neighboring, non-transduced tumor cells (Gulyamoya *et al.,* 2026).

2. Metabolic and Digestive Conditions

Uricase, produced by Aspergillus flavus and Aspergillus niger, catalyses the oxidation of uric acid to the more water-soluble compound allantoin, which is then readily excreted renally. Humans lack functional uricase due to an evolutionary pseudogenization of the corresponding gene, making exogenous uricase a rational treatment for conditions of uric acid excess. This principle underlies rasburicase, a recombinant Aspergillus flavus uricase expressed in genetically modified Saccharomyces cerevisiae and approved for the rapid control of hyperuricemia in tumor lysis syndrome, a metabolic emergency that arises when large numbers of tumor cells are killed simultaneously by chemotherapy and release their intracellular uric acid precursors into the bloodstream. Related uricase-based strategies are also studied for treatment-refractory gout (Patil *et al.,* 2022).

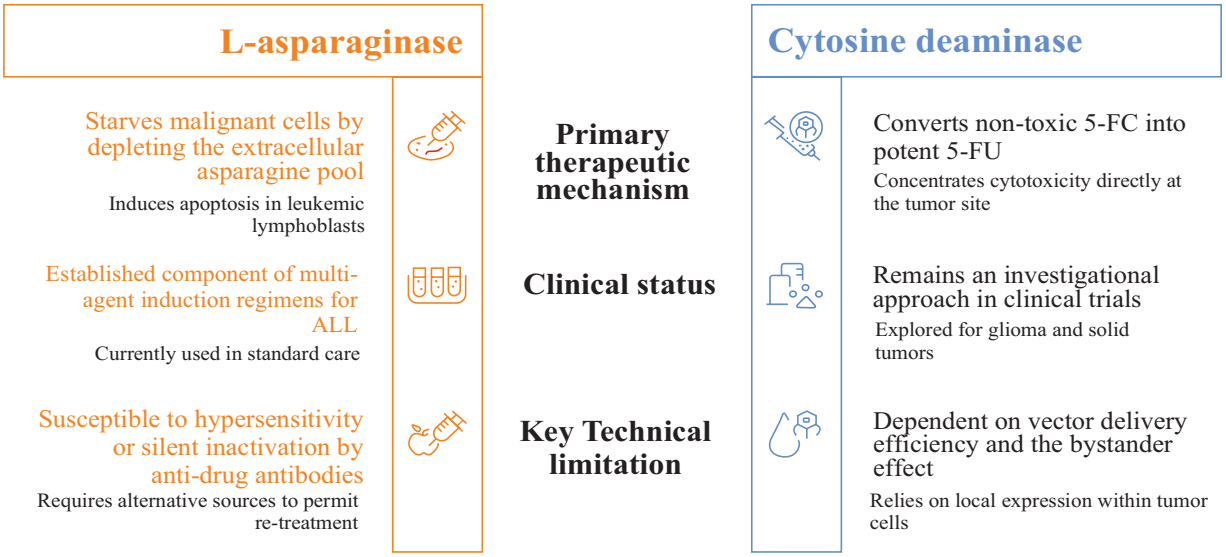


Figure 3: Comparison of two clinically important fungal therapeutic enzymes, illustrating their primary mechanisms, current clinical applications, and technical limitations in cancer treatment

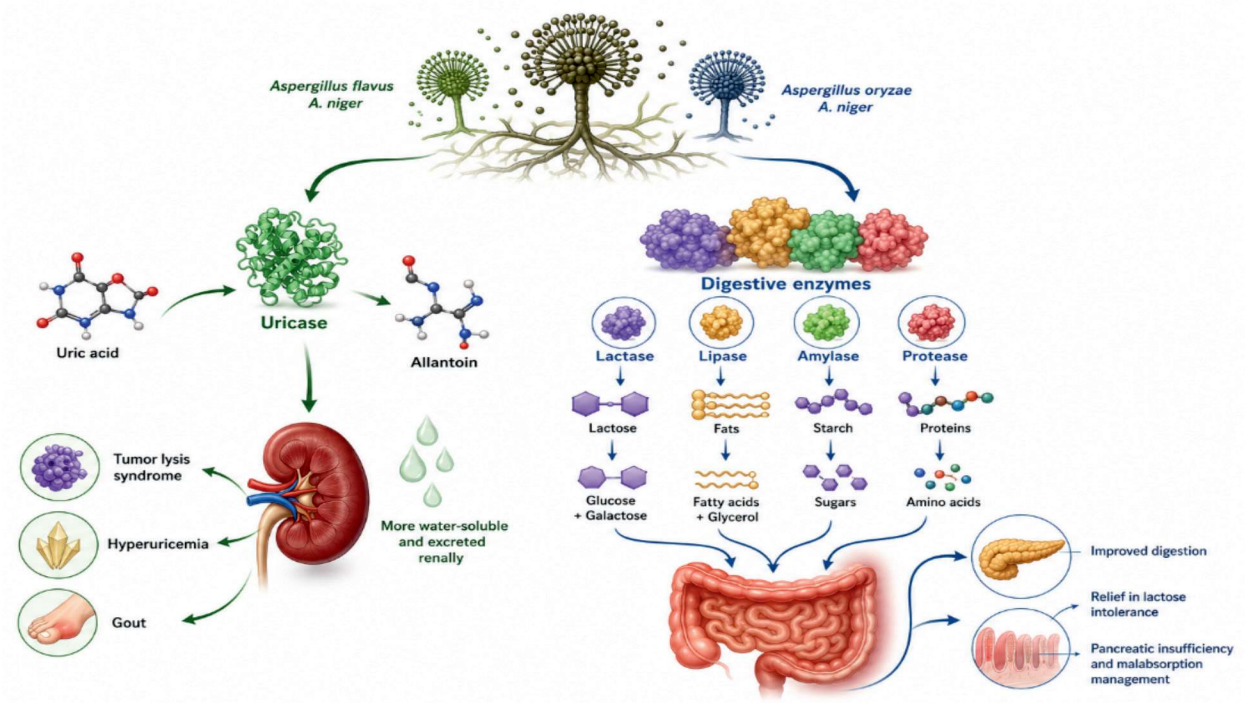
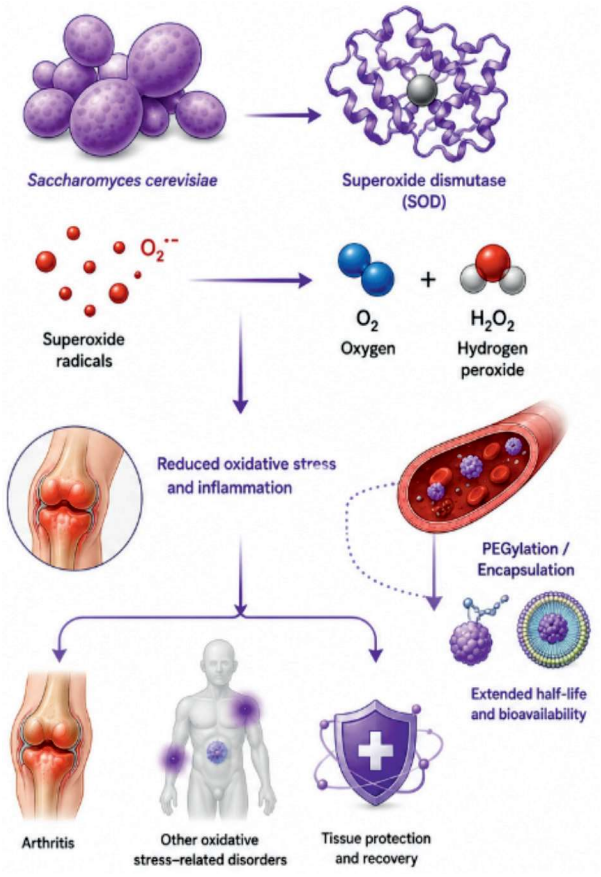


Figure 4: Mechanistic illustration of fungal enzymes used in metabolic and digestive disorders, demonstrating uricase-mediated treatment of hyperuricemia and digestive enzyme-based therapy for lactose intolerance, pancreatic insufficiency, and malabsorption.

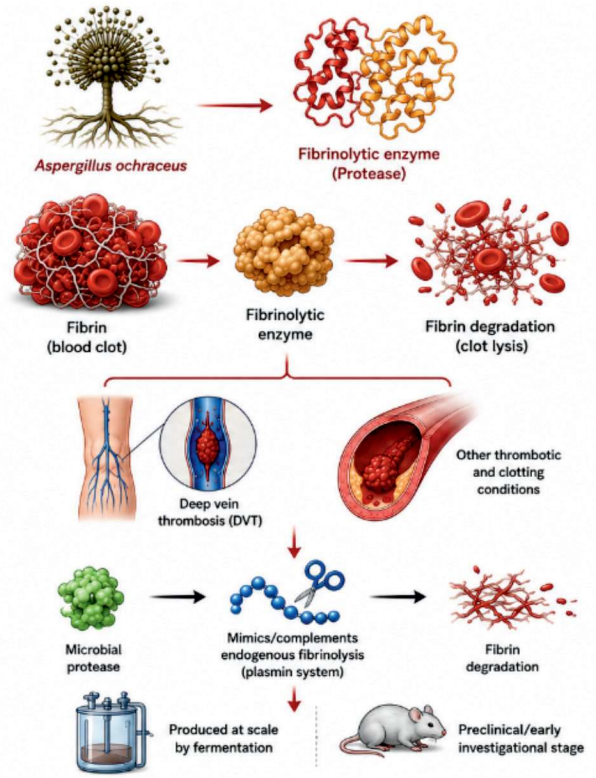
A second cluster of applications addresses digestive enzyme deficiencies. Lactase from *Aspergillus oryzae* and the yeast *Kluyveromyces lactis* hydrolyses lactose into glucose and galactose and is the active ingredient in widely used over-the-counter lactase supplements for lactose intolerance. Lipase, amylase, and protease from *A. oryzae* and *Aspergillus niger* break down dietary fats, starches, and proteins respectively, and microbial or fungal versions of these enzymes are studied as non-animal alternatives to the porcine pancreatic extracts that currently dominate prescription pancreatic enzyme replacement therapy for conditions such as cystic fibrosis-related pancreatic insufficiency, chronic pancreatitis, and other malabsorption disorders (Killedar, M., A. *et al.*, 2024). Because fungal digestive enzymes tolerate a wider pH

range than their porcine counterparts, they are of particular interest for patients who do not respond adequately to standard enteric-coated preparations.



3. Inflammatory and Thrombotic Disorders

Superoxide dismutase (SOD), an antioxidant metallo-enzyme produced by Saccharomyces cerevisiae, catalyse the disproportionation of superoxide radicals into oxygen and hydrogen peroxide, reducing oxidative damage to tissue. This activity underlies its investigation as an anti-inflammatory agent in conditions such as arthritis, where oxidative stress contributes to joint tissue damage, and in other disorders characterized by excess reactive oxygen species. Native SOD has a short circulating half-life and limited oral bioavailability, and clinical formulations generally rely on strategies such as PEGylation or encapsulation to extend activity in vivo; fungal and yeast-derived SOD remain primarily at the investigational and topical/veterinary application stage rather than as a first-line systemic drug (Betmatoug *et al*., 2011).



Fibrinolytic enzymes derived from *Aspergillus ochraceus* degrade fibrin, the structural protein of blood clots, and are studied as thrombolytic agents for thrombotic disorders such as deep vein thrombosis and related clotting conditions. They belong to the same functional class as more established microbial fibrinolytics such as nattokinase, and their development follows a similar logic: a microbially produced protease that mimics or complements the body's endogenous fibrinolytic system (plasmin) but can be manufactured at scale through fermentation (Kotach *et al*., 2017). As with several entries in this section, most fungal fibrinolytic enzyme work remains at the preclinical or early investigational stage, with dosing, delivery route, and bleeding-risk profiles still under study.

CONCLUSION

Fungal-derived enzymes now span nearly every stage of the therapeutic spectrum, from an established chemotherapy adjunct (L-asparaginase) and an approved emergency treatment for hyperuricemia (rasburicase) to widely used over-the-counter digestive aids, investigational anti-inflammatory and thrombolytic candidates, and alternative

manufacturing platforms for enzyme replacement therapy. Their appeal is grounded in two practical advantages: extracellular secretion, which simplifies and cheapens purification, and biochemical robustness across pH and mild-condition environments, which suits oral and systemic administration. The clearest opportunities for future work lie in reducing immunogenicity through protein engineering, improving formulation stability for oral and injectable products, and expanding heterologous fungal expression platforms to lower the manufacturing cost of enzymes currently produced in mammalian or plant systems. As fermentation and protein engineering techniques continue to mature, fungal enzymes are likely to expand from their current niches into a broader share of the therapeutic enzyme market.

Conflict of Interest: There are no conflicts of interest to declare.

REFERENCES

1. Belmatoug, N., Burlina, A., Giraldo, P., Hendriksz, C. J., Kuter, D. J., Mengel, E., and Pastores, G. M. (2011). Gastrointestinal disturbances and their management in miglustat-treated patients. Journal of inherited metabolic disease, 34(5), 991-1001.
2. Craik, C. S., Page, M. J., & Madison, E. L. (2011). Proteases as therapeutics. Biochemical Journal, 435(1), 1-16.
3. Dhankhar, R., Gupta, V., Kumar, S., Kapoor, R. K., and Gulati, P. (2020). Microbial enzymes for deprivation of amino acid metabolism in malignant cells: biological strategy for cancer treatment. Applied Microbiology and Biotechnology, 104(7), 2857-2869.
4. El-Gendi, H., Saleh, A. K., Badierah, R., Redwan, E. M., El-Maradny, Y. A., and El-Fakharany, E. M. (2021). A comprehensive insight into fungal enzymes: Structure, classification, and their role in mankind's challenges. Journal of Fungi, 8(1), 23.
5. Fouillaud M., and Dufosse, L. (2022). Microbial secondary metabolism and biotechnology. Microorganisms, 10(1), 123.
6. Gulyamova, T., Yoldosheva, M., Abdulmyanova, L., Ruzieva, D., Ishimov, U., Mamarakhimov, O., and Yusupov, U. (2026). Identification of pancreatic lipase inhibiting endophytic secondary metabolites of Aspergillus fischeri VO1R. In BIO Web of Conferences (Vol. 228, p. 07001). EDP Sciences.
7. Gupta, M., Saxena, S., Bansal, P., & Goyal, D. (2025). Promising pancreatic lipase inhibitory activity of a novel tetrapeptide isolated from endophytic Fusarium incarnatum. World Journal of Microbiology and Biotechnology, 41(6), 178.
8. Gurung, N., Ray, S., Bose, S., and Rai, V. (2013). A broader view: microbial enzymes and their relevance in industries, medicine, and beyond. BioMed research international, 2013(1), 329121.
9. Hanee, U., Killedar, M. A., Sowmya, K. L., & Ramalingappa, B. (2025). The Ecological and Medicinal Significance of *Agaricus bisporus*: Phytochemical Insights into Its Role in Nutrient Cycling and Health Promotion, *International Journal of Pure Applied Bioscience. 13*(1), 8-19. doi: http://dx.doi.org/10.18782/2582-2845.9152
10. Hani, U., Killedar, M. A., & Sowmya, K. L., & B, Ramalingappa. (2025). Integrated Biochemical, Antioxidant, and Structural Characterization of Pleurotus ostreatus from the Moist Forest Regions of Karnataka, India. International Journal of Innovative Research in Technology (IJIRT). https://doi.org/doi.org/10.64643/IJIRTV12I5-185784-459
11. Kapoor, D., Bhardwaj, S., Landi, M., Sharma, A., Ramakrishnan, M., & Sharma, A. (2020). The impact of drought in plant metabolism: How to exploit tolerance mechanisms to increase crop production. *Applied sciences*, 10(16), 5692.
12. Katoch, M., Paul, A., Singh, G., & Sridhar, S. N. C. (2017). Fungal endophytes associated with Viola odorata Linn. as bioresource for pancreatic lipase inhibitors. BMC Complementary and Alternative Medicine, 17(1), 385.
13. Killedar, M. A., & Ramalingappa, B. (2024). Navigating the Global Obesity a Global Catastrophe: The Role of Pancreatic Lipase Inhibition and Endophytic Fungi in Developing Innovative Therapeutics for Metabolic Health. Journal of Microbiology and Related Research, 10(2), 81-88. DOI: http://dx.doi.org/10.21088/jmrr.2395.6623.10224.5
14. Killedar, m. A., & ramalingappa, b. Recent research in medical diagnostics by using microfluidics and new biosensor invention. Contemporary Trends in Chemical, Pharmaceutical and Life Sciences Volume I Editors: Dr. Bassa Satyannarayana and Mr. Mukul Machhindra Barwant ISBN: 978-93-95847-69-8, 1.

15. Killedar, M. A., Sowmya, K. L., & Ramalingappa, B. (2024). Collection, extraction and phytochemical analysis of Indian borage leaves (Plectranthus amboinicus). International Journal of Plant Pathology and Microbiology, 4(2), 52-56. DOI: https://doi.org/10.22271/27893065.2024.v4.i2a.93

16. Lott, J. A., & Lu, C. J. (1991). Lipase isoforms and amylase isoenzymes: assays and application in the diagnosis of acute pancreatitis. Clinical chemistry, 37(3), 361-368.

17. Meghwanshi, G. K., Kaur, N., Verma, S., Dabi, N. K., Vashishtha, A., Charan, P. D., ... & Kumar, R. (2020). Enzymes for pharmaceutical and therapeutic applications. Biotechnology and applied biochemistry, 67(4), 586-601.

18. Patil, S., Patil, M., Maheshwari, V. L., & Patil, R. H. (2022). Pancreatic lipase (PL) inhibitors from medicinal plants and their potential applications in the Management of Obesity. In Natural Products as Enzyme Inhibitors: An Industrial Perspective (pp. 153-167). Singapore: Springer Nature Singapore.

19. Ramalingappa, B., Sowmya, K. L., & Killedar, M. A. (2024). Morphology, Qualitative Phytochemical Analysis and Antimicrobial Activities of Ramaria botrytis from Davangere, Karnataka, India. KAVAKA: Mycological Society of India-MSI, 60(4), 58-63. DOI: 10.36460/Kavaka/60/4/2024/58-63

20. Roy, R., Dutta, S., and Dutta, A. K. (2026). Fungal Secondary Metabolites in Cancer Therapy. In Advances in Fungal Secondary Metabolites: Bioactive Attributes and Biotechnological Potential of Industrial Interest: Exploring Bioactive Compounds and Their Biotechnological Potential Cham: Springer Nature Switzerland (pp. 49-65).

21. Singh, A., and Negi, P. S. (2025). Biotechnological application of health-promising bioactive compounds. In Biotechnological Intervention in Production of Bioactive Compounds: Biosynthesis, Characterization and Applications (pp. 73-94). Cham: Springer Nature Switzerland.

22. Sowmya, K. L., Killedar, M. A. and Ramalingappa, B., (2025). Study of Pharmacological and Therapeutic Potential of Neem Leaves (Azadirachta Indica) 6(7), 3522-3529. https://doi.org/10.55248/gengpi.6.0725.25141

23. Stajich, J. E., Berbee, M. L., Blackwell, M., Hibbett, D. S., James, T. Y., Spatafora, J. W., and Taylor, J. W. (2009). The fungi. Current Biology, 19(18), R840–R845.

24. Waldorf, A. R., & Polak, A. (1983). Mechanisms of action of 5-fluorocytosine. Antimicrobial agents and chemotherapy, 23(1), 79-85.