Overview: chitin as a shared structural hallmark of fungi and insects

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Abstract. Chitin, a β-(1→4)-linked N-acetylglucosamine polymer, represents a conserved structural hallmark of fungi and insects, forming the backbone of fungal cell walls and arthropod exoskeletons. Despite independent evolutionary histories, chitin in both lineages shares α-chitin microfibrils as a common scaffold, embedded within composite matrices of proteins, pigments, and other polysaccharides, which confer diverse mechanical and functional properties. Recent studies elucidate the biosynthesis of chitin via chitin synthases, its dynamic remodeling by chitinases and chitin deacetylases, and its role as a signaling molecule in cross-kingdom interactions. The conserved biochemical pathways and structural strategies underline the evolutionary and taxonomic proximity of fungi and animals, contrasting with plants and vertebrates that lack chitin. This review synthesizes current knowledge on chitin polymorphism, composite architectures, enzymatic machinery, and functional roles, emphasizing its centrality in structural biology, development, and host–microbe interactions across non-plant eukaryotes.

Key Words: α-chitin, cell wall, chitin, chitin deacetylase, chitin synthase, chitinase, chitosan, composite architecture, evolution, exoskeleton, fungi, insects, Opisthokonta, signaling, structural polysaccharide.

Introduction. Chitin, a linear polymer of β-(1→4)-linked N-acetylglucosamine, is the second most abundant polysaccharide on Earth after cellulose and a fundamental structural component of both fungal cell walls and the exoskeletons of arthropods, including insects (Moussian 2019; Steinfeld et al 2019). In both groups, chitin microfibrils are embedded in composite matrices of proteins, pigments and other polysaccharides to generate mechanically robust, adaptable extracellular structures (Zhu et al 2016; Elsoud & El Kady 2019; Moussian 2019). The presence of chitin in fungi and insects, but not in higher plants or vertebrates, has long contributed to the view that fungi are structurally and evolutionarily closer to animals than to plants, and it remains a central point of reflection for taxonomists considering deep relationships among eukaryotic lineages (Moussian 2019; Steinfeld et al 2019).

This mini-review aims to provide a comparative overview of chitin as a structural and functional polymer in fungi and insects, highlighting its chemical properties, composite architectures, biosynthesis, remodeling, and evolutionary significance.

Chemical structure and polymorphism of chitin in fungi and insects. At the molecular level, chitin is identical in fungi and insects: a homopolymer of N-acetylglucosamine that forms hydrogen-bonded microfibrils (Moussian 2019; Steinfeld et al 2019). These fibrils can assemble into different crystalline polymorphs (α-, β- and γ-chitin) that differ in chain packing and thus in mechanical and physicochemical properties (Kaya et al 2015; Moussian 2019). Comparative work shows that fungal and arthropod chitins are typically in the α form, with antiparallel chain arrangement and high crystallinity, providing stiffness and resistance to enzymatic degradation (Kaya et al 2015; Moussian 2019). Solid-state NMR studies of fungal cell walls reveal that chitin is structurally heterogeneous at the local level and exhibits partial similarity to both α- and γ-allomorphs, suggesting that fungal chitin occupies a continuum of conformations rather than a single idealized crystal form (Fernando et al 2021).

Insect cuticles additionally show pronounced hierarchical order, with α-chitin laminae cross-laminated with proteins to form twisted plywood-like structures that underlie the remarkable mechanical diversity of exoskeletons (Moussian 2019). Thermal and crystallinity measurements indicate that insect chitin often displays higher crystallinity and thermal stability than fungal chitin, reflecting its role in rigid, load-bearing exoskeletons compared with the more flexible, growth-accommodating fungal wall (Kaya et al 2015). Despite these quantitative differences, the shared α-chitin scaffold supports the notion of a conserved structural solution deployed in parallel in fungi and animals.

Cell wall and cuticle architecture: parallel composite designs. In fungi, chitin is embedded in a complex cell wall matrix composed of β-glucans, chitosan (deacetylated chitin), mannans and wall proteins. Recent high-resolution NMR analyses show that in many zygomycetous pathogens the rigid core of the wall is dominated by polymorphic chitin and chitosan, with β-glucans present only in small amounts and linked to specific chitin subtypes (Cheng et al 2024). Chitosan in these walls plays a key role in preserving hydration and dynamics, while hydrophobic proteins become entrapped within the semi-crystalline chitin/chitosan layer, emphasizing the structural centrality of chitin-derived polymers in fungal morphogenesis and pathogenicity (Cheng et al 2024). Similar studies across yeasts and filamentous fungi confirm that although carbohydrate composition varies, chitin and its derivative chitosan provide a conserved polysaccharide scaffold that is dynamically remodeled during development and host interaction (Fernando et al 2021; Kappel et al 2024).

In insects, chitin is likewise part of a composite, but here it forms the fibrous core of the cuticle and peritrophic matrix, closely associated with diverse cuticular proteins, pigments and sometimes minerals (Zhu et al 2016; Moussian 2019). Chitin–protein composites yield materials with a wide range of mechanical properties, from soft, flexible intersegmental membranes to hardened mandibles and sclerotized wings (Zhu et al 2016; Moussian 2019). The growth and metamorphosis of insects are tightly coupled to cycles of chitin synthesis, cuticle assembly, and enzymatic degradation, with large gene families encoding chitin-binding proteins and chitinases that orchestrate cuticle turnover (Rathore & Gupta 2015; Zhu et al 2016). At the structural level, therefore, both fungi and insects rely on chitin-based composites whose mechanical performance is tuned by associated polymers and proteins, reinforcing the conceptual link between fungal walls and invertebrate exoskeletons.

Chitin biosynthesis and chitin synthases in fungi and insects. The shared presence of chitin reflects, at a deeper level, a shared biochemical pathway centered on chitin synthases (CHSs), membrane-embedded glycosyltransferases that polymerize UDP-N-acetylglucosamine into translocating chitin chains (Steinfeld et al 2019; Chen et al 2023; Yu et al 2024; Brain et al 2025). Comparative evolutionary analyses indicate that chitin and CHSs are ancient and widespread across eukaryotes, including fungi, many protists and diverse animal lineages, but are absent from higher plants and vertebrates (Steinfeld et al 2019). This discontinuous distribution has been interpreted as evidence that chitin-based extracellular matrices represent a deep, ancestral feature that has been differentially retained, elaborated or lost in various lineages, including those that gave rise to fungi and animals (Steinfeld et al 2019).

Recent cryo-electron microscopy structures of fungal chitin synthases from *Saccharomyces cerevisiae* have elucidated a conserved domain-swapped homodimer architecture, with defined donor and acceptor binding pockets, a self-priming mechanism and a chitin-conducting transmembrane channel (Chen et al 2023). These structural insights are broadly relevant because the core glycosyltransferase domains are conserved across CHSs from all chitin-containing taxa, including insects (Chen et al 2023; Yu et al 2024). In insects, genomic and functional studies reveal multiple CHS isoforms, with CHS1 and CHS2 typically responsible for cuticular and peritrophic matrix chitin, respectively, and auxiliary proteins coordinating the assembly of chitin into organized fibrils (Zhu et al 2016; Yu et al 2024). Despite independent evolutionary histories, fungal and insect CHSs share key structural motifs and catalytic features, highlighting a common enzymatic foundation for their structurally analogous chitinous matrices (Steinfeld et al 2019; Chen et al 2023; Yu et al 2024).

Chitin remodeling: **chitinases and chitin deacetylases in both lineages**. The dynamic use of chitin as a structural material requires controlled degradation and modification. Both fungi and insects possess extensive repertoires of chitinases, predominantly in the glycoside hydrolase family 18, which cleave chitin into chitooligosaccharides (Seidl 2008; Rathore & Gupta 2015). In insects, chitinases are essential for molting and metamorphosis, mediating partial degradation of old cuticle and facilitating synthesis and expansion of the new one; their expression is tightly regulated in space and time to avoid lethal weakening of the exoskeleton (Rathore & Gupta 2015).

Filamentous fungi encode on average 10-25 distinct chitinases with diverse domain architectures and subcellular localizations, participating in cell wall remodeling during hyphal growth, septation, autolysis and interactions with other fungi or hosts (Seidl 2008). In mycoparasitic fungi such as *Trichoderma*, chitinases and related enzymes contribute to both endogenous wall remodeling and the degradation of host fungal walls, and chitosan accumulation in the parasite’s own wall may act as a sophisticated strategy to evade host recognition (Kappel et al 2024). Fungi uniquely employ chitin deacetylases to convert chitin into chitosan in defined wall regions, thereby altering charge, hydration and susceptibility to host chitinases (Elsoud & El Kady 2019; Cord-Landwehr & Moerschbacher 2021; Cheng et al 2024; Kappel et al 2024). The presence of extensive chitinase families and chitin deacetylases in both fungi and insects underscores the parallel evolution of complex “chitin remodeling systems” associated with growth, defense and interaction with other organisms.

Chitin as a conserved structural and signaling motif. Beyond mechanics, chitin and its derivatives act as key signaling molecules in interactions with other organisms. Fungal chitin and chitosan function as microbe-associated molecular patterns in plant immunity, with specific oligomers recognized by LysM-type receptor kinases to trigger defense responses (Sánchez-Vallet et al 2015; Pusztahelyi 2018). Plants, in turn, produce chitinases and deploy chitin-binding effectors in a molecular arms race with pathogenic fungi, while mutualistic fungi co-opt chitin-derived signals to establish symbiosis (Sánchez-Vallet et al 2015; Pusztahelyi 2018). Similar recognition of chitin fragments occurs in the innate immune systems of animals, including mammals, where chitin serves as a stimulus for inflammatory and allergic responses and where host chitinases and chitinase-like proteins modulate responses to fungal and arthropod exposure (Rathore & Gupta 2015; Steinfeld et al 2019).

These cross-kingdom signaling roles reinforce chitin’s status as a conserved molecular landmark of “non-plant eukaryotic” multicellularity. The fact that chitin is a core structural motif in fungal walls and arthropod exoskeletons, and simultaneously a major elicitor for plant and animal immune surveillance, reflects its deep evolutionary entrenchment in the biology of fungi and animals (Sánchez-Vallet et al 2015; Pusztahelyi 2018; Steinfeld et al 2019).

Taxonomic and evolutionary implications: **fungi closer to animals?** Modern molecular phylogenetics firmly places fungi and animals in the clade Opisthokonta, distinct from plants, with multiple lines of evidence - flagellar structure, mitochondrial organization, gene content - supporting their close relationship. Chitin distribution and metabolism fit naturally into this framework. Chitin is entirely absent from higher plants and vertebrates, but is a central structural component in fungi and arthropods, many protists, and some other invertebrate groups (Moussian 2019; Steinfeld et al 2019). The convergent, sophisticated deployment of chitin as a load-bearing extracellular material in fungal walls and animal exoskeletons, coupled with shared reliance on related chitin synthases and associated enzymes, has historically encouraged taxonomists to align fungi more closely with the animal kingdom than with plants (Moussian 2019; Steinfeld et al 2019).

While chitin alone is not sufficient evidence for common descent of insect exoskeletons and fungal cell walls, its presence as a deeply conserved, functionally homologous structural polymer across fungi and animals, but not plants, reinforces the concept of an ancient opisthokont predisposition toward chitin-based extracellular matrices (Steinfeld et al 2019). The elaborate gene families for chitin synthases, chitinases and chitin deacetylases in both fungi and insects, and the intricate regulatory networks controlling their deployment, argue that chitin biology has been a major axis of innovation in the evolution of both kingdoms (Seidl 2008; Rathore & Gupta 2015; Zhu et al 2016; Cord-Landwehr & Moerschbacher 2021; Yu et al 2024).

Contemporary reviews emphasize that chitins and chitosans form a versatile toolkit whose patterns of acetylation and association with binding proteins encode information - the so-called "ChitoCode" - governing matrix assembly and recognition in both fungal walls and insect cuticles (Cord-Landwehr & Moerschbacher 2021). The shared reliance on this toolkit provides a structural and biochemical bridge between fungi and animals that is absent in plants, resonating with the taxonomic and evolutionary view that fungi are indeed more closely allied to the animal world.

Conclusions. Chitin emerges from this review as a deeply conserved and multifunctional structural polymer that unites fungi and insects through a common biochemical and architectural framework. Despite their independent evolutionary trajectories, both lineages exploit α-chitin microfibrils embedded in composite matrices of proteins, pigments, and other polysaccharides to achieve versatile extracellular structures, from the flexible yet resilient fungal cell wall to the highly rigid and load-bearing insect exoskeleton. The shared reliance on chitin synthases, chitinases, and chitin deacetylases underscores not only the conservation of the enzymatic machinery but also the sophisticated regulatory networks that orchestrate growth, morphogenesis, and environmental interaction in both groups. Beyond its mechanical role, chitin functions as a signaling molecule, mediating interactions with other organisms and shaping immune recognition across kingdoms, further illustrating its centrality in eukaryotic biology. Evolutionarily, the presence and elaboration of chitin-based matrices in fungi and animals, contrasted with its absence in plants and vertebrates, reinforces the close affiliation of fungi with the Opisthokonta and highlights chitin as both a structural and molecular signature of non-plant multicellularity. Overall, the study of chitin in fungi and insects not only illuminates the parallel solutions these organisms have evolved for extracellular scaffolding but also provides insight into the evolutionary innovation and versatility of polysaccharide-based biopolymers in shaping life's diversity.

Conflict of interest. The authors declare that there is no conflict of interest.

References

Brain L., Bleackley M., Doblin M. S., Anderson M., 2025 Fungal chitin synthases: structure, function, and regulation. Journal of Fungi 11(11):796.

Chen D. D., Wang Z. B., Wang L. X., Zhao P., Yun C. H., Bai L., 2023 Structure, catalysis, chitin transport, and selective inhibition of chitin synthase. Nature Communications 14:4776.

Cheng Q., Widanage M. C. D., Yarava J. R., Ankur A., Latgé J. P., Wang P., Wang T., 2024 Molecular architecture of chitin and chitosan-dominated cell walls in zygomycetous fungal pathogens by solid-state NMR. Nature Communications 15:8295.

Cord-Landwehr S., Moerschbacher B. M., 2021 Deciphering the ChitoCode: fungal chitins and chitosans as functional biopolymers. Fungal Biology and Biotechnology 8:19.

Elsoud M. M. A., El Kady E. M., 2019 Current trends in fungal biosynthesis of chitin and chitosan. Bulletin of the National Research Centre 43:59.

Fernando L. D., Widanage M. C. D., Penfield J., Lipton A. S., Washton N., Latgé J. P., Wang P., Zhang L., Wang T., 2021 Structural polymorphism of chitin and chitosan in fungal cell walls from solid-state NMR and principal component analysis. Frontiers in Molecular Biosciences 8:727053.

Kappel L., Yu L., Escobar C., Marcianò D., Srivastava V., Bulone V., Gruber S., 2024 A comparative cell wall analysis of *Trichoderma* spp. confirms a conserved polysaccharide scaffold and suggests an important role for chitosan in mycoparasitism. Microbiology Spectrum 12(8):e03495-23.

Kaya M., Baublys V., Šatkauskienė I., Akyuz B., Bulut E., Tubelytė V., 2015 First chitin extraction from *Plumatella repens* (Bryozoa) with comparison to chitins of insect and fungal origin. International Journal of Biological Macromolecules 79:126-132.

Moussian B., 2019 Chitin: structure, chemistry and biology. Advances in Experimental Medicine and Biology 1142:5-18.

Pusztahelyi T., 2018 Chitin and chitin-related compounds in plant-fungal interactions. Mycology 9(3):189-201.

Rathore A. S., Gupta R. D., 2015 Chitinases from bacteria to human: properties, applications, and future perspectives. Enzyme Research 2015:791907.

Sánchez-Vallet A., Mesters J. R., Thomma B. P. H. J., 2015 The battle for chitin recognition in plant-microbe interactions. FEMS Microbiology Reviews 39(2):171-183.

Seidl V., 2008 Chitinases of filamentous fungi: a large group of diverse proteins with multiple physiological functions. Fungal Biology Reviews 22(1):36-42.

Steinfeld L., Vafaei A., Rösner J., Merzendorfer H., 2019 Chitin prevalence and function in bacteria, fungi and protists. Advances in Experimental Medicine and Biology 1142: 19-59.

Yu A., Beck M., Merzendorfer H., Yang Q., 2024 Advances in understanding insect chitin biosynthesis. Insect Biochemistry and Molecular Biology 164:104058.

Zhu K. Y., Merzendorfer H., Zhang W., Zhang J., Muthukrishnan S., 2016 Biosynthesis, turnover, and functions of chitin in insects. Annual Review of Entomology 61:177-196.

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