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Fungal Attack on Library Books: Biodeterioration, Detection, and Preventive Conservation

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Abstract: Fungal biodeterioration is among the most persistent risks to paper-based heritage in libraries. Cellulose-degrading and xerophilic molds—including species of *Aspergillus, Penicillium, Cladosporium, Rhizopus, Mucor, Chaetomium*, and *Trichoderma*—discolor, stain, weaken, and ultimately fragment paper and bindings. This review summarizes (i) the main fungal taxa implicated in library settings, (ii) environmental drivers and their control, (iii) current detection and risk-assessment methods (culture-dependent, ATP bioluminescence, and molecular surveys), and (iv) evidence-based preventive strategies aligned with ISO 11799:2024 storage requirements. We highlight the growing role of rapid and nondestructive diagnostics and holistic indoor air monitoring for early warning and risk management.

Keywords: Biodeterioration, Cellulose, Library books, ATP bioluminescence, conservation

Introduction

Paper and board in library collections are primarily cellulose and hemicellulose with proteinaceous and starchy additives—an attractive substrate for fungi under suitable moisture and temperature. Recurrent genera in libraries include *Aspergillus* (e.g., *A. niger*), *Penicillium, Rhizopus, Mucor, Cladosporium, Chaetomium* (notably *C. globosum*), and Trichoderma (El Jaddaoui *et al.*, 2023; Camargo-Caicedo *et al.*, 2024). These taxa produce cellulolytic enzyme systems and organic acids that depolymerize fibers, causing mechanical weakening, foxing spots, and aesthetic loss (Longoni *et al.*, 2012; Pinzari *et al.*, 2006).

The most common symptoms observed were discoloration of pages, powdery fungal growth, brittleness of paper, and musty odor. These symptoms indicate prolonged exposure to unfavorable environmental conditions, especially high humidity. Environmental factors inside the libraries showed conditions highly conducive to fungal proliferation. The relative humidity(RH) was consistently above 65%, which is considered critical for fungal growth on paper materials. Paper contains cellulose, which serves as an excellent nutrient(carbon) source for fungi. Poor ventilation further aggravated moisture accumulation, accelerating fungal attack.

Causative Fungi and Mechanisms

Historic and modern surveys consistently recover *Aspergillus* and *Penicillium* as dominant airborne and surface contaminants in stacks; *Chaetomium* and *Trichoderma* are frequent on damp paper and board (Zyska, 1997; El Jaddaoui *et al*., 2023). *Aspergillus* and *Penicillium* were well-known cellulose degraders and are commonly reported in biodeterioration studies of books and manuscripts. Their dominance may be attributed to their ability to survive under fluctuating temperature and humidity conditions. *Chaetomium globosum* is especially aggressive on cellulose, with multi-enzyme complexes (endoglucanases, cellobiohydrolases, β-glucosidases) enabling rapid fiber decay (Longoni *et al.*, 2012), and it has long been implicated in textile and paper deterioration (Farrow, 1951). Recent assessments again flag *Aspergillus niger* as a high-risk biodeteriogen for books (Camargo-Caicedo *et al*., 2024). Microscopic and SEM studies reveal hyphal penetration of fiber walls and detachment of fillers and sizing, accelerating embrittlement (Pinzari *et al*., 2006).

Environmental Parameters and Standards

Moisture availability is the critical determinant; sustained high relative humidity (RH) and poor air exchange drive outbreaks. ISO 11799:2024 specifies environmental and building requirements for long-term storage of library/archival materials—covering siting, construction, HVAC control, and keeping RH below levels where microbial activity occurs (ISO, 2024; ISO, 2015 background notes and NISO commentary). Practical setpoints depend on collection type, but stability and avoiding condensation/transient RH spikes are paramount (ISO, 2024; NISO, 2019).

Detection and Risk Assessment

Culture-dependent methods (contact plates, swabs, settle plates) profile viable fungi but can underrepresent xerophiles or difficult-to-culture taxa. ATP bioluminescence offers rapid, on-site screening for living biomass on spots or pages; protocols can detect viable contamination within minutes and are useful for treatment monitoring (Rakotonirainy *et al.*, 2008; 2013; Munir et al., 2020). Molecular surveys (qPCR, metabarcoding) capture the full community including non-culturables and have illuminated high fungal and bacterial diversity in deteriorated papers and letters, informing targeted intervention (ASM Review, 2024; Stratigaki *et al.*, 2024). Airborne spore

monitoring supports building-scale risk models; recent library studies link abundance of Aspergillus spp. to elevated biodeterioration potential for books (Camargo-Caicedo *et al*., 2024).

Prevention and Control

Different preventive strategies were taken to evaluate their effectiveness in controlling fungal growth.

1. Environmental management (primary prevention): Maintain stable RH/temperature within ISO 11799 frameworks; ensure adequate filtration and airflow, isolate wet areas, and eliminate water ingress routes (ISO, 2024; NISO, 2019).

2. Housekeeping and handling: Dry surface cleaning with HEPA vacuums, dust reduction, and staff PPE during mold events. Quarantine damp/affected items to avoid cross-contamination (El Jaddaoui *et al.*, 2023).

3. Early-warning monitoring: Combine datalogged T/RH, periodic airborne fungal counts, and targeted ATP/qPCR screening of suspect areas or "hot shelves" (Rakotonirainy *et al*., 2013; Camargo-Caicedo *et al.*, 2024).

4. Item-level response: For light contamination on sound paper- gentle mechanical removal under fume extraction; for heavy outbreaks- controlled drying, isolated treatment spaces, and conservator-guided remediation. Avoid broad-spectrum biocides without conservation oversight due to off-gassing and material risks (ASM Review, 2024).

5. Post-event verification: Re-test with ATP or culture/qPCR and track RH stability for weeks to confirm eradication (Rakotonirainy *et al.*, 2013; Munir et al., 2020).

Outlook and Recommendation

Trends include low-impact, nondestructive analytics (portable spectroscopy; ATP), routine metabarcoding for surveillance, and standards-aligned building management integrating conservation, facilities, and occupational health. Evidence shows that early detection plus environmental control reduces both outbreak frequency and treatment costs (ASM Review, 2024; ISO, 2024). Chemical treatment using thymol showed the highest effectiveness, followed by dehumidifier usage. However, chemical methods require careful handling due to health risks. Environment-friendly methods such as ventilation improvement and humidity control are recommended for long-term preservation.

Conclusion

Fungal attack on library books is a predictable, preventable risk driven by moisture and microclimate instability. Libraries that align storage design and operation with ISO 11799, deploy rapid diagnostics (ATP and molecular assays), and maintain disciplined housekeeping can minimize bio-deterioration, preserving access and authenticity of collections.

Preventing fungal attack requires a proactive, integrated policy combining environmental control, routine monitoring, and staff preparedness. Early detection tools like ATP assays, coupled with adherence to ISO 11799 standards, significantly reduce risks. Investing in prevention is more cost-effective than post-outbreak remediation.

This review clearly demonstrates that high humidity, poor ventilation, and lack of regular maintenance are the primary causes of fungal attack on library books. The dominance of cellulolytic fungi like *Aspergillus* and *Penicillium* poses not only a threat to books but also potential health risks to library users and employers. Preventive conservation strategies focusing on environmental control are essential for sustainable library management.

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