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Mold Research Center

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Comprehensive Causes of Mold Growth on Wooden Products: Interactions Between Environmental Parameters and Material Properties

I、Introduction

Wooden products were widely used across industries, including factory handling equipment (such as wooden racks and pallets), furniture, interior building materials, and packaging containers. However, the organic nature and high hygroscopicity of wood made it highly susceptible to fungal contamination. Mold growth not only compromised structural integrity but also posed health risks, particularly in humid environments .(Viitanen & Ritschkoff, 1991) Once mold developed, it often led to surface pigmentation, reduced visual quality, long-term structural damage, and the release of spores and metabolites, which negatively affected indoor air quality. Such contamination threatened both manufactured goods and the health of individuals occupying the same environment.

By quantifying risks, analyzing the impact of environmental parameters on mold development, and establishing preventive measures, the risks associated with mold on wooden products were significantly reduced (Dagnas & Membre, 2013). This article synthesized existing literature to examine the critical factors influencing mold growth on wood—including relative humidity, temperature, and material characteristics—while also reviewing effective control and prevention strategies. Future studies should continue to refine predictive models, develop longer-lasting and environmentally sustainable protective treatments, and design practical monitoring tools to further reduce mold risk and enhance the durability of wooden products.

II. Literature Review

1. Mechanism of Mold Growth on Wooden Products

As a natural organic material, wood contained various nutrients on its surface and interior that were essential for fungal growth. These nutrients, such as low-molecular-weight sugars and nitrogen compounds, provided an ideal substrate for mold development (Viitanen, 1997; Terziev et al., 1996).

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Mold spores were ubiquitous in the air and continuously settled onto wood surfaces.

The growth process began when spores germinated on the surface or within the wood. Germination required sufficient moisture as the triggering condition. When the relative humidity (RH) of the environment reached or exceeded a critical threshold, spores absorbed water and initiated germination. Previous studies demonstrated that germination occurred once RH exceeded 75–80% (Hellenbrand & Reade, 1992). Water availability, measured as water activity (aw), was considered a more direct determinant than wood moisture content in initiating fungal growth. Since RH was closely related to aw (RH = 100 × aw), fungal growth typically required aw > 0.80. Spore germination capacity also depended on the moisture conditions under which the spores had originally formed.

Once spores germinated, they produced hyphae—the fundamental structures for fungal growth and expansion. Hyphae extended at the tip to exploit substrates. On or within wood, hyphae grew, branched, and interwove to form mycelial colonies, which appeared as visible mold stains. Certain wood-decay fungi even developed more complex structures, such as cords, to transport water and nutrients within the substrate.

Hyphal growth rate was strongly influenced by environmental conditions, particularly temperature and humidity. Most common indoor molds grew optimally between 20–35 °C, though individual species adapted to specific ranges. For example, Aureobasidium pullulans, frequently observed in stored wood, grew abundantly on sapwood and tolerated low temperatures (as low as 5.5 °C), which explained its frequent occurrence in winter-stored wood (Sorenson, 1991).

Importantly, environmental humidity and temperature in real-world settings were typically fluctuating rather than constant. Under fluctuating RH conditions, hyphal growth behavior was significantly altered. When RH dropped to levels unfavorable for growth, hyphae ceased extension within hours and underwent dehydration or shrinkage. Once humidity was restored, growth often resumed after a restart delay that depended on the duration of the preceding dry period. This adaptive mechanism enabled mold survival under

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unstable conditions.

Through enzymatic secretion, fungi degraded complex wood polymers (such as cellulose, hemicellulose, and lignin) or exploited simple compounds naturally present in wood. Surface molds primarily utilized readily available nutrients such as low-molecular-weight sugars (Terziev et al., 1996); (Vittanen-Mogelinex, 2020), which were often more abundant in sapwood, kiln-dried wood, or planed surfaces. Different wood species varied in resistance to mold depending on their chemical composition, cellular structure, and water absorption properties. Thermal treatment, chemical modification, or preservative application enhanced resistance by altering these properties.

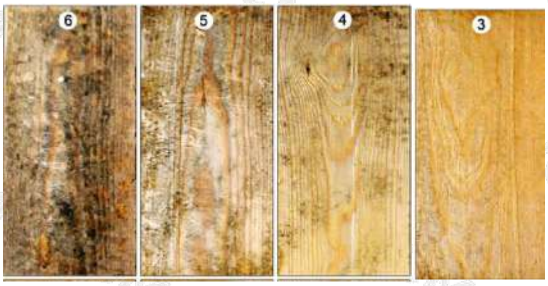
Once colonies matured, fungi produced new spores, which were released into the air to complete the life cycle and spread to other surfaces under favorable conditions, thereby initiating new mold growth. Future studies should continue to investigate how environmental fluctuations and wood modifications interact to influence mold physiology and to develop advanced strategies for preventing fungal colonization in industrial applications.

2. Mold Index (MI)

Viitanen et al. (2000) developed the Mold Index (MI), a mathematical model for assessing mold risk under given en-vironmental conditions (Table 1).

Mould Index	**Description**
0	No visible growth
1	Hyphae visible only under microscope
2	>10% of area contaminated
3	Visible spore formation
4	>10% of area visibly moldy
5	>50% of area contaminated
6	Surface almost completely covered

Using the MI, mold growth trends can be evaluated under varying conditions. For instance, at 97% RH and 20°C, wood surfaces can reach MI = 4 (severe contamination) within 30 days (Viitanen et al., 2000).



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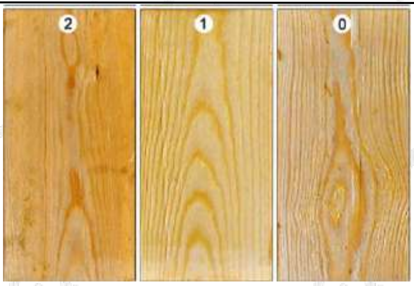

Figure 1. Visualize the proportion of wood mold. A scale (0-6) assessed by the naked eye. After 14 days of culture, the mold index of mold infestation (Mould Index, MI)（0-6）。(Ahmed, Sheikh & Sehlstedt-Persson, Margot & Morén,Tom，2013)

3. Key Influencing Factors

Mold growth on wooden products was not driven by a single condition but by the interplay of environmental parameters and material properties. A deeper understanding of these factors was critical for both risk assessment and practical mitigation strategies in industrial applications. Future research should continue to refine predictive models and explore effective, sustainable methods to mitigate mold risk in wood-based industries.

i. Environmental Parameters

(1) Relative Humidity ：

One of the most critical factors for spore germination and hyphal growth was relative humidity. At RH above 75–80%, spores were able to germinate. High RH was the primary driver of mold, particularly in enclosed or poorly ventilated spaces. For example, at 97% RH, wood reached a mold index (MI) of 3 within approximately two weeks and an MI of 5 (>50% surface affected) within 30 days (Viitanen et al., 2000).

(2) Temperature:

Growth rate was strongly temperature-dependent. Most molds (e.g., Aspergillus sp., Penicillium sp.) grew fastest at 20–35 °C. Below 5 °C, growth slowed significantly, although psychrotolerant species were able to persist. Storage below 15 °C reduced growth risk (Vitanen, 1997; Hellenbrand & Reade, 1992).

(3) Dynamic and Cyclic Conditions:

In real-world environments, RH and temperature fluctuated. Mold grew more slowly under fluctuating RH compared to constant high RH. The critical factor was not the mean RH but the duration of exposure to favorable conditions. For instance, when RH oscillated between 60% and 90%, growth was slower than under constant 90%. Dry periods halted growth, while subsequent rehydration caused delayed regrowth.

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ii. Material Properties

(1) Wood Species and Industrial Applications: Surface Quality:

- **Softwoods (e.g., pine, spruce sapwood):**

Their higher sugar and nutrient content made them more mold-prone (Terziev et al., 1996). Despite their susceptibility, they were widely used in low-cost, short-term applications such as pallets, temporary shelves, packaging boxes, and support structures. Regular inspection and moisture control were essential for these uses.

- **Hardwoods (e.g., oak heartwood):**

Their denser structure and lower nutrient and moisture content provided greater mold resistance and durability. They were suitable for long-term, high-wear equipment such as workbenches, heavy-duty platforms, and storage racks (Vittanen-Mogelinex, 2020).

- **Heat-treated wood:**

This material exhibited enhanced resistance to mold and decay, making it suitable for high-humidity environments such as cold storage rooms, food-processing partitions, pharmaceutical cleanrooms, sauna interiors, and moisture-exposed structural boards (Vittanen-Mogelinex, 2020).

Norway spruce & Scots pine heartwood: Differences in density and moisture content influenced mold resistance, affecting their suitability for factory applications ranging from structural partitions to storage cabinets. Proper wood selection in relation to the intended application environment was essential to minimize contamination risks and extend service life.

(2) Surface Quality:

Planed wood surfaces were smoother, exposed fewer soluble nutrients, and therefore showed lower mold susceptibility compared to sawn surfaces (Terziev et al., 1996).

(3) Water Uptake Capacity:

Hygroscopicity contributed significantly to mold risk. Modified woods, such as acetylated pine sapwood, showed reduced initial moisture content and water uptake.

(4) Chemical Composition and Treatment:

Chemical composition strongly influenced resistance. Treatments such as DMDHEU modification or acetylation enhanced durability. Coatings and preservatives containing biocides were also commonly applied as preventive

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measures (Viitanen & Ahola, 1999).

III. Conclusion

Mold growth on wooden materials was a complex biodegradation process influenced by environmental factors (primarily relative humidity and temperature) and material properties (wood species, surface condition, and chemical composition). Wooden pallets, commonly made from softwoods such as pine, were inexpensive and widely available, but their porous structure and rough surfaces promoted moisture retention and spore attachment, making them highly susceptible to mold. Heat treatment partially reduced microbial load and moisture content, yet the overall risk reduction was limited. Once surface treatments or protective coatings degraded, the pallets' hygroscopic nature and frequent exposure to mold spores during circulation often led to rapid mold development.

The onset of mold depended on the interplay of these factors and the duration of exposure to favorable conditions. Mold indices and mathematical models provided useful tools for quantifying and predicting mold risk. Effective prevention required an integrated approach, combining environmental control of humidity and temperature, the use or modification of more mold-resistant wood species, and the application and maintenance of protective surface coatings. Future research should continue to focus on developing longer-lasting, environmentally sustainable anti-mold technologies, as well as more precise and practical tools for mold monitoring and prediction, in order to further improve the durability and safety of wooden materials.

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