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# Research Progress on the Mildew of Bamboo

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**Abstract**
Bamboo is widely cultivated in China, but it is generally prone to discoloration and rapid development. As an important renewable resource, it broads application prospects in various fields such as architecture, furniture, paper making, etc. However, due to the rich nutrients such as starch, protein, and sugars in bamboo, as well as its strong hygroscopicity, it is very prone to mildew during processing, transportation, storage, and use, which not only reduces the use value of bamboo can also lead to significant economic losses. This paper comprehensively summarizes the causes of mildew in bamboo and bamboo products, and reviews typical anti-mildew treatment technologies and new-mildew agents in recent years, aiming to provide references for further research and application in the field of bamboo anti-mildew/, and to promote efficient utilization of resources and the development of the industry.

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## 1. Introduction

Bamboo, with its fast growth, high strength, and environmental friendliness, is widely used in construction, manufacturing, environmental protection, and other fields Especially its carbon capture capability, which can decompose up to 12 tons of $CO_2$ per hectare, is very important for addressing climate change. The decay of bamboo with the discoloration and mildew of bamboo, which not only affects the appearance of bamboo and reduces its commodity value, but also reduces its anti-decay ability [2] causing bamboo to gradually decay and reduce its service life. Since the 1950s, Chinese experts have been studying bamboo preservation technology and have made some progress, but there is no comprehensive and in-depth report on the research of bamboo discoloration, mildew, and its prevention and control. Therefore, the governance of bamboo mildew is an important topic, and it is imperative to explore the mildew of bamboo and its anti-mildew problems in depth.

## 2. Study on the characteristics of bamboo fungi and their growth

The mildew of bamboo is caused by the growth and reproduction of fungi on its surface. The types and the degree of harm of bamboo fungi in different regions are different. Only by understanding their growth characteristics and influencing factors can we choose effective ways and appropriate antifungal agents to prevent mildew.

### 2.1 Types and characteristics of bamboo fungi

China has a vast territory, diverse climatic conditions many bamboo species, and differences in fungal populations. Experts from the Institute of Subtropical Forestry of the Chinese Academy of Forestry Sciences believe that 15 species of mycete can cause the mold of moso bamboo [5], including 10 important pathogenic fungi, which are: *Alternaria alternata, Aspergillus, Tangerine fungus, Penicillium chrysogenum, P. funiculosum, Trichoderma glabra, Fusarium pallidoroseum, F. camptoceras,* and *Mucor hiemalis*. China has a vast territory, diverse climatic conditions, many bamboo species, and differences in fungal populations. Experts from the Central South Forestry University [1] studied the fungi on moso bamboo and water bamboo in Yiyang and Changde, Hunan, and identified 20 species, including 12 common pathogenic fungi: *Penicillium chrysogenum, P. corylophum,* *P. janthinellum, P. digitatum, P. expansum, Rhizopus nigricans, Aspergillus niger, Pergillus flavus, Trichothecium roseum, Fusarium lactis, F. javanicum,* and *F. moniliforme*; the fun isolated and identified by experts from the Hunan Agricultural University from naturally moldy bamboo basically, match these fungi. Zhao Guihua *et al*. [7] isolated 6 species of fungi from moldy moso bamboo and Sasa bamboo, namely *Phoma necatrix, Alternaria viticola*, *Aspergillus* restrict, Sphaeropsis sclerotiorum, *Melanconum* sp., and *Macrophoma fabae*; he also reported several fungi on bamboo plywood, Penicillium *citrinum*, *Aspergillus flavus*, *Cladosporium herbarum*, and *Pestalotiopsis* sp. Experts from Southwest University [8] studied the fungi causing the mold and decay of bamboo in Changning and Anning, Yunnan, and identified a total of 52 species including 3 species in the *Ascomycota*, 3 species in the *Basidiomycota*, 29 species in the Deuteromycotina, and17 species in the Phycomycotina.

### 2.2 The physiological status of mold on bamboo

Weng Yuexia, Wu Kaiun, *et al*. [4], in their research, believe that the decisive factor for the moldy decay of bamboo is the humidity of the environment. When the relative humidity of the environment is lower than 75%, mold decay does not occur; when the relative humidity is higher than 95%, it is very conducive to the reproduction of mold, causing mold decay to develop rapidly. In addition, temperature also plays an important role in the mold decay of bamboo. When the ambient temperature is lower than 1 ℃ or higher than 35 ℃, the growth of mold is slow, and the most suitable temperature for the growth of mold is between 20～30 ℃. Guangjin, *et al*. [1], researched the biological characteristics of some molds on bamboo and believed that the conidia of Gibberella culminate at a relative humidity of 41%, and the conidia of Penicillium atrium, *Penicillium chrysogenum*, and *Monascus purpureus* could start to germinate at a relative humidity of 63%, while the conidia of Saccharomyces cerevisiae could only germinate at a relative humidity of 70%. The rate of conidium germination increased with the increase in humidity, and the relative humidity was 93%, which was suitable for the germination of spores of various bacteria. The influence of temperature was: the optimum temperature of *Gibberella* was 20～30 ℃, the temperature of Penicillium atrium, *Penicillium chrysogenum*, and *Monascus purpureus* was 15～30 ℃, and could grow at 35 ℃. *Ruan Longxian, et al*.[9], studied the biological characteristics of five common molds on bamboo, namely, *Aspergillus niger*, *Aspergillus flavus*, *Penicillium citrinum*, *Penicillium oryzae*, and *Nigrospora* space, the effects of the total soluble sugar and starch content in bamboo on the growth of mold, and the correlation between the amylase, cellulase activity of the molds and the tangential compressive strength of the decayed bamboo. The results showed that the mold spores germinated and grew the fastest at 25～30 and above 93% relative humidity, while the spores of the five molds did not germinate and the colonies did not grow at below 5 ℃ or below 5% relative humidity. The optimum growth pH value was between 4 and 6; all five molds were able to use starch or soluble sugar as a carbon source but only *Aspergillus niger* could use total soluble sugar and starch content and mold growth were significantly positively correlated [10], all five molds hadylase activity, but only *Aspergillus niger* had cellulase activity. The amylase activity of the mold was negatively correlated with the tangential compressive strength of the decayed bamboo.

## 3. The causes of bamboo wood decay

There are many reasons for the mold of bamboo, including internal and external causes. To sum up, there are the following main points.

### 3.1 The impact of pathogenic microorganisms

The main function of the fungi that cause discoloration of bamboo is to secrete pigments, making the surface or interior of the bamboo show different colors, such as brown, black, blue, green, etc. fungi usually belong to the Ascomycota and Basidiomycota, and the specific classification includes Penicillium, *Aspergillus*, Fusarium Alternaria, and Beauveria. In Japan, more than 30 species of molds on bamboo have been reported, mainly belonging to the Aspergill (*Aspergillus P. Micheli* ex Link), Penicillium (Penicillium Link), and Cladosporium (Cladosporium) of the imperfect fungi. Zhao Guihua and others in China reported 13 species of fungi in the Nanjing area that cause bamboo to mildew and discor, mainly Alternaria (Alternaria Nees), *Aspergillus*, Penicillium, and Cladosporium. Bamboo decay is mainly caused bygi of the Ascomycota and the imperfect fungi, and common molds include *Aspergillus niger*, *Aspergillus flavus*, green, etc. Studies have shown that the content of soluble sugar and starch in bamboo is significantly positively correlated with the growth of mold [10], and the mold resistance bamboo is closely related to its age, treatment method, and environmental conditions.

### 3.2 Bamboo wood contains nutrients suitable for microbial growth

At present, a large number of chemical components have been identified from bamboo, mainly including carbohydrates, nitrogen-containing compounds, nitrogen-containing heterocyclic compounds, various enzymes, organic acids, phenolic compounds, cement, ether extracts, and various mineral elements, which can be utilized by a variety of microorganisms existing in nature. The monosaccharides and disaccharides of bamboo are the final carbon source nutrients for the growth and reproduction of mold. Some complex organic matter that cannot be directly utilized can be decomposed into simple compounds by mold and then absorbed. The nitrogen-containing compounds such as proteins in bamboo are first decomposed into simple compounds such as amino acids by mold and then absorbed and assimilated to form their own components. The contained in bamboo, such as phosphorus, sulfur, magnesium, sodium, iron, calcium, etc., are all substances needed in the growth and reproduction process of mold. Especially when the moisture content of bamboo reaches a certain level, bamboo itself is a suitable culture medium for the growth of mold, and its possibility of mildew is even greater.

### 3.3 The effect of temperature

Under the two treatments of constant temperature and humidity incubator and natural conditions, when the moisture content is the same, the time for the bamboo in the temperature and humidity incubator with higher temperature to mildew is shorter than that in the natural condition with lower temperature, so it is very important to control the environmental temperature of bamboo in bamboo mildew. Ma Xingxia, Qin Daochun [11], and others have studied it. For most strains, about 28 ℃ the most suitable temperature for growth. Generally speaking, at 5 ℃, the growth rate slows down or even stops, but it still maintains its activity. Generally speaking, at 40 ℃, the growth of the strain is also inhibited or even killed, but some mold strains, such as Y-50 smoke *Aspergillus*, still grow slowly at 50 ℃.

### 3.4 Effect of PH and light

Research by Ma Xingxia [11] found that the bamboo fungi had a wide range of adaptability to acidity and alkalinity, and could grow normally under a pH value of 11, with the optimum pH value between 5 and 8. Under dark conditions, the growth rate of hyphae increased slightly with the use of fluorescent light natural light, and the color of the hyphae became white, but with the extension of time, the diameter of the colonies and the secretion of pigments under various conditions consistent, indicating that light had little effect on the growth of the bamboo fungi.

## 4. Antifungal Measures

Bamboo is infected by discoloration fungi during its growth period, as the adhesion and reproduction of the fungi require appropriate temperature, humidity, nutrients, etc. As long as one or more of these conditions are properly, the fungi cannot invade the bamboo. For example, if bamboo and bamboo products are placed in a dry and ventilated place, the moisture content of the bamboo can be as low as possible. However, it is extremely difficult to maintain this condition for a long time in actual use, so antifungal treatment is very important.

### 4.1 Physical Methods

The method of antimicrobial treatment of bamboo is different from that of wood because of the great difference in anatomical structure [12]. The outer of bamboo is dense, and the drug solution is extremely difficult to penetrate. Physical treatment methods include high-temperature sterilization, water immersion, fumigation, and white painting High-temperature sterilization is a method of killing fungi by using methods such as baking, drying, steaming, and boiling. Bamboo treated by the first two methods be stored in a ventilated and dry place, otherwise, it is easy to grow mold after absorbing moisture; bamboo treated by the last two methods should be dried in time to prevent this. The water immersion method is to immerse bamboo and its products in flowing water or living water for a while, so that the soluble sugars and other nutrients on the surface can be leached out, to achieve the effect of antimicrobial treatment.

### 4.2 Chemical Methods

Since the 1930s, chlorophenol-type chemical agents have been used as antimicrobial preservatives, and the types of bamboo preservatives have increased day by day. The use of antimicro agents should be selected according to the use of bamboo, the use environment, and the antimicrobial requirements for bamboo. Liu Yuan [3] and others have studied chemical antimicrobial agents. The selection of agents is decisive, and the concentration has a great influence on the antimicrobial effect, generally speaking, the higher the concentration, the antimicrobial effect. Nowadays, the antimicrobial agents used do not exceed half a year, some are even shorter, so it is very important to avoid temperature and high humidity environments as much as possible after treatment, and strengthen ventilation, such as sodium benzoate, ductting oil, etc. Otherwise, it will affect the antimicrobial effect.

### 4.3 Biological methods

The traditional method of de-mildewing has its disadvantages and there are few biological methods of de-mildewing on the market. Wang Haowei, Yu Zhiming [6], and others have studied biological anti-ildewing. In recent years, many research results have been achieved in new anti-mildewing treatment technologies for bamboo, such as inorganic nano-anti-mewing, biological anti-mildewing agent anti-mildewing, γ-ray irradiation anti-mildewing, ultrasonic anti-mildewing, etc. With the extensive application and continuous development of nanotechnology, nanotechnology has gradually been applied to the bamboo processing field. Inorganic nano-anti-mewing technology can achieve the purpose of sterilization and anti-mildewing by in-situ forming a nanometer anti-mildewing film with any growth structure on the surface of the bamboo, and it has the advantages of low toxicity, thermal stability, and strong bactericidal power. The biological anti-mildew agent anti-mildewing technology of bamboo refers to a kind of anti-mildewing technology that enhances the anti-mildewing performance of bamboo by using secretions or extracts, such as camphor leaf extract, bamboo vinegar, plant essential oil, and other biological anti-mildewing agents to treat bamboo. It has unique such as non-toxic and environmentally friendly, as well as a broad application prospect. Wang Anke [13] and others used a variety of essential oils such as *Lavandula multifida*, *Melaleuca alternifolia*, and *Eucalyptus globulus* to treat bamboo and observed that all three types of essential oil-treated bamboo had excellent anti-mildewing performance.

## 5. Conclusion

The invasion of discoloration fungi is the main cause of bamboo discoloration, and its growth reproduction depends on the nutrients in bamboo. Temperature and humidity have a significant impact on discoloration fungi. In an environment of 25 - 30 ℃ and humidity, the discoloration fungi are highly active and accelerate the discoloration of bamboo. Different bamboo species and treatment methods have different abilities to resist discoloration fungi Chemical agent treatment, drying treatment and so on can effectively inhibit the growth of discoloration fungi and reduce the risk of bamboo discoloration.

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