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BIODETERIORATION AND BIODEGRADATION OF CULTURAL & RELIGIOUS HERITAGE MADE OF PAPER AS A WOOD DERIVATIVE

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Abstract: Many valuable cultural and religious heritage materials suffer from the process of biodeterioration and biodegradation, such as by the contamination of microbes—these contaminations affect the quality of the material as well as the health of the surrounding people. Several studies have been conducted to study the impacting entities as well as to overcome the biodeterioration and biodegradation problems. This review provides a fundamental definition of the said phenomenon and elaborates on the actions done by previous researchers with several approaches to identify and hinder future decay. This literature study compiles and selects previous studies to reach a conclusion. Fungi and bacteria are the two main classes of microorganisms responsible for biodegradation. Both of those organisms have the potential to degrade and deteriorate various types of cultural and religious heritage. The riskiest contamination for paper or manuscripts is brought on by fungi because of their capacity to degrade wood-based products. Additionally, the said microorganisms can have an impact on the health of those who are in close proximity to them, like librarians. The microbes have been studied, identified, and their growth has been prevented using various techniques. More research is still required to avoid the biodegradation and biodeterioration of the priceless cultural and religious heritage, as well as to develop techniques that are both effective and environmentally safe.

Keywords: biodegradation, biodeterioration, cultural heritage, filamentous fungi, degrading bacteria

Abstrak: Banyak material berharga yang merupakan warisan budaya dan religi, namun mengalami proses biodeteriorasi dan biodegradasi. Proses tersebut diantaranya adalah ditemukannya kontaminasi mikroorganisme—kontaminasi ini mempengaruhi kualitas material serta kesehatan orang-orang di sekitarnya. Beberapa penelitian telah dilakukan untuk mempelajari entitas yang terkena dampak serta untuk mengatasi masalah biodeteriorasi dan biodegradasi. Tinjauan ini memberikan definisi mendasar dari fenomena tersebut serta memberikan elaborasi mengenai penelitian-penelitian sebelumnya yang melakukan beberapa pendekatan untuk mengidentifikasi dan menghambat terjadinya penguraian material kuno di masa depan. Studi kepustakaan atau *literature study* ini dilakukan dengan cara menyusun dan menyeleksi penelitian-penelitian sebelumnya untuk mencapai suatu kesimpulan. Jamur dan bakteri adalah dua kelas utama mikroorganisme yang bertanggung jawab untuk biodegradasi. Kedua organisme tersebut berpotensi untuk melakukan biodegradasi dan biodeteriorasi berbagai jenis warisan budaya dan agama. Mikroorganisme tersebut telah dipelajari, diidentifikasi, dan pertumbuhannya telah dicegah dengan menggunakan berbagai teknik. Untuk menghindari biodegradasi dan biodeteriorasi warisan budaya dan agama yang tak ternilai harganya, penelitian lebih lanjut masih diperlukan untuk mengembangkan teknik yang efektif dan aman bagi lingkungan.

Kata Kunci: bakteri pendegradasi, biodegradasi, biodeteriorasi, *filamentous fungi*, warisan budaya

Introduction

Paper is one of the most essential materials for the transfer of knowledge and the preservation of ideas. Many cultural and religious heritage is made of paper, such as the ancient Qur'an and other Islamic books, as well as all the manuscripts written in the Jawa Pegon alphabet found in Indonesia. Jawa-Pegon is a form of alphabet resembling the Arabic alphabet, but all of the words are using the Javanese language. However, as time passes, paper materials can undergo phenomenons named biodeterioration and biodegradation.

Because they provide resources for researchers to study a variety of historical eras, archaeological manuscripts and archives are a vital part of the cultural heritage. These materials primarily consist of organic substrates like paper, photographic paper, parchment, or papyrus that could encourage microbial growth and lead to biodeterioration (Kraková et al., 2018; Sterflinger & Pinzari, 2012). Paper, ever since

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its invention, has become one of the primary carriers of our information, be it historical, cultural, scientific, political, or economic in nature. Because of the significance of this content, ensuring its safety is a topic that garners a lot of attention. Paper's integrity can be compromised by a variety of factors, including physical, chemical, and biological agents. Fungi are the most important paper biodeteriogens that can be found among microorganisms. Throughout the course of human history, a number of approaches have been utilized to slow or halt the progression of fungal deterioration on paper-based materials (Sequeira et al., 2012). For the purpose of conserving paper, a number of physical and chemical techniques have been used, including gamma rays, calcium propionates, and parabens (Sequeira et al., 2017; Michaelsen et al., 2013).

Documents are written on paper, papyrus, parchment, and electronic supports are preserved in archives. Physical, chemical, and biological agents degrade these organic and synthetic materials (Walker & British Library. National Preservation Office., 2003 in Sahab et al., 2014). Biodeterioration can act as a hazard to the physical quality of the manuscript made of paper and other organic as well as synthetic materials. It is a common problem found in various libraries across the globe (Shamsian et al., 2006; Walker & British Library. National Preservation Office., 2003; Zyska, 1997). The most frequently known threats to the paper manuscript are caused by biological agents, such as fungi, bacteria, or insects. Fungi and bacteria are the primary cellulosic degrading agents.

The biodeterioration of organic and inorganic materials, as well as polymers, is a complex of transformation processes induced by the growth and metabolic activity of organisms. Monuments, wall paintings, and objects made of stone, wood, paper, vegetal/animal fibers, and parchment all contain traces of it, which can be identified on all of these substances. In Hueck's (1968) words (Hueck HJ, 1968), biodeterioration is "any change in the properties of a material that is caused by the vital activities of organisms," and this definition is generally accepted as the meaning of the phenomenon. Both macroorganisms (such as animals, plants, and fungi) and microorganisms can contribute to the deterioration of cultural heritage (such as autotrophic or heterotrophic bacteria, microfungi, cyanobacteria, algae, and lichens). To determine the type of interaction that occurs with the material and to evaluate the cause-effect relationship of the biodeterioration action of a specific identified biological agent, it is necessary to understand the morphological and physiological characteristics of the vast majority of biodeteriogens. Therefore, it is necessary to evaluate and quantify the presence of biological systems that cause damage to cultural heritage materials in order to apply prompt and effective conservation measures to prevent further damage. This is because it is known that the presence of biological systems that cause damage to heritage materials causes damage (di Carlo et al., 2017). Microorganisms are capable of interacting positively and negatively with humans, animals, and plants, as well as nonliving things. On a daily basis, positive contributions are made to health, food, industry, and the environment, while negative effects include diseases in humans, animals, and plants, as well as damage to conservation materials (Dirhamzah et al., 2020). As Allah describes in Surah Shaad/38:27.

وَمَا خَلَقْنَا السَّمَآءَ وَالْاَرْضَ وَمَا بَيْنَهُمَا بَاطِلًاۗ ذٰلِكَ ظَنُّ الَّذِيْنَ كَفَرُوْا فَوَيْلٌ لِّلَّذِيْنَ كَفَرُوْا مِنَ النَّارِۗ

Meaning:

"And We created not the heaven and the earth and all that is between them in vain. That is the opinion of those who disbelieve. And woe unto those who disbelieve, from the Fire!" (QS. Shaad/38:27).

According to the interpretation of the Ministry of Religion of the Republic of Indonesia, Allah explains in this verse that He created the heavens, the earth, and all the creatures that exist between them for a purpose. Each of the functions of the sky, the stars, the sun, and the moon is very beneficial for living and non-living things. In the course of the development of civilizations, artisans made extensive use of wood in the production of works that now hold cultural significance. They have undergone biodegradation as a result of their organic composition and the fact that they have been subjected to a variety of environmental factors. Fungi that are capable of efficiently degrading cellulose through the use

of excreted enzymes play a dominant role in the process of wood biodegradation (exo-glucanases and beta glucosidases). When oxygen is present, fungal communities predominate, whereas bacteria communities predominate when oxygen is not present. Communities of fungi and bacteria predominate or are almost absent depending on the level of oxygen (Kretschmar et al., 2008) in (Lupan & Popescu, 2012). For the purpose of creating protection strategies, it is crucial to comprehend how bacteria degrade wood and the factors that affect the rate and extent of decomposition. This is especially important when it comes to restoring historically and culturally significant wooden objects. For the purpose of creating protection strategies, it is crucial to comprehend how bacteria degrade wood and the factors that affect the rate and extent of decomposition. This is especially important when it comes to restoring historically and culturally significant wooden objects (Singh et al., 2016).

In addition to microbial species, factors such as pH, temperature, light exposure, poor ventilations, and humidity all play a role in the biodegradation of cultural heritage materials (Karbowska-Berent et al., 2011). Inorganic and organic pollutants, climatic conditions, and chemical treatments (biocides, surfactants, and hydrophobic compounds) all contribute to the growth of microbial organisms, resulting in physical, chemical, and aesthetical changes in cultural heritage and architectural monuments. When this occurs, the value of a work of art is irreparably diminished, and the process is referred to as "Biodeterioration" (Dakal & Arora, 2012). Biological deterioration occurs when living organisms alter or degrade materials in a chemical or physical manner, or both. Organisms are capable of colonizing and eradicating priceless relics of human civilization. In a nutshell, biodeterioration occurs when living organisms alter or degrade materials in some way. Organisms have the ability to colonize and destroy priceless relics and manuscripts of human civilization(Kakakhel et al., 2019).

Fungi and bacteria are the foremost microorganisms responsible for biodeterioration. Several genera, including *Penicillium, Alternaria, Aspergillus, Cladosporium, Chaetomium, Bacillus, Pseudomonas, Staphylococcus, Micromonospora,* and *Virgibacillu*s, were isolated from archaeological documents (Kraková et al., 2018; Sterflinger & Piñar, 2013). Fungi are the predominant organisms responsible for destroying and degrading carbon and residues such as wood and paper. They are capable of generating hydrolytic enzymes. Numerous researchers demonstrated that some *Alternaria, Aspergillus, Chaetomium, Fusarium, Humicola, Myrothecium, Penicillium, Stachybotrys, Stemphylium, Trichoderma*, and *Ulocladium* species are frequently isolated from biodeteriorated manuscripts (Duncan et al., 2008; Ismail & Sahab, 2004; Reinikainen et al., 1995; Abdel-Mallek, 1994; Klyosov, 1990; Sharma et al., 1990; Hurst et al., 1983; Kowalik, 1980). The study performed by Sahab et al. (2014) had aimed to identify fungi that are capable of degrading cellulose materials and polluting valuable old manuscripts, as well as their control with fungicides and exposure to paraformaldehyde. The research had revealed that *Aspergillus, Fusarium*, and *Penicillium* spp. were the dominating contaminating fungi in all examined manuscripts, accounting for over two-thirds of the contaminations. Applications of fungicides and fumigants have resulted in an effective suppression of fungi.

Cellulolytic filamentous fungi have the ability to degrade wood and its derivatives, such as paper, due to their hydrolytic enzymes' activities, especially cellulases. Cellulases are a class of hydrolytic enzymes that can break down cellulose into smaller sugar molecules (Abreham et al., 2015). Cellulolytic enzymes (exoglucanase, endoglucanase, and -glucosidase) that degrade the structure of cellulose are the primary cause of microbial biodeterioration of cellulose-containing cultural heritage objects (Zhang & Lynd, 2004). Another possibility is that the release of pigments or weak acids, known as "foxing," is to blame for the rusty stains and discoloration of paper surfaces (el Bergadi et al., 2014). Exposure to microbes, bio-aerosols, fungal spores, mycotoxins, and related metabolites may have serious health consequences for library staff, conservators, and visitors, particularly for the skin and respiratory system (Sterflinger & Pinzari, 2012). To ensure the long-term viability of such valuable materials and health, it is imperative to prevent the growth of microbial populations in the contaminated goods of cultural heritage (Fouda et al., 2019). The biodeterioration of these items, which includes the presence of microorganisms, has the potential to cause the irreparable loss of historical records. As a result, it is critical to recognize the microorganisms that are present on the surface of historical objects, keep track of their metabolic activity,

and then, using this information, come up with a solution that could help safeguard the cultural heritage (Branysova et al., 2022).

Methods in Studying Biodeterioration and Preserving the Manuscripts

The prevention of biological deterioration of paper goods has long been a major concern. According to Tsuen-hsuin (1985) in Sequeira et al. (2012), Chhi Min Tao Shu, a writer from the sixth century, advised that book rolls should be unrolled and rerolled three times between the fifteenth and twentieth days of the fifth month. Books should not be exposed directly to the sun as this will cause the paper to turn brown. This should be done on a clear day in a large, airy, and cool house. Rolls heated by the sun attract insects easily, so it is best to avoid them on days that are rainy and humid. This kind of preservation would allow books to last for several hundred years. Another simple method to avoid fungal contamination is by controlling the humidity. It is possible that the easiest and most risk-free method to stop the growth of fungi is to restrict the access to water by reducing the amount of water activity on the substrate. Drying is one method that can be used to accomplish this goal; however, when working with large quantities of damp or wet paper, due to the hygroscopicity of this material, drying is typically a slow process, and time is an important factor in the growth of microorganisms (Sequeira et al., 2012).

Young scientists and conservationists of today are growing up with the so-called "next generation" of sequencing techniques, which enables them to acquire an enormous amount of data regarding microbial communities even from the tiniest amounts of sample material. Using non-destructive sampling methods such as cotton swabs, membranes, and adhesive tape to collect only a few cells, hyphae, or spores from the surface of an object in order to extract DNA or RNA is greatly facilitated by this. Scientists, especially biologists, who perform these analyses in the laboratory may never see the object from which samples are collected. This is a potential disadvantage of these innovative and sensitive new methods, but the benefits they provide outweigh this potential disadvantage by a significant margin. Better management and more effective uses of such information promote rapid progress in the advancement of scientific research. This is because the amount of data that is being collected is growing, not just in public databases that are already known about, but also in the private hands of scientists. For these reasons, some suggestions are made in the followings to promote the sharing of resources and the establishment of validated protocols for the collective advancement of science and development on the topic of cultural heritage (Sterflinger et al., 2018). Nevertheless, these approaches have a variety of drawbacks, such as their transient effects, high costs, and reliance on toxic chemicals (Sequeira et al., 2017). Because of this, a new, environmentally friendly strategy that is effective in the long term while also being affordable and safe must be devised. One of the solutions is by the application of nanoparticles (NPs) for paper conservation, as suggested by the study by Fouda et al. (2019). The application of 1 mM Ag-NPs or two mM ZnO-NPs displayed the best conservation effect against the degradation caused by microorganisms to successfully implement a green strategy that is effective in preventing the damage caused by microbes to cultural heritage that contains cellulose. This strategy could be implemented by spraying NPs materials onto the existing manuscripts in order to protect them from further biodeterioration. This would be done in order to preserve the documents. It is also recommended that green synthetic NPs be included in the paper manufacturing process as a constituent in the production of future manuscripts. For the purpose of microorganisms' identification, such as bacterial identification, amplification, and sequencing of the 16S rRNA gene were carried out, while for fungal identification, the internal transcribed spacer (ITS) region was amplified and sequenced (Fouda et al., 2019).

Biotechnology and applied microbiology are providing new information on cultural heritage conservation. However, despite numerous attempts, no method has ever been successful in completely halting the growth of organisms. A wealth of new knowledge has emerged in the fields of biotechnology and applied microbiology that can aid in the preservation of cultural heritage. It has previously been attempted to stop the growth of organisms using various physical and mechanical methods, but this has not been successful. When microflora is exposed to biocides and develops resistance, organic biocides, particularly commercial formulations, do not last long because indigenous microflora can use them as a source of nutrients. Inorganic nanoparticles, on the other hand, have a better chance of preserving

cultural artifacts because of this. Metallic silver (Ag2O) is effective against biofilm, and titanium (TiO2) oxide (O2) nanoparticles (ZnO) are effective antibacterial agents. New biocides are much smaller in size, but they're also much more potent at damaging DNA or RNA. Additionally, green biocides derived from natural sources provide an alternative to chemical biocides because they are less toxic. A new generation of biocontrol agents and methods with the potential for long-term development could benefit from further research into the control of biofilms (Kakakhel et al., 2019).

Conclusion

The two main kinds of microorganisms that cause biodegradation are fungi and bacteria. Both of those organisms can act as a biodeterioration and biodegradation agents for various cultural and religious heritage. For the paper or manuscript, the riskiest contamination is caused by fungi for its ability to degrade the materials derived from wood. Moreover, the said microorganisms can also affect the health of the closely-related people, such as librarians. Several methods have been implemented to study and identify the microbes, as well as to halt their growth. Further study is still needed to develop an effective and environmentally safe techniques to hamper the biodegradation and biodeterioration of the valuable cultural and religious heritage.

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