JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

"Fungal Diversity and Biodeterioration of Historic Monument at Krishnapura Chhatris, Indore, Madhya Pradesh"

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Abstract

The present study investigated the fungal diversity and biodeteriorative potential of fungi associated with the historic monument of Krishnapura Chhatris, Indore, Madhya Pradesh, India. Fungal samples were collected from different microhabitats and identified using morphological and microscopic characteristics. The major fungal genera identified were *Aspergillus*, *Penicillium*, *Fusarium*, *Alternaria* and *Cladosporium*, with *Aspergillus* being the dominant colonizer. Environmental conditions, particularly relative humidity, surface moisture and light exposure, influenced fungal distribution. *Aspergillus niger* showed high biodeteriorative potential, associated with organic acid production. The findings indicate that fungal colonization may contribute to mineral alteration, discoloration and gradual weakening of stone surfaces. Regular monitoring and eco-friendly conservation measures are therefore recommended for the protection of Krishnapura Chhatris.

Keywords: Biodeterioration, fungal diversity, historic monument, stone deterioration, Krishnapura Chhatris, *Aspergillus*, cultural heritage.

Introduction

Historic monuments are important symbols of cultural heritage and provide valuable information about the history, architecture and artistic traditions of past civilizations. However, these structures are continuously exposed to environmental conditions that can cause physical, chemical and biological deterioration. Stone monuments are particularly vulnerable to weathering processes because their surfaces remain exposed to fluctuations in temperature, moisture, solar radiation, atmospheric pollutants and biological colonization (Warscheid & Braams, 2000; Gorbushina, 2007; Caneva et al., 2008).

Biodeterioration refers to undesirable changes in materials caused directly or indirectly by living organisms. Fungi are particularly important agents of biodeterioration because of their ability to grow under diverse environmental conditions and produce metabolites capable of interacting with mineral substrates (Gadd, 2007; Sterflinger, 2010). Fungal colonization of stone monuments can result in surface discoloration, mineral dissolution, cracking, exfoliation and weakening of stone materials (Warscheid & Braams, 2000; Gorbushina, 2007). Many fungi produce organic acids, including oxalic, citric and gluconic acids, which can react with mineral components of stone and promote chemical deterioration. In addition, fungal hyphae can penetrate pores and microcracks, resulting in mechanical stress and physical disruption of stone surfaces (Gadd, 2007; Sterflinger, 2010).

Krishnapura Chhatris is one of the important historic monuments of Indore, Madhya Pradesh. The monument is characterized by its historical architecture and stone construction and is exposed to changing environmental conditions and urban influences. The location of the monument and its exposure to humidity, dust, pollution and moisture may provide favourable conditions for microbial colonization (Caneva et al., 2008; Gorbushina, 2007).

Despite the cultural importance of Krishnapura Chhatris, limited information is available regarding the diversity of fungi colonizing its stone surfaces and their role in biodeterioration. Therefore, the present study was undertaken to investigate the fungal diversity associated with the stone surfaces of Krishnapura Chhatris and evaluate the potential role of these fungi in the biodeterioration of the monument.

Materials and Methods

Study Site -

The present investigation was conducted at Krishnapura Chhatris, a historic monument located in Indore, Madhya Pradesh, India. The monument is an important example of the architectural and cultural heritage of the region. The stone surfaces of the monument are exposed to varying environmental conditions, including seasonal fluctuations in temperature and humidity, light exposure, dust deposition and atmospheric pollution.

Different sampling locations were selected based on visible biological growth, surface discoloration, moisture conditions and exposure to sunlight. Samples were collected from exposed as well as shaded areas to study differences in fungal colonization.

Collection of Samples

Samples were collected aseptically from different stone surfaces of the monument. Sterile cotton swabs, scalpels and brushes were used for sampling. Surface deposits, biofilms, discoloration and fungal growth were carefully collected and transferred to sterile containers. The samples were properly labelled according to their sampling location and transported to the laboratory for microbiological analysis.

Isolation of Fungi

Fungal isolates were obtained using standard culture techniques. The collected samples were inoculated onto suitable fungal culture media such as CDA and PDA. After incubation, morphologically different fungal colonies were selected and sub-cultured repeatedly to obtain pure cultures. The purified isolates were maintained for further identification and biodeterioration studies.

Identification of Fungal Isolates

Fungal isolates were identified based on colony characteristics and microscopic features. Parameters studied included colony colour, texture, growth pattern, pigmentation, conidial structures, hyphal characteristics and reproductive structures.

Assessment of Environmental Parameters

Environmental parameters were recorded at different sampling locations to understand their influence on fungal colonization. The following factors were considered: Temperature, Relative humidity, Light exposure, Surface moisture.

The environmental observations were compared with the occurrence and distribution of fungal isolates.

Assessment of Biodeterioration Potential

The biodeteriorative potential of selected fungal isolates was evaluated based on their growth characteristics and metabolic activities. The following parameters were considered:

Organic Acid Production

Selected fungal isolates were evaluated for the production of organic acids. Organic acids are important biodeteriorative metabolites because they can react with minerals present in stone surfaces.The major organic acids associated with fungal deterioration include: Oxalic acid, Citric acid, Gluconic acid, Other low molecular weight organic acids.

Results

The present investigation revealed considerable fungal diversity on the stone surfaces of Krishnapura Chhatris. Fungal colonization was observed in different areas of the monument, particularly in locations with relatively higher surface moisture and reduced sunlight exposure. The major fungal genera isolated from the monument were *Aspergillus*, *Penicillium*, *Fusarium*, *Alternaria* and *Cladosporium*. Among these genera, *Aspergillus* was found to be the most dominant group.

Table 1. Major fungal genera isolated from Krishnapura Chhatris

S. No.	Fungal genus	General occurrence
1	*Aspergillus niger*	Highly frequent
2	*Penicillium*	Frequent
3	*Fusarium*	Moderately frequent
4	*Alternaria*	Moderate
5	*Cladosporium*	Moderate

Dominance of Aspergillus Species - Species of *Aspergillus* were frequently isolated from different stone surfaces of the monument. Their dominance may be attributed to their ability to produce large numbers of spores and survive under fluctuating environmental conditions. *Aspergillus niger* was among the important fungal isolates associated with biodeterioration. This species is known for its rapid growth and ability to produce organic acids. The dark pigmentation associated with *A. niger* may also contribute to visible surface discoloration. Other species of *Aspergillus* may also contribute to the formation of fungal colonies and biofilms on monument surfaces.

Distribution of Fungi According to Surface Conditions - The distribution of fungal isolates varied according to the microenvironment of the stone surfaces. Areas receiving lower sunlight and retaining higher moisture generally supported greater fungal colonization. Shaded surfaces showed increased fungal growth because of reduced drying and relatively stable moisture conditions. In contrast, highly exposed surfaces showed comparatively lower visible fungal growth.

Table 2. Relationship between environmental conditions and fungal colonization

Environmental condition	Observed fungal response
High surface moisture	Increased fungal colonization
Shaded surfaces	Greater fungal diversity
High relative humidity	Favorable for fungal growth
Dry exposed surfaces	Reduced visible fungal growth

Biodeteriorative Potential of Fungal Isolates

The fungal isolates demonstrated different levels of biodeteriorative potential. *Aspergillus niger* showed comparatively high biodeteriorative potential because of its rapid growth and ability to produce metabolites capable of interacting with stone minerals. *Penicillium* species also showed considerable biodeteriorative potential, particularly due to their metabolic activity and organic acid production. *Fusarium* species showed moderate biodeteriorative activity, while *Alternaria* and *Cladosporium* were important colonizers of exposed and environmentally stressed surfaces.

Role of Organic Acid Production- Organic acid production was considered an important mechanism involved in fungal biodeterioration of stone surfaces. The production of acids such as oxalic acid and citric acid can alter the chemical properties of stone materials. The acids produced by fungi can react with mineral components and may contribute to: Mineral dissolution, Chelation of metal ions, Formation of secondary mineral deposits. *Aspergillus niger* showed significant potential for organic acid production and therefore may represent an important biodeteriorative fungus associated with the monument.

Discussion

The present study demonstrates that the stone surfaces of Krishnapura Chhatris support a diverse fungal community. The occurrence of *Aspergillus*, *Penicillium*, *Fusarium*, *Alternaria* and *Cladosporium* indicates that the monument provides suitable microhabitats for fungal growth. Similar fungal communities have frequently been reported from stone monuments and other cultural heritage materials, where microorganisms colonize surfaces in response to favourable environmental and substrate conditions (Gorbushina, 2007; Sterflinger, 2010; Warscheid & Braams, 2000). The dominance of *Aspergillus* species can be explained by their high ecological adaptability. These fungi produce large quantities of airborne spores and can tolerate fluctuating temperatures, low nutrient availability and relatively dry conditions. Their metabolic flexibility and ability to colonize mineral surfaces make them important microorganisms involved in the biodeterioration of cultural heritage materials. Previous studies have also highlighted the importance of fungi in stone colonization and bioweathering processes (Gorbushina, 2007; Gadd, 2007; Sterflinger, 2010).

The higher fungal diversity observed on shaded and moisture-retaining surfaces highlights the importance of microclimatic conditions. Relative humidity and surface moisture are major factors controlling fungal colonization because water availability supports spore germination, hyphal growth and metabolic activity. Variations in temperature, moisture and light exposure can therefore influence the composition and distribution of microbial communities on stone monuments (Warscheid & Braams, 2000; Gorbushina, 2007; Sterflinger, 2010).

Organic acid production represents one of the most important biochemical mechanisms of fungal stone deterioration. Fungi can produce low-molecular-weight organic acids that promote mineral dissolution, metal chelation and chemical alteration of stone materials. These metabolic processes contribute to the bioweathering of mineral substrates and may result in progressive weakening of monument surfaces (Gadd, 2007; Gorbushina, 2007). The ability of *Aspergillus niger* to produce organic acids makes this species particularly significant in the context of stone biodeterioration. Fungal hyphae can also penetrate pores, fissures and microcracks present in stone materials. The growth and expansion of fungal structures within these spaces may generate mechanical stress, resulting in gradual weakening, cracking and surface disintegration. Such physical and biochemical interactions between fungi and stone substrates have been recognized as important mechanisms in the biodeterioration of cultural heritage materials (Warscheid & Braams, 2000; Sterflinger, 2010).

Environmental pollution and dust deposition may further contribute to microbial colonization by providing nutrients and modifying the physicochemical properties of monument surfaces. Atmospheric particles, organic debris and other deposited materials can create favourable conditions for fungal establishment and biofilm development. Therefore, the urban environment surrounding Krishnapura Chhatris may influence the composition, abundance and distribution of fungal communities on the monument (Caneva et al., 2008; Gorbushina, 2007). Overall, the findings indicate that fungal biodeterioration is a complex process involving physical penetration, metabolic activity, organic acid production and interactions between microorganisms and environmental conditions. The results emphasize the importance of monitoring fungal colonization and microclimatic conditions for the effective conservation of Krishnapura Chhatris. Understanding the mechanisms of fungal biodeterioration can support the development of appropriate preventive and eco-friendly conservation strategies for the long-term protection of this important cultural heritage site (Caneva et al., 2008; Sterflinger, 2010).

Conservation Implications

The findings of the present study have important implications for the conservation of Krishnapura Chhatris. The following measures are recommended:

1. Regular monitoring of fungal growth on monument surfaces.
2. Periodic measurement of environmental parameters, particularly humidity and surface moisture.
3. Removal of excess vegetation and organic debris from areas surrounding the monument.
4. Prevention of prolonged water accumulation on stone surfaces.
5. Development of environmentally safe antifungal treatments.
6. Use of eco-friendly plant-based extracts for microbial control.

Conclusion

The present study revealed that the stone surfaces of Krishnapura Chhatris, Indore, support diverse fungal communities, with *Aspergillus* species being the dominant colonizers. Environmental factors, particularly humidity, surface moisture and light exposure, significantly influenced fungal growth. The biodeteriorative activities of fungi, including hyphal penetration, organic acid production and enzymatic activity, may contribute to the gradual deterioration of stone surfaces. Therefore, regular monitoring and eco-friendly conservation strategies are essential for the long-term protection of this important heritage monument.

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