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Biological Deterioration of Wooden Components of *Balla Lompoa Ri Galesong* in South Sulawesi, Indonesia

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ABSTRACT

Balla Lompoa Ri Galesong, known well as the traditional house of the Takalar Regency, South Sulawesi, has become a historical building in Indonesia. Nowadays, it still functions as a residence for the royal family, a repository for historical artifacts, and a venue for annual cultural performances. Maintaining and protecting buildings from damaging factors is crucial to maintaining their life and function. This research focuses on detecting the damage characteristics of wooden parts of buildings, identifying biological deterioration agents, and assessing the level of infestation. Data collection uses the visual detection method. The results showed that the activities of biodeterioration agents, namely subterranean termites (*Microcerotermes serrula*), drywood termites (*Cryptotermes*), powder-post beetles, wood-staining fungi, and wood-decaying fungi found on pillars, windows, doors, walls, floors, and ceiling. Most pillars are targets of attacks by wood-destroying organisms, characterized by the highest attack intensity (70.13%) and the moderate category in the degree of attack (50–74). Understanding and mitigating the damage to historic buildings is critical for implementing effective preventive measures.

1. Introduction

Indonesia, with its ethnic diversity reaching 1,320 tribes based on the Central Statistics Agency census in 2010, contributes to an abundance of cultural heritage, such as buildings with various architectural styles (Arif et al. 2019; Irwansyah 2017; Ramli et al. 2020), landscapes, and others (Damayanti et al. 2024; Haries and Riesa 2023; Sulistyorini et al. 2022). According to the Cultural Heritage Act (Chapter P-9.002) of 2020, cultural heritage has a broad scope, such as deceased persons of historical importance, historical events and sites, heritage documents, immovable objects, objects and sites, heritage cultural landscapes, and intangible heritage. In South Sulawesi Province, the *Balla Lompoa Ri Galesong* is a cultural heritage building inherited from the Galesong Kingdom, which is the community's pride, especially in the Takalar Regency (Syamsuriadi et al. 2019). As with most ancient cultural heritage, it can not be denied that some traditional architecture, such as traditional house buildings, become objects of weathering and even become extinct with age. On the other hand, historical buildings with unique, exciting architecture and full of symbols that contain meaning and social value must be preserved. In Indonesia, the preservation of cultural heritage is regulated in the Indonesian Law Number 11 of 2010 concerning cultural heritage, including activities for protection, development, and utilization.

The existence of cultural heritage as an identity of a region or country requires serious prevention and control efforts of various damaging factors, both biotic and non-biotic (Esteban-Cantillo et al. 2024; Jia et al. 2023; Kakakhel et al. 2019; Yue et al. 2023). The biological deterioration of cultural heritage has become a global problem and has been intensively studied (Kozlov and Kisternaya 2014; Megna and Liotta 2017), including in historical wooden buildings (Abdel-Azeem et al. 2019; Arif et al. 2019). Microbial agents such as bacteria, fungi, actinomyces, cyanobacteria, lichens, algae, mosses, and liverworts have been reported to colonize wooden parts of historical buildings (Alfieri et al. 2016; Branysova et al. 2022; Ortiz et al. 2014). Insects such as termites and powder beetles have also caused fragmentation and holes in the wood of objects and structural parts of buildings (Kim and Chung 2022; Palazzo et al. 2021). These biodeterioration agents' activities cause the buildings' function to decrease, causing economic losses, health problems, and discomfort (Carlo et al. 2016). Studies regarding the methods used to detect and assess the biodeterioration of wood components vary, such as the use of omic technologies (Beata 2020; Marvasi et al. 2019), near-infrared spectroscopy (Sandak et al. 2015), and systematic analytical approach for diagnosing microbial biodeterioration (Liu et al. 2022).

The structure of *Balla Lompoa Ri Galesong* used wood for its construction. Unique characteristics, such as decorative, renewable, and easy to handle and process, make wood suitable for construction raw materials. However, as an organic material produced by photosynthesis processing, wood provides a source of nutrition for some organisms. These natural properties make wooden buildings vulnerable to invasion by various biodeterioration agents (Kim and Singh 2016). This building, built in the 17th century, has undergone several renovations, with the last renovation being in 1991. Still, initial surveys and inspections of the *Balla Lompoa Ri Galesong* building showed damage to the wooden components of the building's structure caused by wood-destroying organisms. These organisms are usually categorized as insects (termites and beetles) or microbes (fungi and bacteria), which actively damage the substrate by decomposing the chemical components of the wood or fragmenting or creating galleries and tunnels in the wood. Termite and fungus attacks are dangerous (Damanik et al. 2023). The existence of these organisms in invading buildings cannot be separated from the availability of sources of infection around the building. Unfortunately, the location around the building is also overgrown with multiple plants and piles of wood that are very likely to occur as a source of transmission of biodeterioration agents. Although studies on the deterioration of historic buildings in several other parts of the world have been widely and intensively studied, studies of the extent of the historical building damage and its biological agents are still very limited in Indonesia. This study aims to determine the level of damage caused by biodeterioration agents, record the characteristics or symptoms of damage, and identify wood-destroying organisms. This study is intended to contribute to policy-making for the conservation of historic wooden buildings.

2. Materials and Methods

2.1. Study Sites

This study took place in *Balla Lompoa Ri Galesong*, which is located in Galesong Baru Village, South Galesong District, Takalar Regency, with a geographical location at coordinates

5019'04.79" S and 119021'59.31" E, as shown in **Fig. 1**. This location can be accessed by public transportation from the city of Makassar via the Sungguminasa Takalar axis road to Jalan Galesong North Poros with a distance of 28 km and a travel time of 1 hour 2 minutes, while via the Tanjung Bunga metro road with a distance of 24.3 km and a travel time of 53 minutes.

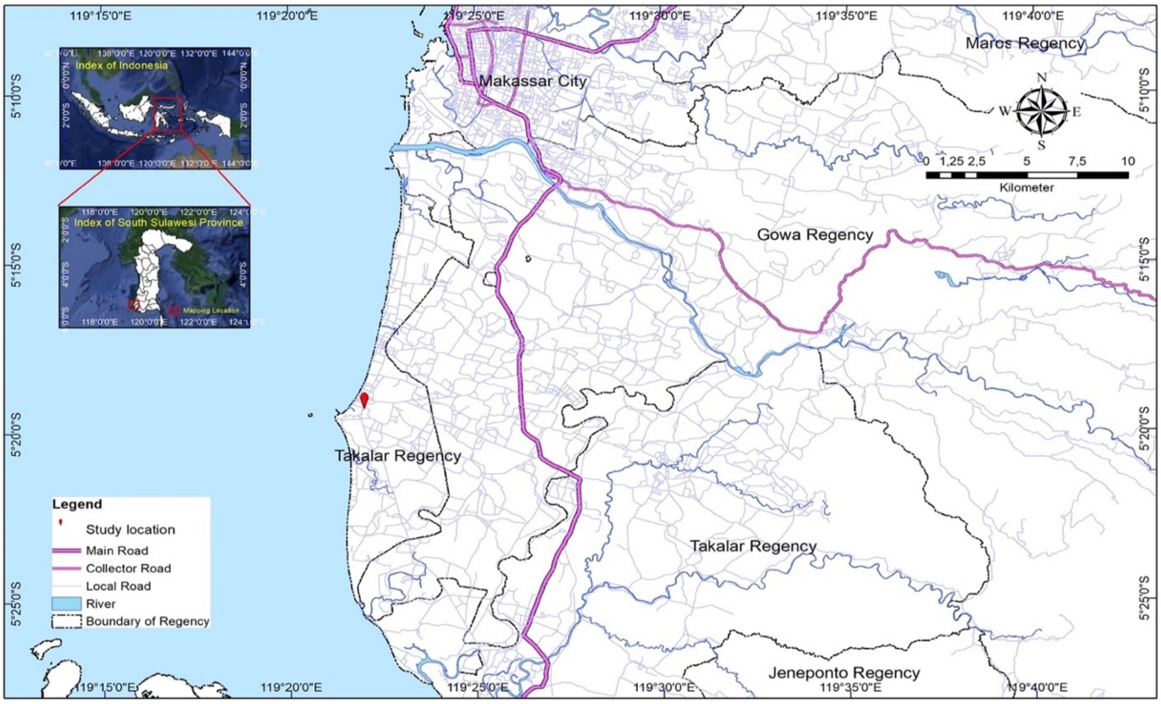

Fig. 1. Site map of *Balla Lompoa Ri Galesong*.

2.2. Damage Evaluation

The occurrence of wood damage in the *Balla Lompoa Ri Galesong* was determined based on the intensity and degree of attack. Evaluation of building damage begins with data collection on all parts of the building structure made of wood, carried out during initial survey activities. The assessment was conducted based on Arif et al. (2019) in the following stages:

a) Each part of the building structure made of wood (pillars, windows, stairs, doors, walls, floors, and ceilings) was observed with their wood species and the type of component (beam, board, or profile board). In this study, the roof structure was not observed.
b) The total number of component types was calculated for each part of the building structure. Observation, assessment, and documentation of signs or characteristics of damage caused by biodeterioration agents were also performed simultaneously.
c) Damage assessment was conducted visually by observing the surface of each component of each part of the building structure to determine the degree of attack (DA). Scoring was determined by referring to the criteria, as shown in **Table 1**.

Table 1. Scale for assessing the degree of protection against destroying agents

Score	Degree	Remarks
100	Intact	No attack on all parts of the surface
75-99	Light	Real damage was found on the surface
50-74	Moderate	Damage is located on the inside of the wood but has not spread
25-49	Severe	Damage is located on the wood, and it is widespread
0-24	Very heavy	The wood is found to be significantly damaged or destroyed

d) The presence of signs or characteristics of organism attack on the surface of each component was expressed and calculated as damaged component units, which were then used to determine the intensity of attack (IA). The intensity of attack by wood-destroying organisms was defined as a percentage of the wooden components attacked. The intensity of the attack was calculated as the ratio of the wooden components invaded against the total number of wooden components of each part of the building structure, with the following formula in Equation 1.

$$IA = a/b \times 100 \tag{1}$$

where IA is attack intensity (%), a is the number of invaded wood (pieces), and b is the number of wooden components (pieces).

2.3. Identification of Wood-Destroying Organisms

Organisms on the deteriorated wood substrate are collected and preserved (if any). If no organism is found, the species or genus is determined using an approach based on the character of the damage it causes:

(1) Termites: Wood components that show signs of damage, such as excrements or coarse grains on the floor around the infested wooden component, tunnels from soil, and nest, have been investigated, and organisms collected (if any). Termite specimens were placed in a vial bottle filled with 70% ethanol, and then their morphology was observed using a Stereomicroscope Stemi 2000 with an ERc 5S phototube camera. To determine species identification by referring to the determination key (Takematsu and Vongkaluang 2012; Tho 1992).

(2) Fungi: Fungi are determined based on general groups, namely wood-staining fungi and wood-decaying fungi, by observing wood components that show signs of weathering or coloring, such as white, black, blue, or other pigments.

(3) Beetles: Wood components that show signs of damage, such as fine powder on the floor around the affected wood component and exit hole diameter, have been investigated and measured, and organisms collected (if any). The beetles found were placed in a vial bottle, and their morphology was observed using a stereomicroscope stemi 2000 with an ERc 5S phototube camera to determine the species or genus.

3. Results and Discussion

3.1. History of Balla Lompoa Ri Galesong

3.1.1. Brief description of Balla Lompoa Ri Galesong

The traditional house of *Balla Lompoa Ri Galesong* is a historical heritage from the Galesong Kingdom as one of the territories of the Gowa Kingdom. This building was built during the reign of the first Karaeng Galesong. The first Karaeng Galesong was the eldest son of Sultan Hasanuddin from his fourth wife, I Hatijah I Lo'mo Tobo, who came from Bonto Majannang. Karaeng Galesong was born on March 29, 1655. During the reign of Sultan Hasanuddin, he was appointed by his father as Karaeng (Kare) in Galesong because of his leadership talents. He was given the name and title I Mannindori Karaeng Tojeng Karaeng Galesong and later became the warlord of the Gowa Kingdom (Yulianti 2017). This traditional house has a unique architecture in the form of '*rumah panggung*', as shown in **Fig. 2**, which was built on a one-hectare plot of land bordered by a wall fence. Until now, the shape and structure of the building have been maintained to maintain the culture and symbolic elements attached to the building. As the age of the building increases, the quality of the building's wooden components also decreases, requiring renovation in several parts. This building has undergone several renovations; the last renovation was on October 27, 1991.

The architecture of *Balla Lompoa Ri Galesong* represents the traditional house style of the Makassar Tribe, especially in the Takalar Regency, which functioned as the residence of kings during the Dutch colonial period. Currently, the house is a place for deliberation regarding local customs. The building used as the owner's residence consists of the main room containing the king's private room, a place to store historical objects, and the royal room. Apart from being a residence, this building also functions as a place for annual cultural performances, namely '*Gaukang Karaeng Galesong*' (Arsad and Suhaeb 2022), a gathering place for traditional officials every Thursday afternoon, and a place for prayer before reciting prayers together on Friday nights.

Fig. 2. The traditional building of *Balla Lompoa Ri Galesong*: (a) front view, (b) left side view, and (c) right side view.

3.1.2. Wooden structures of Balla Lompoa Ri Galesong

The architecture of *Balla Lompoa Ri Galesong* is in the form of a stage with pillars under the building, known locally as a '*rumah panggung*'. There are thirty-six pillars of the Balla Lompoa main house, namely six rows to the side, seven to the back, and sixteen on the '*paladang*' (Syamsuriadi et al. 2019). This building model is generally found in tribes in South Sulawesi (Bugis, Makassar, Mandar, and Toraja) with different architecture and names, such as Balla Lompoa in Gowa Regency (Mustakim 2016), Bola Soba in Bone Regency (Permatasari 2018), Karampuang in Sinjai Regency (Hasfiranita 2019), and Tongkonan in Toraja Regency (Limbu 2022).

The *Balla Lompoa Ri Galesong* has one main building with two forms of profiled tin roofs, initially made of palm fiber (**Fig. 2a**), and one additional building as a kitchen with a tin roof (**Fig. 2c**). Considering that this building still functions as a residence for the descendants of Karaeng Galesong, another additional building is made of bricks used as a bathroom and toilet (**Fig. 2c**). The components of this building structure are made of teak wood (*Tectona grandis* L.f.), which is known to have a high strength and durability class. Pillars are placed on rectangular stones to maintain contact with the ground as a source of moisture.

3.2. Damage Characteristics and Biodeterioration Agents

Before using brick houses, the community of South Sulawesi built wooden houses, known locally as '*rumah panggung*' (**Fig. 2**). This wooden house architecture is also found in *Balla Lompoa Ri Galesong*, using wood to connect parts instead of nails, known as '*pasak*'. The wooden components in the building structure observed were pillars, windows, doors, stairs, walls, floors, and ceilings. The upper parts of the building (roof) were not observed and measured for personal reasons by the building owner. The damaged wooden components are presented in **Table 2**.

Table 2. Type and number of wooden components from *Balla Lompoa Ri Galesong*

No.	Parts of building structures	Number of components (pieces)	Number of damaged components (pieces)	Type of wooden components	Wood species
1	Pillars	77	54	Beam	Teak wood
2	Windows	11	3	Board	Teak wood
3	Stairs	22	0	Board	Teak wood
4	Doors	13	1	Board	Teak wood
5	Walls	94	9	Board	Teak wood
6	Floors	127	14	Board	Teak wood
7	Ceiling	107	19	Profile board	Teak wood

In **Table 2**, the wooden components used are beams and boards. The number of components used for each part of a building structure varies depending on its size and shape. The data shows that the pillars are the part whose members experienced the most damage, with an attack intensity value of 70.13%. The causes of damage vary, although most of the damage is found on the surface of the pole, so it does not eliminate the mechanical function of the pillars. As is typical with traditional houses in the South Sulawesi region, people tend to choose types of wood with a durable and robust class, namely I-III, which is based on the purpose and function of use and the economic capabilities of the building owner. The same thing was found in the *Balla Lompoa Ri Galesong* components made from *T. grandis*, which is well known for its high natural resistance to attacks by biodeterioration agents. Teak wood contains many bioactive compounds with insect-fungal activity (Colbu et al. 2021). However, inspection results still show the presence of attacks by wood-destroying organisms. Deterioration occurrence of teak wooden structures caused by wood-eating insects and fungi also found in the architectural heritage of Myanmar, such as piles at Bagaya Monastery in Inwa, reproduction of an early forest farmhouse at the archeological museum near Loikaw, and Thaka-wun Kyaung in Mandala (Christian 2020).

Visual observation of all the wooden components of the building showed that almost all parts of the building structure were attacked by wood-destroying organisms, except for the stairs.

However, the intensity and degree of attack varied. Symptoms or characteristics of attacks can be seen in **Table 3**.

Table 3. Damage characteristics and types of wood-destroying organisms

No.	Parts of building structures	Damaged characteristics	Biodeterioration agents
1	Door frames, pillar connecting beams, floor and floor support beams	On the surface of the infested wood, a thin layer of wood at least 0.1–0.2 mm in thickness and rough brown grains in the galleries were found	Drywood termite
2	Pillars, ceilings, subfloor surfaces	There are many traces of single-shaped tunnels from the ground and live workers in galleries	Subterranean termite
3	Pillars, floor support beams	There are pinholes on the surface (without coloring around the boreholes) with various hole sizes and fine powder	Powder-post beetle
4	Pillars, pillar connecting beams	Colored stains on the surface of the wood	Wood-staining fungi
5	Pillar connecting beams, subfloor surfaces, ceilings	Mycelial colonization of wood and wood decay	Wood-decaying fungi

3.2.1. Biodeterioration by drywood termites

Termites are xylophagous insects that decompose the cellulose of dead wood (Mugerwa 2015) and lignocellulosic waste, such as paper products, and also known as structural pests such as wooden structures, household furniture, books, and museum collections (Govorushko 2019). This study found traces of drywood termite attacks on wooden components from *Balla Lompoa Ri Galesong*, although individual organisms could not be collected due to their absence. Drywood termites belong to the Family Kalotermitidae, which can survive without contact with the soil and only depend on their food source. Workers of these termites deteriorate the dried structural sawn timber and wooden furniture. In this study, the part of the building attacked by these termites was the frame doors, pillar connecting beams, floors, and support beams. Damage caused by drywood termite attacks was indicated by internal damage, rough brown grains in the galleries, and a layer of wood as thick as veneer covering the galleries. Symptoms of damage are shown in **Fig. 3**.

No termite specimens were found in the gallery during the study; wood deterioration was caused by *Cryptotermes* based on the visible traces and characteristics of the damage. The appearance of the wood becoming porous, the presence of a thin layer of wood remaining on the surface of the wood, and the presence of small brownish excrement grains which often fall on the floor or around the attacked wood are symptoms of attack by *Cryptotermes cynocephalus* (Arif et al. 2019).

3.2.2. Biodeterioration by subterranean termites

Apart from drywood termites, the building components of *Balla Lompoa Ri Galesong* are also attacked by subterranean termites. Traces and tunnels from the ground on the surface of objects, such as houses and wooden objects, indicate that subterranean termites attacked the wooden components. These termites were found to be actively still invading the wood of the building, as seen in **Fig. 4a**, by making single tunnels from the ground in the pillars, ceilings, and subfloor surfaces. Based on the symptoms and characteristics of wood damage (**Fig. 4**) and the identification of termite specimens found in the tunnel, the infested termite was *Microcerotermes serrula* (**Fig. 5**). Soldier caste of this species characterized by an elongated subrectangular head capsule, thick-set mandibles dan serrate, without marginal teeth, and mandible have slightly longer than half of head length (Tho 1992). This species also infects residents in Makassar City, South Sulawesi Province (Arif et al. 2020), showing similar morphological characteristics of soldier caste found attacking the *Balla Lompoa ri Galesong*, such as the rectangular shape of the head capsule, light brown, and serrated mandibles. In these studies of the hazard mapping of subterranean termite attacks in Makassar City, this species was found eating the wooden baiting planted near buildings in resident complexes.

Fig. 3. Damage and open galleries caused by drywood termite attacks on (a) door frames, (b) pillar connecting beams, and (c) floors and floor supporting beams.

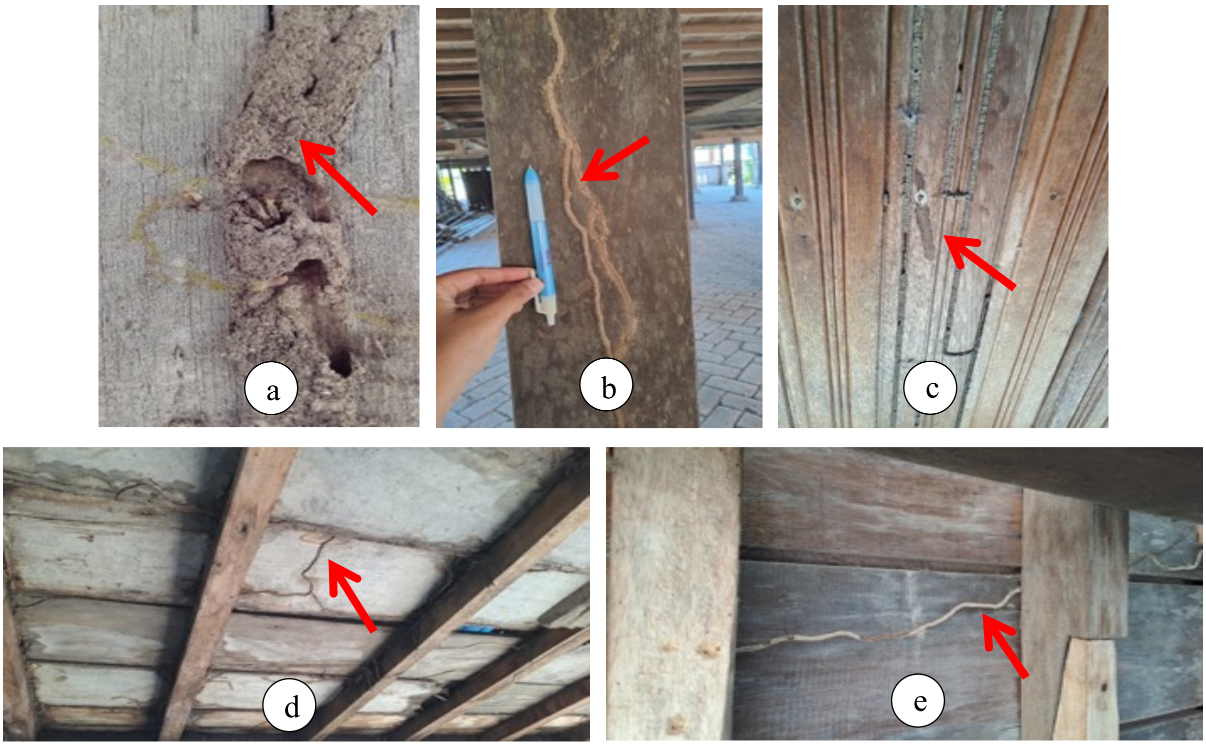

Fig. 4. Subterranean termite tunnels in (a-b) pillars, (c) ceiling, and (d-e) subfloor surface.

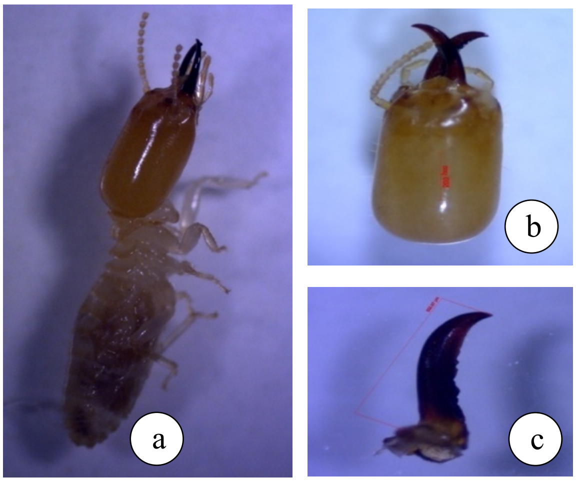

Fig. 5. (a) The body of *Microcerotermes serrula*, (b) rectangular head, and (c) serrated mandible.

Fig. 4 shows traces of many tunnels, especially in the additional building of *Balla Lompoa Ri Galesong*, which functions as a kitchen. The condition of the subfloor surface indicates that this structural part is frequently exposed to water, providing a favorable environment for termites and fungi. In addition, the teak wood used in this kitchen building may not have the same natural durability as the teak wood in the main building, which makes it more susceptible to attack by biodeterioration agents. For subterranean termites, tunnels function to maintain the environmental humidity needed by termites for foraging activities. Subterranean termites can reach wooden objects not directly connected to the soil by building protective pipes from the ground to food sources through cracks in foundations and walls.

3.2.3. Biodeterioration by powder-post beetles

Another insect that was also found attacking wooden components of *Balla Lompoa Ri Galesong* was the powder-post beetle. Traces of beetle attacks can be seen from the pinhole-shaped holes found on the pillars and floor support beams (**Fig. 6**), with variations in diameter. In the pinhole formed, no active insects exist, and neither imago nor larvae are in the galleries. Measurement of the diameter of the round exit hole resulted in a diameter range between 0.66–4.02 mm with an average diameter of 1.80 mm. The characteristics of the damage with a round exit hole with a diameter of between 0.8 mm and 1.6 mm are caused by lyctidae.

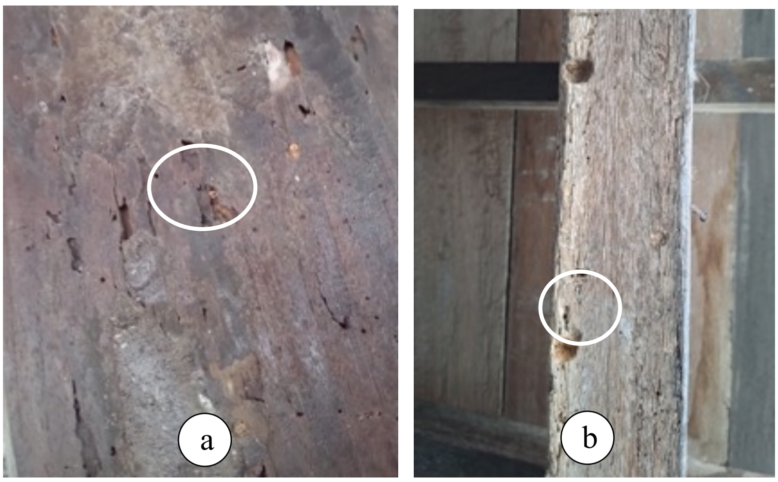

Fig. 6. Characteristics of powder-post beetle attacks on (a) pillars and (b) floor support beams.

In comparison, the moon-shaped exit hole with a diameter of between 1.6 mm and 3 mm is caused by Anobiidae (Houseman 1914). Apart from that, no hyphae are colored by wood-staining fungi in the boreholes, a characteristic of ambrosia beetle attacks. Bark and ambrosia beetles bore into the xylem and phloem, then grow mutualistic fungi as a food source (Diehl et al. 2023; Kirkendall et al. 2015). The beetle species were difficult to identify due to the absence of beetle specimens in the gallery, but they were confirmed to be powder-post beetles based on the tracks and pinholes. Even though no individuals were found, another attack could occur as long as food sources are available or some activities allow transmission from the external environment. Biebl and Querner (2021) reported a powder beetle attack due to the transportation of wood-based materials into the museum.

3.2.4. Biodeterioration by wood-staining fungi

Fungi are essential biodeterioration agents easily found in colonizing materials in architectural heritages, cultural heritage, and wooden heritage (Branysova et al. 2022; Ilieş et al. 2018; Koul and Upadhyay 2018; Ortega-Morales et al. 2019). In *Balla Lompoa Ri Galesong*, wood-staining fungi can be seen on the poles. This fungus usually grows on materials, especially on high-moisture wooden surfaces. Colonization of this staining fungus is indicated by the presence of spots, as seen in **Fig. 7**. Various colors are produced by hyphae pigments depending on the fungal species (Gutierrez et al. 2022). Green stains can be produced by several fungi, such as *Trichoderma*, *Penicillium*, *Gliocladium,* and *Chlorociboria* (Toma et al. 2023).

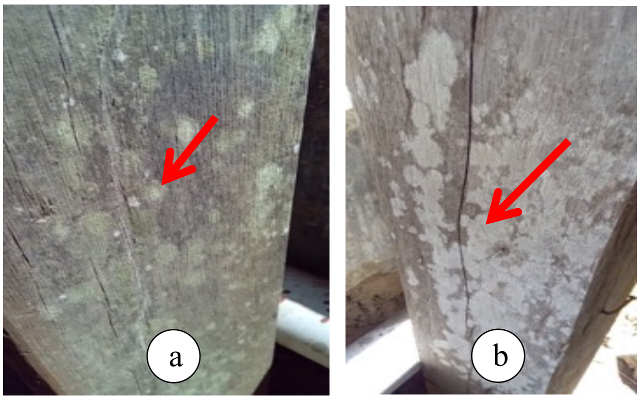

Fig. 7. Characteristics of wood-staining fungi attacks: (a) spots or stains on the pillar surface, and (b) the pillar surface connecting the beam.

3.2.5. Biodeterioration by wood-decaying fungi

Wood-decaying fungi are biodeterioration agents that decompose wood cell wall polymers by involving enzymatic mechanisms, using either hydrolase or oxidase enzymes (Ezeilo et al. 2017). These fungi can be classified into white-rot fungi, brown-rot fungi, and soft-rot fungi based on the type of decay, with the ability to degrade partially or entirely the primary chemical components of cell walls (Procópio and Barreto 2021; Schmidt 2006). White-rot fungi can decompose lignin, cellulose, and hemicellulose, and brown-rot fungi can degrade holocellulose but can not degrade lignin and modify its chemical properties (Li et al. 2022). In the *Balla Lompoa Ri Galesong* building, the activities of these microorganisms can be seen on the beams connecting the pillars, the bottom surface of the floor, and the ceiling (**Fig. 8**).

Fig. 8. Biodeterioration symptoms are caused by wood-decaying fungus on (a) the beam connecting the pillars, (b) the bottom surface of the floor, and (c) the ceiling.

3.3. Building Damage Level

The observation results of damage caused by biodeterioration agents to the *Balla Lompoa Ri Galesong* are termites and fungi. These agents were found to attack almost all wooden parts of structural buildings except stairs. Data regarding the building components attacked, the type of wood used, the intensity of the attack, the degree of attack, and the type of attacking organisms are presented and summarized in **Table 4**.

Table 4. Level of damage by wood destroying organisms to structural parts of buildings

No.	Parts of building structures	Damage Level		Biodeterioration Agents				
		Damage intensity (%)	Degree of damage	Drywood termites	Sub-terranean termites	Powder-post beetles	Wood-staining fungi	Wood-decaying fungi
1	Pillars	70.13	50–74	+	+	+	+	+
2	Window	27.27	75–99	–	–	–	–	–
3	Stairs	0	100	–	–	–	–	–
4	Door	7.69	75–99	+	–	–	–	–
5	Walls	9.57	75–99	–	–	–	–	–
6	Floor	11.02	75–99	+	+	+	–	+
7	Ceiling	17.76	75–99	–	+	–	–	+

Notes: (+) infestation; (–) no infestation.

Table 4 presents variations in the values of attack intensity, with the highest attack intensity found on pillars, which means that most of the pillars are the target of attacks by biodeterioration agents (**Table 2**), although, in terms of the degree of attack, they are classified as moderate attacks.

Pillars are part of building construction under attack from all deterioration agents. The attacks on the pillars occurred on the surface; however, the pillars of the additional building, which functioned as a kitchen, received more intensive attacks and were not limited to just the surface. The part of the building construction where no attacks were found, or the intensity value was equal to 0%, was the stairs, which means that all the components making up that part were still intact. In general, even though the intensity value is < 30%, with the degree of attack being classified as light, some efforts are still needed to protect from continuing deterioration, especially for components attacked by wood-decaying fungi and termites. These two biodeterioration agents are responsible for degrading the main chemical components of cell walls, which are responsible for the structural properties of wood (Martín and López 2023).

4. Conclusions

Historic buildings can deteriorate with the intensity of attack, and the degree of attack varies depending on the structural part of the building and the biodeterioration agent. The wood-destroying organisms found in the *Balla Lompoa Ri Galesong* building based on the detection of symptoms and characteristics of damage were subterranean termites (*Microcerotermes* serrula), drywood termites (*Cryptotermes*), powder-post beetles, wood-staining fungi, and wood-decaying fungi. Studies on microbial species, prevention, and control to protect buildings from further damage are still needed.

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