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Biodeterioration of Building Timbers in the High-Water-Activity Built Environment of Nigeria

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Abstract: Moulds have been reported to destroy volumes of timbers in buildings annually. As a result, timber components within the built environment decline and fail to fulfill their basic requirements. This research focused on the isolation and evaluation of the prevalence and effects of deteriorating moulds in the rain forest and swampy rain forest regions of Nigeria where the water activity is as high as 0.7. To accomplish this, decayed timber samples were aseptically collected on buildings from six strategic locations. The samples were serially diluted and inoculated onto Sabouraud Dextrose Agar medium in Petri dishes. The Petri dishes were incubated for 72 h at 30 °C. Thereafter, moulds were isolated through visual and microscopic observations. The commonly encountered moulds were evaluated and analyzed. It was observed that, prevalence of moulds on buildings used for non residential purpose were higher. There was no significant difference between the prevalence on the components located inside the building and those outside the building. Ceiba pentandra exhibited highest degradation while Masonia altissima resisted most. The most deteriorating moulds were Aspergillus, Mucor, Rhizopus and Gliocladium. The deteriorations of Ceiba pentandra, Afzelia africana, Lophira alata, Anogessus leocarpus and Gossweilerodendron balsamiferum timbers under Aspergillus attack were projected.

Key words: Mould, timber in building, biodeterioration, high-water-activity, microclimate.

1. Introduction

Buildings are designed to serve specific functions desired by users [1]. However, as soon as they are put to use, they start to deteriorate, losing important functional qualities. Such deteriorations do occur as a result of normal wear and tear, weather, chemicals or biological agencies. Whichever means, can lead to serious effects on the entire capabilities of a building. The principal causal factor of deterioration of timber is the biological agency whose action is referred to as biodeterioration [2].

Biodeterioration is any undesirable change in the properties of material of economic importance brought about by the activities of living organisms [3]. For biodeterioration to take place, suitable temperature, *RH* (relative humidity), a_w (water activity), pH and a substrate–a substance (timber) that serves as food must be in place. Ref. [4] reported that each substrate possesses special properties that attract moulds just like what flowers do to insects. Hence, prevalence of moulds inhabiting one piece of timber differs from one another and even though not all are capable of utilising the timbers as substrate [2]. Ref. [5] specified extents of timber biodeteriorations to cover mere surface growth, blue stain and outright decay of cell wall structure. Biodeterioration in timber usually occurs when the *RH* value is greater than 95%, temperature between −5 °C~50 °C [6], and a_w ranging between 0.5~0.94 [7].

A combination of the favourable conditions for biodeterioration is obtainable in the rain forest and swampy rain forest regions of Nigeria where adequate humidity, a_w and temperature required for the growth of deteriorating moulds are guaranteed. The rain forest belt has an average annual rainfall of 1,300~2,000 mm, 27 °C, and *RH* of 80% [8] while the swampy rain forest has average rainfall of 3,175 mm, temperature of 30 °C

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with a *RH* over of 90% coupled with a wet season of over 10 months [9]. These regions can continuously ensure adequate supply of these factors to sustain substantial degree of deteriorations almost throughout the year. The values of pH and a_w—the measure of energy status of water in individual timber are dependent upon specific local conditions of timbers in the buildings. The a_w in this region is considered high not only because of the availability of the two major factors (*RH* and temperature that are directly related to it), but also the ability of the region to support the growth of a wide range of moulds. The a_w is a determinant factor for availability of water for moulds to grow, since they exploit energised, not still water to survive and flourish, without which deterioration is considered impossible [10]. Ref. [11] states that even if a timber contains high moisture content it would not be liable to deterioration as long as the energy level is not sufficiently high for the moulds to remove it to support growth.

By definition, a_w is the ratio of vapour pressures under normal working conditions [7], a_w = vapour pressure of water over a p (substance) divided by vapour pressure of pure p_o (water). Hence, $a_w = p/p_o$. And $a_w \times 100 = RH$ (%). This is, the *RH* in equilibrium with a piece of timber, being a hygroscopic material. As long as the condition is conducive, biodeterioration will remain continuous and progressive until the timber substrate is exhausted. Therefore, if timber buildings and components operated within these zones are to fulfil their objectives as expected, there would be need to know how they deteriorate and lose potentials that may affect owners, occupants, society and the built environment.

2. Materials and Methods

2.1 Sampling and Sample Collections

The study population was subdivided into six subregions along geogaphical local microclimates [8] of U, V, W, X, Y, and Z. Buildings within each microclimate were selected for the study based on local environmental conditions. On each of these buildings, bulk samples of 10 g were aseptically collected on timber components that showed visible signs of deteriorations and documented. In addition, samples of sound and fresh timbers, and designation of buildings were also recorded.

2.2 Cultivation and Evaluations of Moulds

SDA (Sabouraud Dextrose Agar) was used as the culture media and was prepared according to manufacturer's specification: glucose 40.0 g, peptone 10.0 g, streptomycin 0.01%, agar 15.0 g, and distilled water 1,000 ml. This was poured into 20 ml Petri dishes and sterilized at 121 °C for 15 min and then allowed to solidify. A stock of 1 g of decayed sample collected from buildings used for residential and non residentialpurposes was dissolved in 10 ml of peptone water. These were thoroughly shaken to dislodge the mould spores that may be present. From this, dilutions of 0.5 mm of the second and fourth series were inoculated on to the Petri dishes already labeled. The inoculums were then spread over the entire surface using sterile glass rod spreaders. The plates were incubated at 30 °C for 72 h [12], after which developed colonies were identified and isolated and then counted.

2.3 Identifications and Classification of Moulds

Visual observations and light microscopes observations were used to identify the moulds. The isolates were stained with methyl cotton blue and viewed at 40 times magnification. During the observations under the microscope, attention was paid to characteristic growth and presence and forms of conidia, septa, conidiophore, appendage, hyphae, texture, catenation, and colour features [12]. The observed features were recorded and compared with existing standards. The moulds were finally identified by comparing the growth morphology characteristics and the observed features with dichotomous keys and picture keys from text books [3] and online sources [13, 14].

2.4 Determining Degradability of Timbers by the Moulds

To determine the biodegradability of the timbers commonly used in construction of buildings in the region and to identify the saprophytic moulds, known weights of sterile timber samples were inoculated with the moulds in a minimal medium and incubated for 72 h at 30 °C [15]. In this experiment, the only source of nutrients available to the moulds was the timber substrate and temperature were controlled and maintained throughout the period of the study. Percentage growths as a result of utilization of the timbers were recorded and graded as:

- 0% = nil;
- 1%~24% = scanty;
- 25%~49% = moderate;
- 50%~100% = profuse.

3. Results and Discussions

3.1 Evidences of Presence of Moulds on Timbers in Buildings Situated in the Regions

Table 1 represents the prevalence of moulds identified on the timber components in the buildings in the six subregions. The species of Aspergillus and Alternaria were the most dominant in each subregion.

Other studies isolated similar organisms in damaged building. Ref. [16] isolated Acremonium, Aspergillus, Alternaria alternata, Cladosporium mucor and Penicillium species among others in European homes; Ref. [10] isolated Alternaria alternata, Aspergillus species, Cladosporium cladosporioides, Paecilomyces variotii, Penicillium species and Trichoderma viride in American homes and also in India [17].

3.1.1 Prevalence of Moulds on Residential and Non Residential Buildings

The prevalence of moulds on timber components from buildings used for residential and non residential purposes is shown in Fig. 1. In comparison, there was higher prevalence on residential buildings than on non residential and reverse is the case in the W and Y Subregions, considered in isolation.

3.1.2 Prevalence of Moulds on Indoor and Outdoor Environment

The prevalence of moulds inhabiting timber components at the indoor and outdoor environment of the buildings are presented in Fig. 2. There is no much difference between the prevalence.

Table 1 Presence of moulds in decayed timber samples from the buildings.

Moulds	Rain forest region			Swampy rain forest		
	U	V	W	X	Y	Z
	CFU/G (colony forming unit per gramme)					
Acremonium	1.800×10^5	1.000×10^4	2.000×10^4	-	-	4.800×10^5
Alternaria	1.900×10^5	3.300×10^5	2.200×10^6	5.700×10^5	-	1.380×10^6
Aspergillus	1.290×10^6	1.470×10^6	3.040×10^6	2.010×10^6	8.970×10^6	2.340×10^6
Cladosporium	5.000×10^4	-	-	-	-	-
Geotrichum	2.400×10^5	-	5.800×10^5	-	1.600×10^5	2.400×10^5
Gliocladium	1.600×10^5	-	5.000×10^4	1.700×10^5	-	4.000×10^4
Mucor	2.800×10^5	1.200×10^5	-	1.300×10^5	8.000×10^4	3.100×10^5
Mycelia sterilia	3.000×10^4	-	1.900×10^5	-	2.600×10^5	1.000×10^4
Paecilomyces	9.000×10^4	8.000×10^4	8.000×10^4	-	-	-
Penicillium	7.000×10^4	1.700×10^7	-	5.000×10^5	7.200×10^5	3.000×10^5
Rhizopus	3.000×10^4	3.000×10^4	2.700×10^5	6.100×10^5	-	8.000×10^4
Saccharomyces	-	4.000×10^4	4.400×10^5	1.600×10^5	3.000×10^4	4.000×10^4
Streptomyces	-	-	1.200×10^5	2.300×10^5	2.200×10^5	5.000×10^4
Syncephalastrum	-	1.000×10^5	-	6.000×10^4	1.800×10^5	3.000×10^4
Trichoderma	-	4.000×10^4	4.900×10^5	-	-	-
Trichothecium	-	7.000×10^4	6.000×10^4	7.000×10^4	-	4.000×10^4
Unidentified	2.000×10^4	1.100×10^4	3.100×10^4	8.000×10^4	4.200×10^5	5.800×10^4

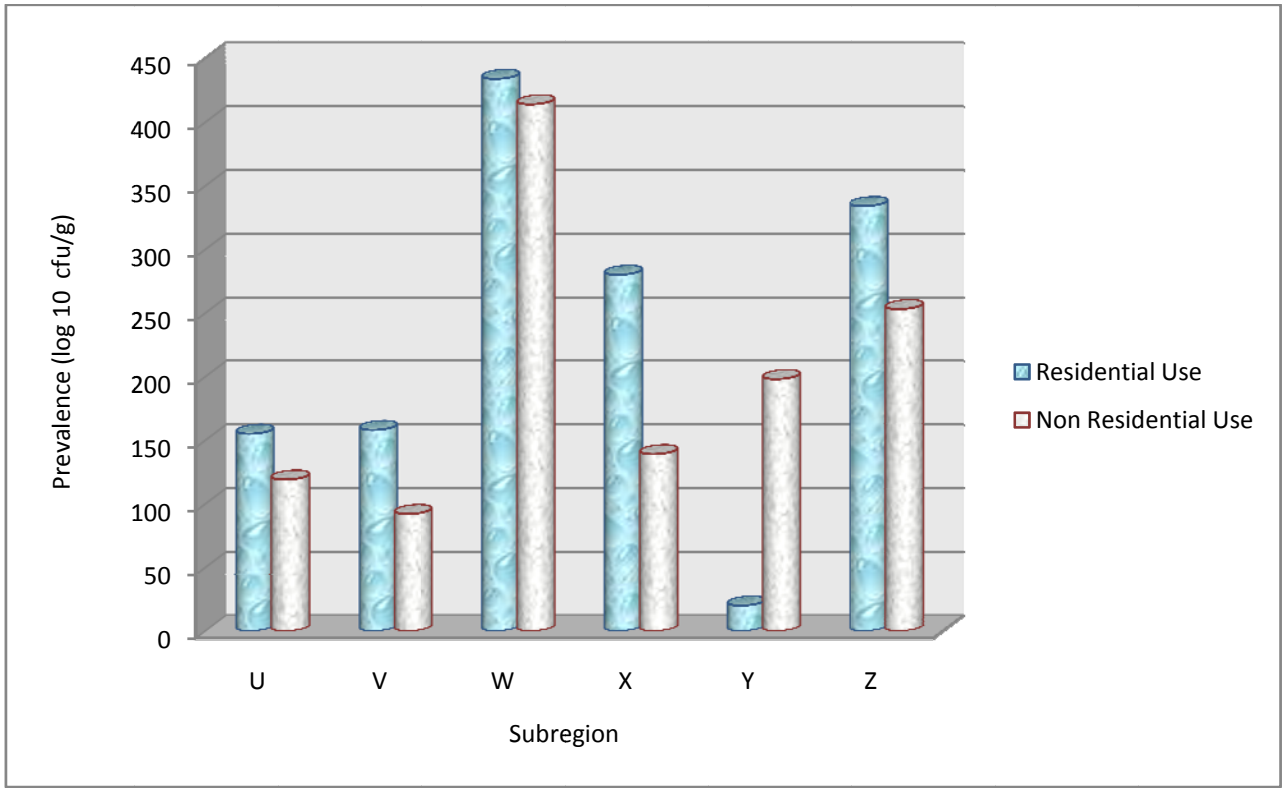

Fig. 1 Prevalence of moulds on timbers in residential and non residential.

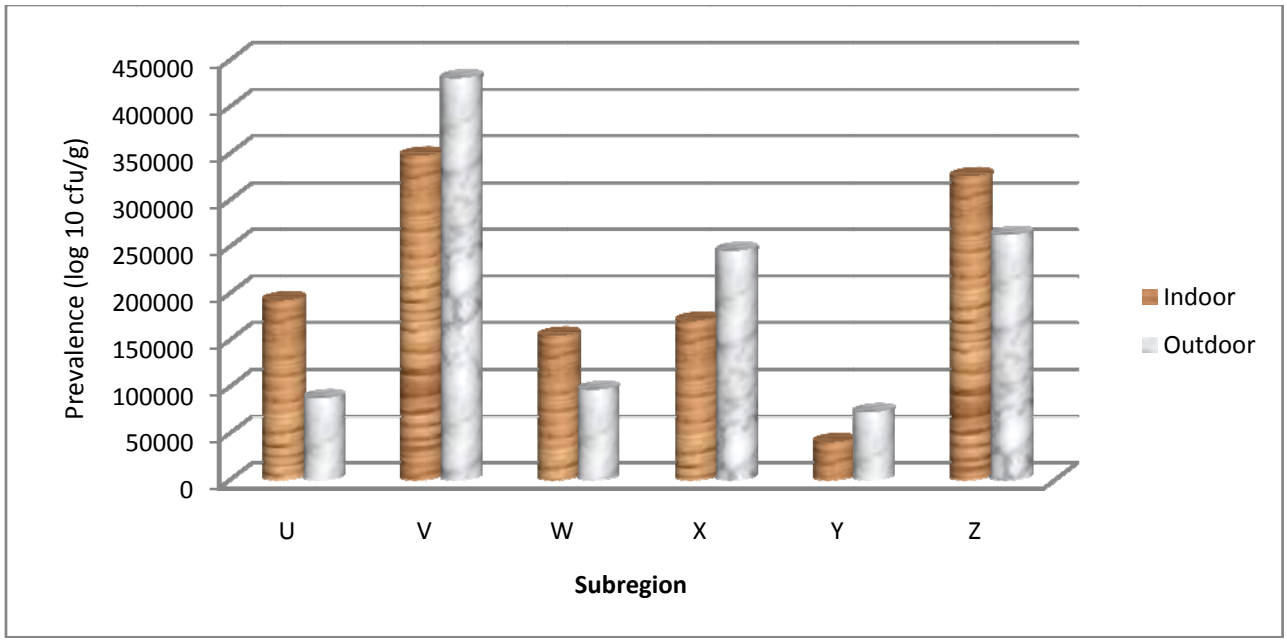

Fig. 2 Prevalence of moulds on components located indoor and outdoor.

3.1.3 Prevalence of Moulds on Decayed Timber Samples

An investigation into prevalence of the moulds on fresh timber samples commonly used in construction of buildings in the region shown in Fig. 3 suggests higher prevalence of Terminalia ivorensis, Daniellia ogea, Cordia millennii, Terminalia superba and Pentadesma butyracea compared to Mitragyna stipulosa, Anogeissus leocarpus and Masonia altissima species which are significantly low.

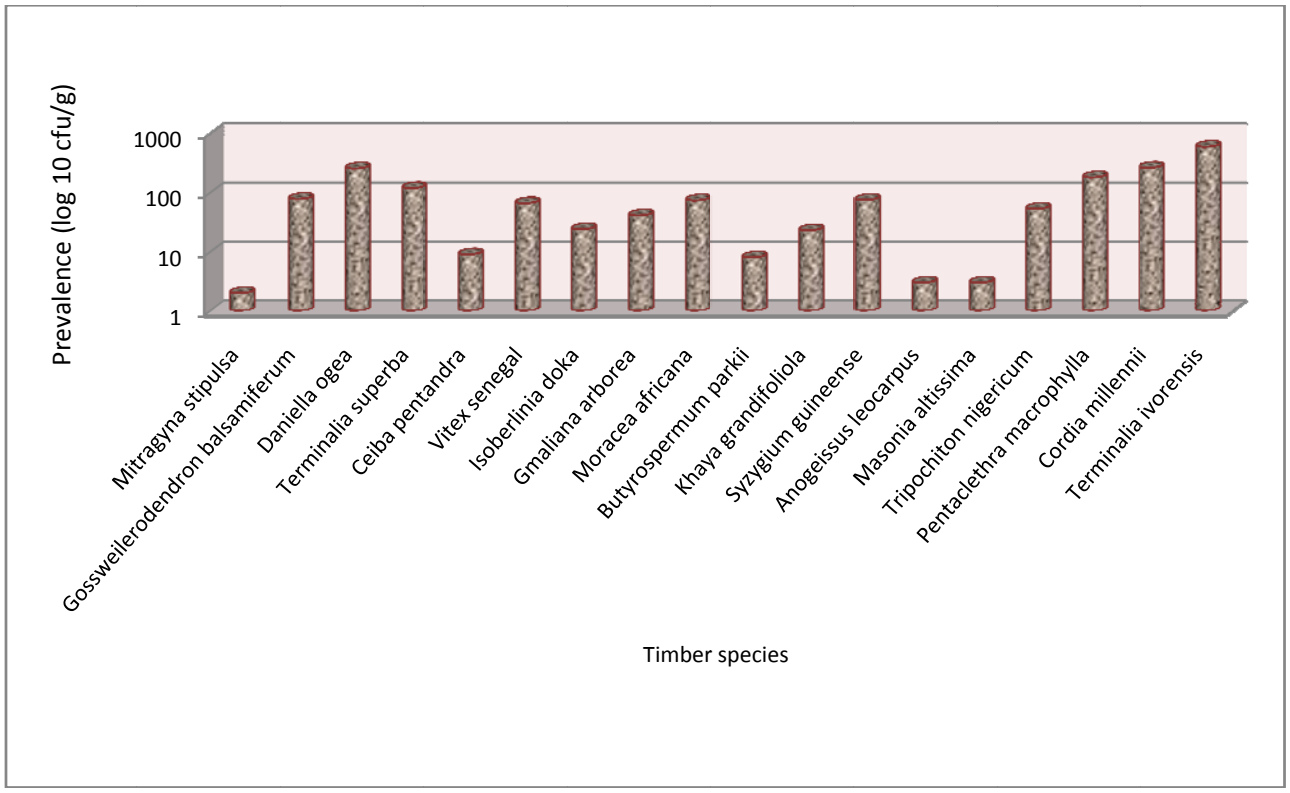

Fig. 3 Prevalence of moulds on timber species used in buildings.

3.2 Effects of Moulds on Timbers in the Region

3.2.1 Biodeterioration of the Timbers

Fig. 4 depicts the ease at which the various timbers deteriorate under the attack of the moulds species. The natural resistivities of the timbers used in the regions to the attacks of the moulds in Table 1 are presented in this Fig. 4. Terminalia superba, Anogeissus leocarpus and Mitragyna stipulosa demonstrated high levels of resistance. Other species with high susceptibilities were Ceiba pentandra, Gosswellerodendron balsamiferum, Syzygium guineense and Triplochiton nigericum. Masonia altissimia showed less signs of deteriorations. In the study by Ref. [15], the resistivity of West African timbers subjected to combined effects of microorganisms and termites were compared. The values obtained in Fig. 4 are close to that of Ref. [18] who subjected the organisms to similar conditions.

3.2.2 Comparison of Abilities to Breakdown the Timbers

The intensity of deteriorations of some of the moulds to deteriorate timbers in the region is presented in Fig. 5, portraying viabilities of attacks. Ref. [6] reported that Aspergillus and Alternaria can utilize wide varieties of timbers because of their ability to produce a large spectrum of enzymes.

3.2.3 Estimating Aspergillus Degradation on Selected Timbers Samples over Time

Fig. 6 presents forecasted deteriorations of five commonly used timbers species: Ceiba pentandra, Afzelia africana, Lophira alata, Anogessus leocarpus and Gossweilerodendron balsamiferum that responded more to biodeteriorations in Fig. 4 under the attack of Aspergillus for the period of 24 months. 62% lose was forecasted for this period for Lophira alata being the deteriorating sample. The laboratory results of Ref. [5] on different species of timbers and fungi confirmed 1% loss in weight led to 6%~50% losses in toughness and at 10% weight losses more than 50% of strength was lost.

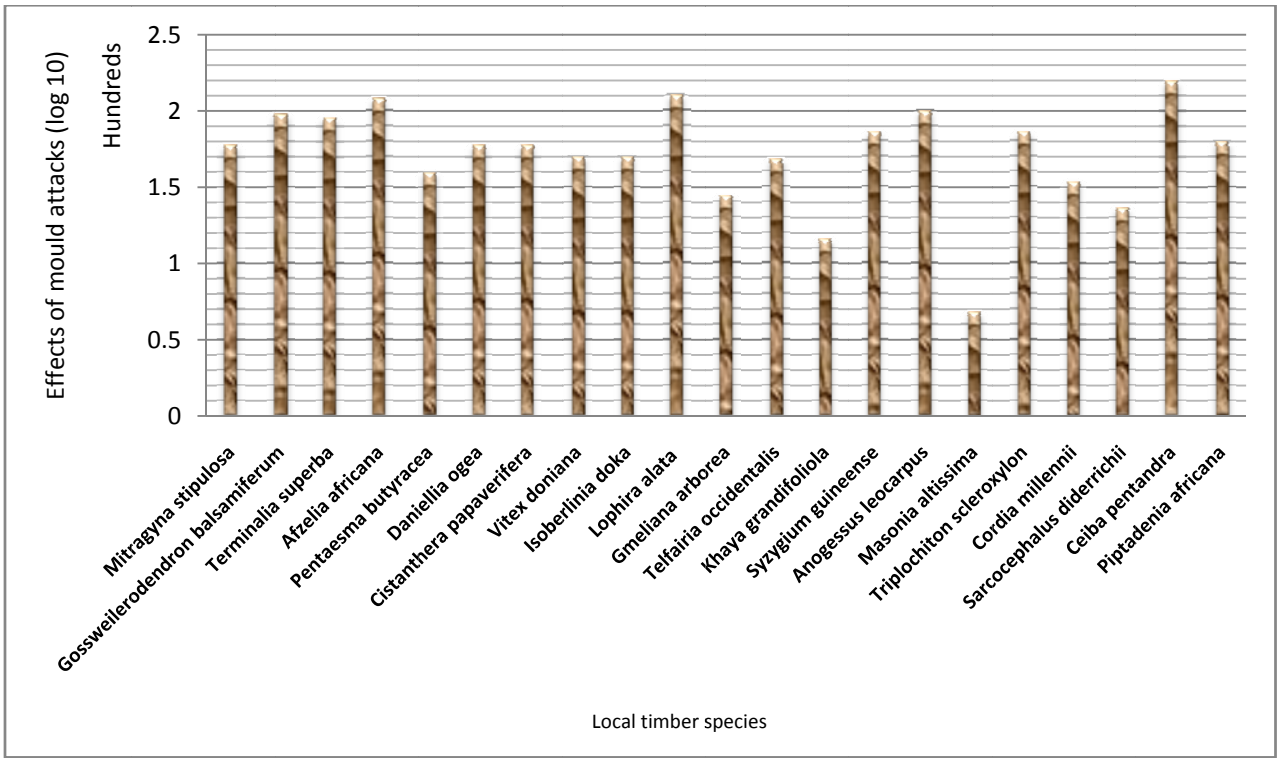

Fig. 4 Mould degradation of common timbers used in the region.

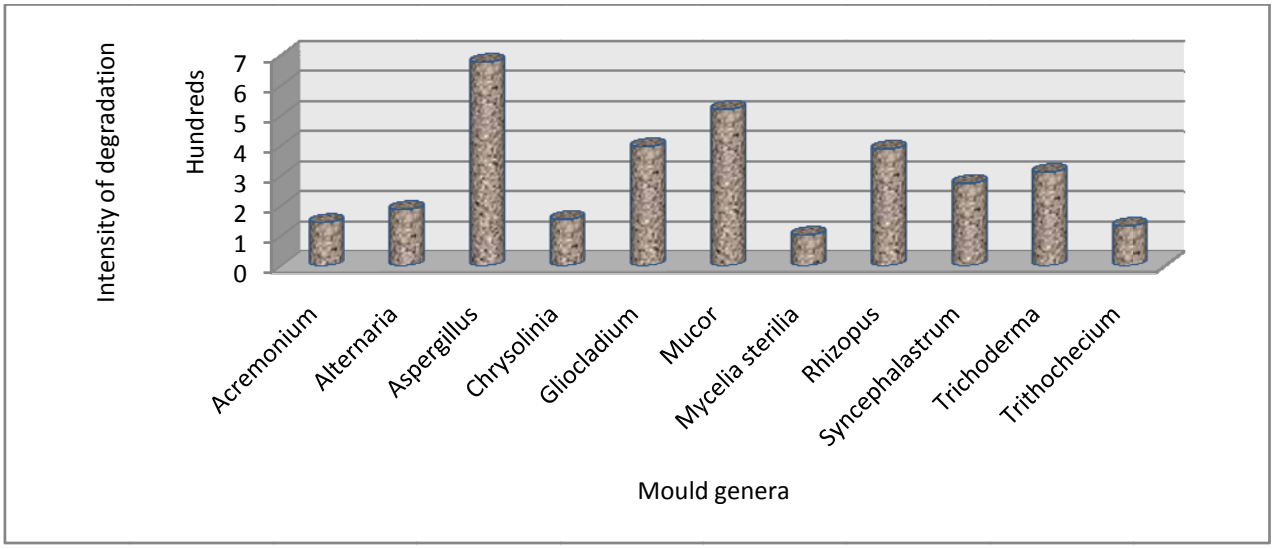

Fig. 5 Intensity of mould attack on timbers.

The regression equation forecasting weight loss in Lophira alata is expressed:

$$y^1 = 0.244x^{1.391} \quad (1)$$

where, y^1 = percentage of mass loss and x is the durations of the attack in months. The associated value of coefficient of determinant R^1, is equal to 0.875%. This value determines how much the model represents the data used and is computed as SS_R/SS_T, where SS_R represents the regression sum of squares, and the equation is shown as:

$$SS_R = \sum^n_{i=1} - (\dot{y}_i - \tilde{y})^2 \quad (2)$$

where, SS_T represents the total sum of squares of the response variable y or the corrected sum of squares of y, and the equation is shown as:

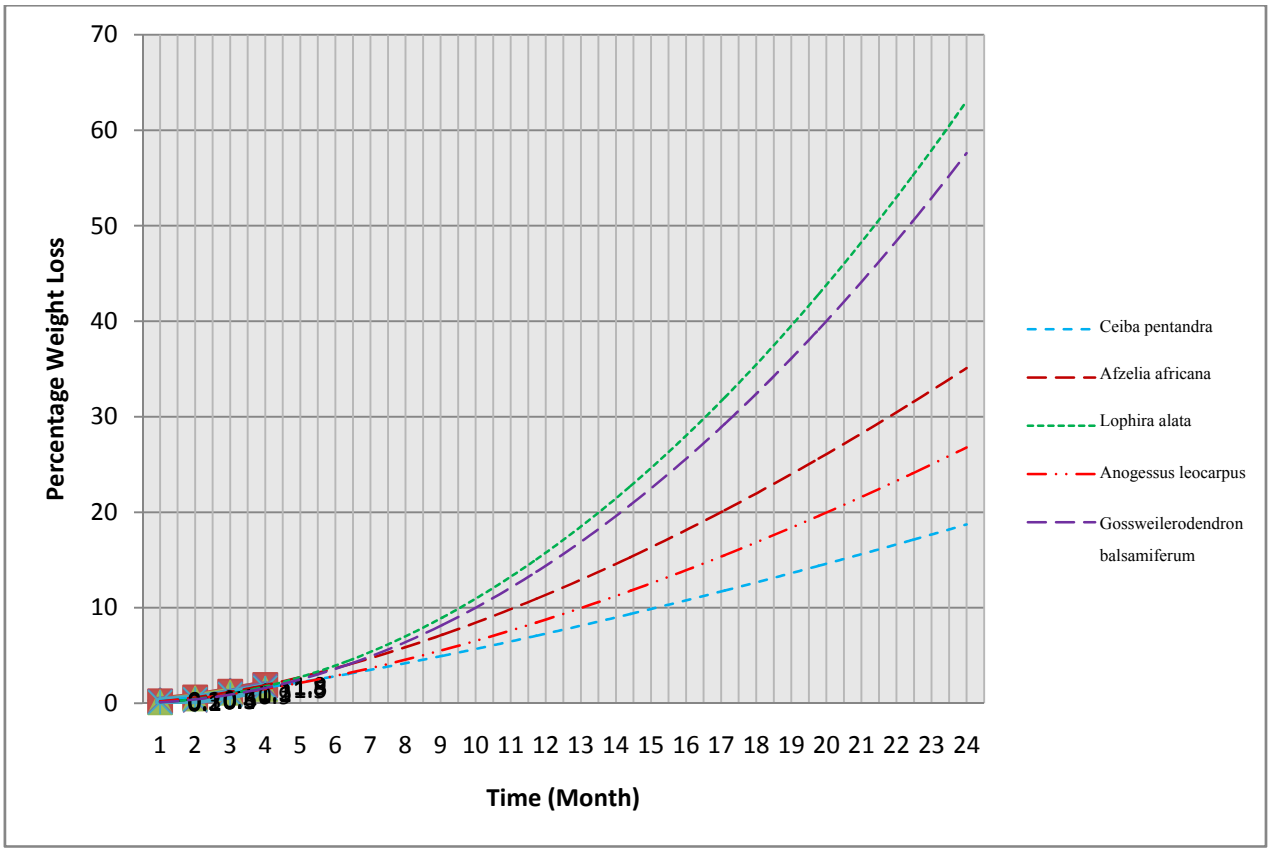

Fig. 6 Forecasted deteriorations of some commonly used local timber species.

Legend: Series 1-Ceiba pentandra; Series 2-Afzelia africana; Series 3-Lophira alata; Series 4-Anogessus leocarpus; and Series 5-Gossweilerodendron balsamiferum.

$$y = \sum_{i=1}^{n} - (y_i - \tilde{y})^2 \quad (3)$$

The following values represent the regression values obtained using the equation for Series 1, 2, 4, and 5, respectively in Fig. 6:

- $y_1 = 0.244x^{1.391}$, $R^1 = 0.875$;
- $y_2 = 0.196x^{1.656}$, $R^2 = 0.999$;
- $y_3 = 0.106x^{2.068}$, $R^3 = 0.993$;
- $y_4 = 0.159x^{1.612}$, $R^4 = 0.896$;
- $y_5 = 0.108x^{2.035}$, $R^5 = 0.990$.

3.3 Consequences of Biodeteriorations on Performance of the Buildings

The varieties of timbers used for buildings in these regions are prone to the actions of the moulds available. Biodeterioration of timbers in building is accompanied by emissions of CO_2, mycotoxin, dust particles, volatile organic compounds, and can directly lead to destruction of aesthetics, strength and other vital properties. It also enhances nutritional values of timbers for further insect attacks [16], causing sick building syndrome, building related illnesses, and increased running costs. The effects are directly borne by occupants, owner, society, built environment and the global environment.

When the intensive deterioration is assisted by the high-water-activity environment, the effects on the performance of the buildings is enormous and so is the effects on the users.

4. Conclusions

Buildings with timber components in the high-water-activity built environment of Nigeria have high prevalence of moulds on them. The wide varieties of the moulds isolated were able to deteriorate the timbers commonly used for construction of buildings. Biodeterioration is a degradation that can make

buildings lose their performance capabilities.

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