Feb. 2014, Volume 8, No. 2 (Serial No. 75), pp. 160-168
Journal of Civil Engineering and Architecture, ISSN 1934-7359, USA

Cost Implications of Biodegradation of Khaya Grandifoliola (Dry Land Mahogany) by Aspergillus in Residential Buildings

Isa Hassan-Enua Mshelgaru
Department of Building, Ahmadu Bello University, Zaria 8100001, Nigeria

Abstract: Degradation of timbers in building due to microorganisms was reported to cause enormous economic loses and species of Aspergillus are among the major cause of degradation of timbers in Nigeria. This research aims at evaluating the cost of implications of biodegradations of Khaya grandifoliola by Aspergillus spp in residential buildings empirically. Decayed Khaya grandifoliola samples were collected on residential buildings to extract, cultivate and identify the Aspergillus spp present. The cultivation went through serial dilutions and inoculations on sabouraud dextrose agar in petri dishes before incubation for 72 hours at 30 ^{o}C. The species were identified through visual and microscopic observations. Percentage rate of degradation was determined under laboratory conditions by inoculating known weights of Khaya grandifoliola with the Aspergillus and incubating in a minimal medium for 24 weeks at 30 ^{o}C. Weight loses and spore counts were recorded at four weeks intervals. A pattern of the degradation was forecasted. Accumulative weight loss of 16% for this period was obtained. Methods and costs of repair and replacement of decayed portions were evaluated. Residential Buildings constructed of Khaya grandifoliola experienced low cost of maintenance in this region but may not be in wetter regions where the conditions could be more favorable.

Key words: Biodegradation, Aspergillus, Khaya grandifoliola, cost, residential building.

1. Introduction

Khaya grandifoliola is a variety of mahogany commonly used as structural and non structural members in construction of buildings in the dry land region of Nigerian. It is a species of Meliaceae family that is locally recognized in Nigerian local dialects as “madachi”, “oganwo”, “ono” and “dalchi” [1]. Timber produced from Khaya grandifoliola is distinguished by its reddish color which becomes dark with age, hardness, and close network of thick circum-medulary lines of parenchyma [2, 3]. It is also a durable material with high strength-to-weight ratio and many excellent structural and aesthetic properties that earn it its popularity in the region. It is termite proof and excellently suitable for all construction purposes. Places of common application in buildings are: rafter, pole, strut, wall plate, beam, facial, door, window and furniture. Despite these good qualities, Khaya grandifoliola, offers some ecological niche to many microorganisms that hold on as a source of food and shelter [4, 5]. The engagements of the organisms usually lead to development of microscopic decays to the cell walls [6] that form the basis of the attributed qualities. The varieties of microorganisms that are capable of causing the decay are of basidiomycetes and ascomycetes phyla [7]. Such decays are categorized as soft-rot, white-rot and brown rot [3] depending on characteristics of the advanced stage of the decay. According to Morris [8], Aspergillus is one of the white-rot causing organisms. The effects of white-rot decay on several physical and mechanical properties of timber were illustrated by Smulski [9].

Aspergillus spp are filamentous saprophytic organisms that are capable of degrading complex

Corresponding author: Isa Hassan-Enua Mshelgaru, Ph.D., research fields: building maintenance, construction materials, building health, risk and environmental assessment. E-mail: hassangaru468@gmail.com.

cellulosic structures of timbers enzymatically into simple digestible products [5]. Cellulose, hemicellulose and lignin constitute 45% of the dry weight of timber while hemicellulose alone makes 25%-30% of the total weight. The aspergillus grows and spreads its fine, threadlike strands mycelia throughout the microscopic cell walls to excrete the enzymes that break down the cell wall. The rate and extent of decay that affects properties of timber depends on duration, favorable conditions as well as the type of timber and organisms involved [10]. Many spp of aspergillus have the abilities to digest various types of timbers used in buildings [4, 11]. The decays cause enormous damage to timbers in buildings around the world that are not restricted to structural performance but also tarnish aesthetics, integrity and economic benefits. For instance, Morris [8] reported that the timber structures in the coastal region of British Columbia experienced great loss as a result of decay, and Beesely [12] also reported escalating annual costs of timber damage in the United States to be two billion dollars. Albinas and Bronius [13] on a similar issue in Europe estimated a yearly cost of 4,000 million Euros of maintaining fungi damage buildings in Finland.

The basic requirements for the degradations are temperature, moisture and substrates or food. The food is provided by the timbers, especially those in buildings which may have special characteristics that attract the microorganisms [7] due to the settings of human activities. This behavior makes some timbers more prone to attacks and experience more serious degradations than others [14].

To reinstate already infected buildings to normalcy, the affected components or elements have to be freed from the attack and before restored back to function. Reinstatements of a component may comprise one of these: (1) clean–up and fumigation; (2) clean-up, fumigation and partial replacement; (3) removal and substitutions of the affected components. Substitutions become necessary when the damage inflicted is on essential performance characteristics and is significant when compared to the designed functional requirements of the position of the component in the building. Each of these activities' cost build up the total cost estimates of the remediation and maintenance of the entire buildings.

2. Materials and Methods

2.1 Sampling and Sample Collections

Deteriorated bulk samples of ten grammes were aseptically collected on timber components that showed visible signs of deteriorations at different microclimates; internal or external parts of some selected residential buildings. Information on age and designations of the buildings were also gathered to determine the condition of the component and to know how the degradations observed developed. In addition, decayed samples from sound and fresh Khaya grandifoliola were also collected.

2.2 Cultivation and Evaluations of Aspergillus spp

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 ^{o}C for 15 minutes and then allowed to solidify. A stock of one gramme of decayed sample was dissolved in 10 millilitre of peptone water. These were thoroughly shaken to dislodge the fungi spores that may be present. From this, dilutions, of 0.5 millimetres of the second and fourth series were inoculated on to already labeled petri dishes. The inoculums were then spread over the entire surface using a sterile glass rod spreader. The plates were incubated at 30 ^{o}C for 72 hours [10].

2.3 Identifications and Isolation of Aspergillus spp

Visual observations with the aid of dissection microscope and light microscopes were the main techniques used to identify the Aspergillus spp.

Microscopic observations were also carried out. During the observations, attentions were paid to distinguishing characteristic such as growth morphology, presence and forms of conidia, septa, conidiophore, appendage, hyphae, texture, catenation, and colour features which distinctly differentiate one species or genera from another [15]. The information obtained was referred to relevant fungi dichotomous and picture keys [5, 15, 16] for inferences and proper identifications. Another set of SDA plates containing the same inoculants was incubated at 30 ^{o}C for 72 hour after which developed colonies were identified and isolated and then counted with the aid of dissection microscopes.

2.4 Determination of Degradability of Khaya Grandifoliola by Aspergillus spp

To determine the biodegradability of the Khaya grandifoliola and to sort out saprophytic spp from non saprophytic ones, known weights of sterile samples were inoculated with the Aspergillus spp in a minimal medium and incubated for 72 hours at 30 ^{o}C [10]. The only source of nutrients to the spp was the Khaya grandifoliola and the temperature and moisture supply were controlled and maintained throughout the period of the study. Percentage growths of the spp as a result of utilization of the sample were recorded after 72 hours and was graded as: 0% = nil, 1% – 24% = scanty, 25% – 49% = moderate, 50% – 100% = profuse.

To determine the biodegradability of the fresh Khaya grandifoliola, known weight of sterile samples of the Khaya grandifoliola were inoculated with Aspergillus spp in a minimal medium and incubated for 24 week at 30 ^{o}C. Equally, the temperature and moisture supply were controlled and maintained throughout the period of the study. Cumulative percentage loss of weight due to the degradation process was recorded at intervals of 4 weeks.

3. Results and Discussion

3.1 Prevalence of Aspergillus spp on Decayed Khaya Grandifoliola in Buildings

The prevalence of aspergillus spp on decayed samples of Khaya grandifoliola components in residential buildings located in the dry land region is shown in Fig. 1. The determination of the prevalence was done conventionally based on cultivation methods of serial dilutions, as recommended by literature [9]. A high prevalence of aspergillus spp on samples of Khaya grandifoliola is an indication of involvements of the organisms in the degradation of the decayed samples [2]. Samples H1-H15 had high prevalence and the repeated encounter of the same spp of Aspergillus in several locations proved their dependency on Khaya grandifoliola for survival.

Although the experiments conducted suggested that not all of the Aspergillus spp identified on the residential

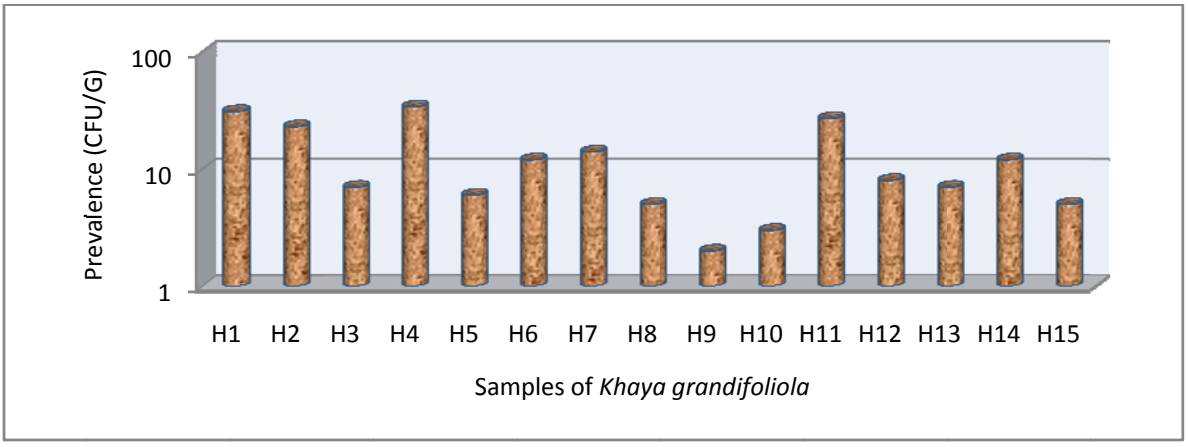

Fig. 1 Prevalence of Aspergillus spp on Khaya grandifoliola.

buildings could break down Khaya grandifoliola cell tissues; Highley and Flournoy [17] reported that fungi have been the major biodegradants of timbers and are not likely that other organisms may be involved. Similar studies by Pe'rez et al. [7] linked Aspergillus genera to saprophytic characteristics and confirmed their effects on timbers in buildings.

3.2 Potentials of Aspergillus spp to Utilise Khaya Grandifoliola

In an attempt to verify and evaluate involvements of aspergillus spp in the degradations of the Khaya gradifoliola 10 grammes of samples, sterilized fresh samples (non degraded) in minimal medium were inoculated with the same Aspergillus spp extracted from the decayed samples obtained from the buildings and incubated for 15 days. The resultant influence of these relationships was recorded and evaluated.

Fig. 2 shows the intensity of attack of the aspergillus spp on Khaya grandifoliola samples. The experiment shows viability of these spp in the current environmental settings. Species AS2, AS4 and AS8 exhibited properties that suggested inability to degrade Khaya grandifoliola while the remaining spp had prolific degrading effects under the same conditions. Over 66% of the spp was active and capable of degrading the samples.

3.3 Degree of Degradation of Khaya grandifoliola by Aspergillus spp

Fig. 3 shows the degree of degradation of 20 samples of Khaya grandifoliola from different sources under the

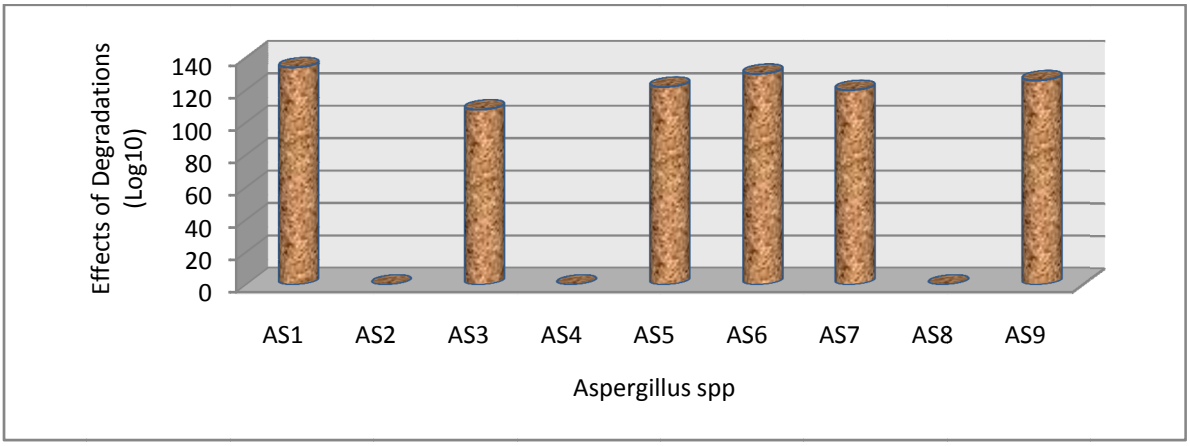

Fig. 2 Effects of Aspergillus spp on Khaya grandifoliola.

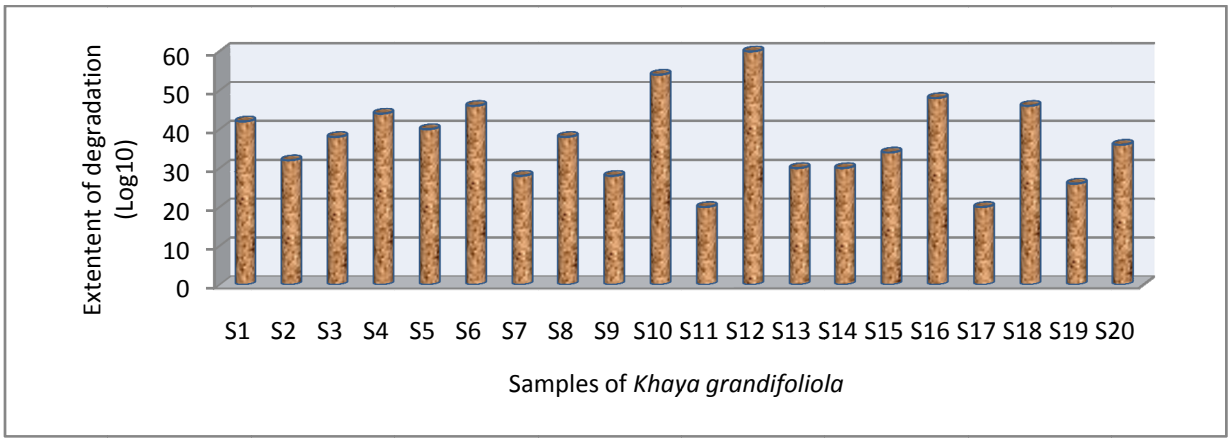

Fig. 3 Extents of Degradation of Khaya grandifoliola Aspergillus spp.

attacks of Aspergillus spp. The isolated species were challenged with steriled samples of the Khaya grandifoliola as in Fig. 2 to observe the extent of decay over a long period of time. The natural characteristic of the Khaya grandifoliola was displayed under the influence of various species of aspergillus and the effects were noted.

Degradation observed was higher on samples S12 and S10 compared to S11 and S17 that bear the least. The differences arise as a result of natural resistance of the samples vis-a-vis the degrading characteristics of the organisms.

In the study conducted by Usher and Ocloo [3] similar method was adopted to categorise West African timbers according to their natural resistances to decay under combined fungal and termite attacks.

3.4 Biodegradation Pattern of Khaya Grandifoliola Due to Aspergillus Attack

3.4.1 Biodegradation of Khaya Grandifoliola by Aspergillus spp under Laboratory Conditions

Table 1 shows cumulative percentage loss of weight of Khaya grandifoliola in a period of 24 weeks. The loss of weight at the end of the initial experiments at the fourth and eighth week periods were inconsistent and insignificant to be measured and so was not presented. The experiment measured the growth activities of the Aspergillus spp at controlled conditions of moisture, oxygen, thermal loads and all other activating factors at 100%. An empirical damage function of up to 2.482% of the sample and the degrading spp were developed and presented.

Usually, when microorganisms are moved from favorable to harsh conditions, they tend to either cease to flourish and retard until they are able to produce appropriate enzymes that are capable of digesting the new environment to source for food that will enable further growth [17]. This act of slowing down disrupts process of degradation and sometimes desirable spp fails to survive. This fact could have been the cause of the inconsistencies experienced at the early stage of the experiments. To reduce the negative effect of the phenomenon, a small quantity of yeast extracts was added to the minimal medium to guaranty survival for the period of disability to source for food. But since the aim of the experiment is to study the activities and the behavior of healthy organisms, the radical shift in metabolic activities was also prevented again by introduction of KH_2PO_4 and K_2HPO_4 into the media [9] to serve as a buffer.

Table 1 Percentage weight loss of khaya grandifoliola attacked by aspergillus spp.

Period	Sample	Mass loss (%)	Average percentage mass loss
12th week	K1a	0.24	0.246
	K2a	0.25	
	K3a	0.27	
	K4a	0.23	
16th week	K5b	0.64	0.648
	K6b	0.67	
	K7b	0.65	
	K8b	0.63	
18th week	K9c	1.68	1.653
	K10c	1.66	
	K11c	1.65	
	K12c	1.62	
24th week	K13d	2.42	2.482
	K14d	2.31	
	K15d	2.67	
	K16d	2.53	

The results obtained employing 16 samples were progressive and consistent. Perhaps, the period of the experiment failed short of retardation of growth as a result of physiological abnormality. These organisms degraded the cellulose of the cell walls by secreting enzymes that convert the cellulose into compounds absorbable. The action depletes the cellulose content of the wood and leaves a collapsible residue rich in lignin. Lappalainen et al. [4] described the characteristic of depleted residue as dark in color, lacks strengths, and soft, and cross-checked, or fibrillated.

3.4.2 Forecasted Degradations of Khaya Grandifoliola

Fig. 4 presents the forecasted trend line of the degradation of the Khaya grandifoliola for a period of 24 months. 16% lost was forecasted for this period. This is obtained from the regression equation, $y = 0.191x^{1.836}$. Where y is the percentage mass loss of the degrading sample under the aspergillus attacks and x is the durations of the attack in months. The value of the coefficient of determinant of the model, R^2 is 99.1% and it shows how much the model represents the data used. R^2 is computed as SS_R/SS_T. Where $SS_R = \sum_{i=1}^{n} - (\dot{y}_i - \tilde{y})^2$ being the regression sum of squares and; $SS_T = \sum_{i=1}^{n} - (y_i - \tilde{y})^2$, representing the total sum of squares of the response variable y or the corrected sum of squares of y. Erickson et al. [2] in his research reported 66% weight loss at an advanced stage of such degradations. The laboratory results of Highley and Flournoy [17] on different spp of timbers and fungi also confirmed losses in toughness ranging from 6% to > 50% at a time when 1% weight loss was recorded; and at 10% weight loss more than 50% of most of the strength properties were lost.

As degradation progresses, the metabolic activities of the growing spp population can change the nature of environment in a media to a point that is unfavorable and the population may became physiologically abnormal at an advanced stage of degradation. This can lead to death or inhibition in a prolonged experiment [13], even when the activation factors are still in place. This occurs when there is drastic change in the hydrogen ion concentration (pH) either being acidic or basic, or by the accumulation of toxic organic metabolites, or by the depletion of oxygen [9]. Conditions similar to the laboratory conditions that can cause damage at the same scale in service can be attained when the water activity (A_w) Levels rises above 0.90, the RH value is at 90% [5], the oxygen level in the air is at 20%, and the atmospheric temperature is 30 ^oC [4].

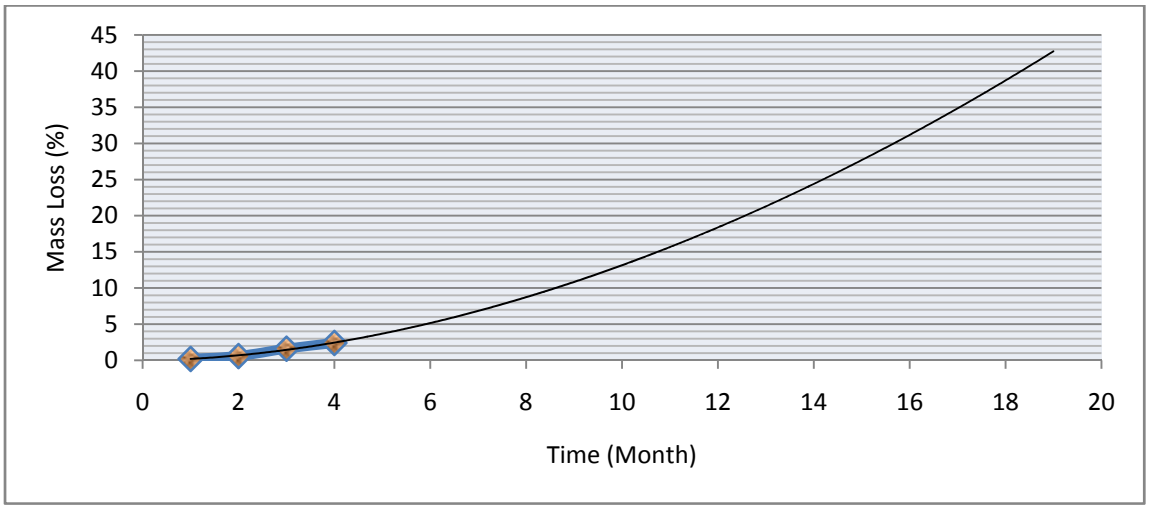

Fig. 4 Loss of weight of Khaya grandifoliola under the attacks of aspergillus spp.

4. Cost of Restorating Degraded Khaya Grandifoliola Elements in Buildings

Degrading elements in buildings can lead to obsolescence when care is not taken. This is because with infected components, important properties such as mechanical properties, acoustic and insulating properties [6], good appearances, and fireproof of the buildings are lost [17] and the degraded elements themselves would have problems of emitting volatile organic compounds, toxins and unpleasant odours, increases attractions to degrading insects as well as causing sick building syndrome and allergens [7, 11] that always affect comfort and well being of building users.

Buildings with unresolved biodegradations lack energy efficiency and have inflated life-cycle cost [14, 18] and it is difficult and expensive to effectively remedy. To remedy Aspergillus infected Khaya grandifoliola elements in buildings at economic cost that will regain the primary function of the elements is the main objective of fungal remediation. Sometimes, decay may be on the surface but can also be partially or substantially damaging essential properties. The costing of maintenance work packages may take one or more of the followings, depending on the nature and degree of damage.

4.1 Cost of Treating Infected Components

This is applicable where the component is merely infected with degradations that are restricted to the surfaces and it is yet to influence any strength property. Treatment at this stage involves clean-up and redecoration of the affected area. Affected areas are classified as small, moderate and large. Clean-up of small area that is fewer than 3 patches and each parch smaller than a square meter of noticeable prevalence (Fig. 1) can be removed by at less cost [6]. The operation may not require the attention of consultants. Fumigants such as 32% sodium N-methyldithiocarbamate in water, methylisocyanate, Basamid (tetrahydro-3, 5-dimethyl-2-H-1,3,5, thiodazine-6-thione) [7] are recommended to arrest internal decays [19]; and additionally, water diffusible boron-based and fluoride-based rods, pasts, or solutions can be used [16]. But cleaning-up of moderate and large contaminations that may be caused by profuse spp like S10 and S12 (Fig. 2), a consultant firm must be consulted. Treating an infected, but serviceable component can be done not only to eradicate the active Aspergillus, but also to guard against future infections [12], in which case the services of the consultant firm is also required.

4.2 Cost of In-Place Remediation of Degraded Potions

In a situation where partial but serious damage is caused to an element, a partial remediation may be required to fully reinstate functionality. The activity involves clean-up, partial removal and strengthening. A times, replacement may not be a better option to repair in order to restore lost properties of a component [13]. Therefore, a repair that would preserve the original part as much as possible without compromising essential qualities may be the most desirable choice. Despite that, a successful repair operation that restores components may also need additional stabilization effort. Epoxies are useful stabilizing materials used to consolidate rotted component to restore lost portions of moldings and carvings, and are also useful for strengthening weakened structural members [18].

4.3 Cost of Replacing Decayed Components

Components with visually discernable decay have been greatly reduced in all strength values and therefore need to be totally replaced. Cost of replacement comprises costs of removal, material and construction or installation and finishes. It starts with removing the degraded and damaged components as indicated on the plan design. Richardson [19] stresses understanding of the cause of infection and the philosophy of the biodegradation as necessary

prerequisite for good replacements. Removal of decayed components is done as much as practicable and economical until sound portion is reached, especially with beams, columns, and other critical members whose load-carrying ability may be compromised. This is because difficult-to-detect incipient decay can extend well beyond visibly rotten areas. Even though, Lappalainen et al. [4] and The Hidden Forest [5] denounced the existence of any known means of accurately determining residual strength of decayed timber in place, Erickson et al. [2] suggested the use of strength-to-weight ratio values, velocity of ultrasonic and other visual means as guides. The cost of the Khaya grandifoliola is relatively expensive due to its versatility especially in construction of buildings and scarcity [1].

5. Conclusions

This study on biodegradations of Khaya grandifoliola by Aspergillus spp suggested that most of the species available on the residential buildings in the dry land region had the ability to degrade and caused enormous damage. A loss of weight of about 16% in 24 months was forecasted based on laboratory experiments carried out under controlled conditions. The conditions for the biodegradations in the residential buildings would warrant such an optimum degradation that could hardly be met under normal situations. Therefore, it is unlikely that the rate of degradation can be as high as 16% in two years. However, where it is coincidently possible, the implication will lead to frequent maintenance work in order to keep residential buildings having Khaya grandifoliola components in them functioning effectively as required. Degradation can be minimized through control of extra contact with source of water and proper detailing for components placed at highly prone locations. Discovering presence of moulds at early stage of development and preventing further growth will enhance performance of buildings and drastically reduce overall costs of maintenance.

References

[1] I.H. Mshelgaru, Biodeterioration of Timbers in Building and Building Performance: Sustainability Implications under the Nigerian Microclimates, Lambert Academic Publishing AG & Co. KG., Germany, 2010.

[2] K.E.L. Erickson, R.A. Blanchette, P. Ander, Microbial and Enzymatic Degradation of Wood and Wood Components, Springer-Verlag, Berlin and New York, 2005.

[3] M.B. Usher, J.K. Ocloo, Natural Resistance of 85 West African Hardwood Timbers to attack by Termites and Microorganisms, Bulletin of Tropical Pest, Number 19, 1979.

[4] S. Lappalainen, E. Kahkonen, E. Loikanen, E. Palomaki, O. Lindroos, K. Reijula, Evaluation priorities for repairing in moisture damaged school buildings in Finland, Journal of Build Environment 36 (2) (2001) 981-986.

[5] The Hidden Forest, Fungi Classification, Fungi Identification Guide, What Fungi do www.hiddenforest.co.nz (accessed Feb. 20, 2011).

[6] J.M. Dinwoodie, Timber: Its Nature and Behaviour, 2nd ed., E & FN Spon., New Fetter Lane, London, 2000.

[7] J. Pe´rez, J. Mun˜oz-Dorado, T. de la Rubia, J. Martı´nez, Biodegradation and biological treatments of cellulose, hemicellulose and lignin: An overview, International Microbiology 5 (2002) 53-63.

[8] P.I. Morris, Understanding Biodeterioration of Wood in Structures, Forintek Canada Corporation Specialist Inc. Shutsbury, Massachusetts, USA, 1998.

[9] S. Smulski, Wood-Destroying Fungi in Residential Construction, Wood Science Specialist Inc., Shutsbury, Massachusetts, USA. 1996.

[10] D. Malloch, An Introductory Guide to the Study of Mould, Mould: Isolation, Cultivation, Identification, Books on Demand, Canada, 1997.

[11] I.H. Mshelgaru, O.S. Olonitola, Health and safety conditions of building maintenance sites in Nigeria: Evaluating the post occupancy contaminations of timber buildings by microorganisms, African Journal of Environmental Science and Technology 4 (1) (2010) 13-20.

[12] J. Beesely, Wood Deterioration in Buildings: A Guide to the Indication and Treatment of Wood Deteriogens, Technical Bulletin 7.1, Australian Council of National Trusts, Melbourne, 1987.

[13] L. Albinas, J. Bronius, Microbiological destruction of constructional and decoration materials of buildings, Materials Science (Medžiagotyra) 13 (1) (2007) 70-73.

[14] Forest and Wood Products Research and Development Corporation, Environmental Friendly Housing Timber-Principles, 1st ed., Australia, 2001.
[15] H.L. Barnett, Illustrated Genera of Imperfect Fungi, 2nd ed., Burgess Publishing Company, West Virginia, Morgantown, West Virginia, USA, 1993.
[16] L. Kleagerb, Dichotomous Keys, www.thermes.mbl.edu./biological Bulletin (accessed Apr. 1, 2011).
[17] T.L. Highley, D. Flournoy, Decomposition of cellulose by brown-rot fungi, International Biodeterioration and Biodegradation 11 (1994) 191-221.
[18] P. Worldsworth, Lee's Building Maintenance Management, 4th ed., Blackwell Science and the Estate of Reginald Lee, Liverpool, United Kingdom, 2001.
[19] B.A. Richardson, Remedial Treatment of Buildings, Second edition, Butterworth-Heinemann Limited Oxford, London, 1995.