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Antimicrobial Characteristics of Untreated Wood: Towards a Hygienic Environment

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Abstract

Wood, as a contact surface, has been used for centuries but is usually questioned because of its porosity and organic composition. It has natural antimicrobial properties and, hygienically, can stand the comparison with other materials such as plastic, glass and steel. In this review, we focused on potential microbe-inhibiting properties of wooden surfaces being used in hygienically important places like health institutes and food industries. This article addresses the questionable properties of untreated wood like hygroscopicity, porosity, roughness and chemical composition, and their relation to the hygienic and antimicrobial nature of this material. The other factors linked to the hygienic properties of wood, such as age, species and type of wood, have also been discussed. Our analysis of literature will create better understanding for acceptance of wood as a safety renewable resource. It also provides an outline for future research considering wood material in critical healthcare or food industries.

Keywords

Wood, Antimicrobial Characteristics, Physicochemical Properties

1. Introduction

Hospitals, healthcare facilities and food industries are confronted daily with the problem of transfer of contamination, especially from the solid surfaces of infrastructures, tools and equipment. In this context, surface hygiene is an important aspect for prevention of environmental contamination/infection [1]. These surfaces have different properties according to their constructing material such as wood, glass, steel and plastics [2]. Wood is a commonly used renewable resource in construction of these contact surfaces despite its reputation of a non-hygienic and non-cleanable material. In the last decades, several studies proved that wood is a better surface to control microbial growth and minimize microbial transmission [3] [4] [5] [6] [7], and aid the psychological welfare of inhabitants when used for indoor construction [8] [9] [10].

As previously described, wood naturally contains a microbial population according to its moisture content, decay status and duration of storage after cutting the tree [11] [12]. The microorganisms described in different studies are usually not human pathogens but the parts of the total flora of microorganisms commonly found in soil and on plants [13] [14]. Nevertheless, the presence of types of microbes determines the interrelated population diversity because of their symbiotic relations [15].

Hygienic characteristics of wood are often misunderstood because of its organic, porous and moisture absorbing surface. In fact, these properties are thanksgiving because the organic nature of wood makes it environment-friendly, the absorption potential of wood can cause desiccation conditions for microbes, and the presence of extractives can kill or inhibit harmful microorganisms [16] [17]. Such implication may allow to decrease the use of chemical agents for cleaning operations, which are a big concern regarding chemical hazard and antimicrobial resistance [18] [19]. There is a gap of knowledge to relate the antimicrobial nature of wood to its applications as a suitable hygienic surface for interior constructions.

Current review describes the major microbe inhibiting physicochemical strategies of untreated wood material. It summarizes the antimicrobial mechanism of wood involving porous structure, moisture content and chemical profile. It does not include the treated wood surfaces for the phytosanitary and esthetic purposes that may interfere with the natural properties of wooden surfaces [20] [21] and also cause chemical hazards to the environment and public health [19].

2. Porous Structure: Does It Support Microbial Growth?

Wood is a complex porous material which has specific arrangement of lignocellulose walls cells in parallel and perpendicular directions. Such arrangements leave open spaces on surface in form of pores. The size, frequency and arrangement of pores vary in different species of wood. According to the size of the pore, they are classified into three categories: micropores (80 - 1.8 nm), mesopores (500 - 80 nm) and macropores (radius 58 - 2 μm and 2 - 0.5 μm) [22]. It is generally regarded that these tiny holes retain microbes and make the cleaning difficult because of the probability that bacteria meets disinfectant is very weak. Ultimately, the wood surfaces are considered to be more contaminated than other, non-porous surfaces [21] [23]. It is true that wood surface retains bacteria but it does not strictly mean that bacteria are then, necessarily, transferred to something which is in contact with wood [24]. For instance, for Soares *et al.*, 2012, the wood pine absorbs inoculum more rapidly as compared to other smooth materials [25] and the difficulty to recover microbes from wood surfaces means that these organisms are stuck inside wood structures [26]. Thus, it can be assumed that these bacteria do not contaminate the contact objects like food or hands [3] [5] [27]. This phenomenon was confirmed by Vainio-Kaila *et al.* [28], who observed that Colony Forming Units (CFUs) of *Escherichia coli* and *Listeria monocytogenes* not only decreased faster on pine heartwood as compared to glass surface but also did not increase on the next day, which excluded the possibility that microbial recovery was less because of bacteria hidden in the wood and stay viable.

The porosity helps in the drying process of wood, contrarily, non-porous materials take longer time to get dry [29]. For example, Chiu *et al.* [30] compared bamboo plant and wood which were considered as rough and porous material, with plastic, stainless steel, and glazed ceramic tile which were apparently considered as smooth and less porous material. *Vibrio parahaemolyticus* seemed to survive better on smooth surfaces as compared to porous material, probably because smooth surfaces could maintain higher surface moisture conditions for longer time [31].

Porosity of wood material varies in different planes of cutting [32]. Furthermore, the presence of more pores means more exposure of extractives from cut cells and deeper retention of bacteria inside the wood. Prechter *et al.* [33] studied the penetration depth of *E. coli* and spores of *B. subtilis* in wooden cutting boards in longitudinal and transversal directions. They observed that bacteria and spores could enter deeper (around 3 mm) in transversal cuttings than in longitudinal cut woods, thus, probably posing lesser threat of recontamination with higher number of microbes. Moreover, the wood better utilizes the antimicrobial potential of extractives in transversal direction [6]. In contrast, the longitudinal cut boards of wood were easier to clean because of shallow and wider openings on surface [34].

Contrarily, the porosity not only offers difficulties in microbial recovery but may also provide shelter to some of them. The study of Boucher *et al.* [32] reported that the *Campylobacter jejuni* cells, when stressed by aeration of the liquid culture medium, were protected from death when a block of beech wood was present in the broth. They didn't observe any protective effect by using wood chemicals (free radical scavengers) or sawdust which means access to physical structure of wood, to be precise sufficiently small pores (around 16 μm) and at least 4 mm thickness, was necessary for the protection of cells. Interestingly, the deeply scored plastic blocks did not enhance the survival of cells in aerated broths. In this case, wooden pieces were kept in broth, which eliminates the possibility of desiccation effect owing to porosity that may have resulted in survival of bacteria on wood.

3. Do the Hygroscopicity and Capillary Action Dry out the Bacteria?

The hygroscopicity of wood is the property of taking moisture from environment. It is mostly influenced by relative humidity and temperature of environment [35]. The free water, bound water and fiber saturation point, determine the shrinkage and swelling of wood [36]. The porous structure and hygroscopic characteristics of wood lead to desiccation of bacteria [2]. Most bacteria are desiccation-sensitive and require a water potential of −2.8 MPa or less for growth in wood [16] [17]. It is significantly above the moisture content of air-dried wood stored indoors [37], so that properly dried wood does not offer enough water for microbial growth and multiplication [38] [39].

The hygroscopicity of wood leads to faster absorption of moisture as compared to other non-porous contact surfaces, therefore, the microbes survive longer on smooth and non-absorptive surfaces such as metal and plastics [30] [40]. Coughenour, [41] observed that Methicillin-Resistant *Staphylococcus aureus* (MRSA) survived longer on plastic, vinyl, flannel cloth and glass as compared to wood surface. In another study, the turkey coryza agent survived for shortest period on wood as compared to aluminum, glass, dust and feces [42].

Once the fiber saturation point is reached the wood does not absorb more moisture, therefore the hygroscopic antimicrobial potential may decrease [43]. Gehrig *et al.* [29] studied the survival of *E. coli* on wood and polyethylene by comparing Colony Forming Unit after manual and machine washing of these surfaces and 15 hours of storage at room temperature. It was observed that both wood and polyethylene showed very high numbers of bacteria in high moisture conditions. However, bacterial number was lower on wood in drier environment. This effect was attributed to the faster drying potential of wood, particularly the drainage capacity, as compared to polyethylene surface. If wood surfaces are exposed to external weathering conditions, especially, abundant rain and humidity levels, the passive effect of wood against microbes may decrease. Williams *et al.* [44] observed that the *E. coli* O157 persisted greater on wood than on galvanized steel, on the common farmyard surfaces, for a considerable length of time, under high moisture environmental conditions.

4. Microbial Adherence and Biofilm Formation on Wood Surface

The adherence of microbes to substrate is a complex phenomenon and it is the first step to biofilm formation [45]. This bonding is carried out by van der Waals, electrostatic and acid-base interactions, which depend on the physicochemical properties of the microbe and substrate, especially hydrophobicity, surface charge, and electron donor-electron acceptor properties [46]. Wood can serve as support material for biofilm formation of such microbes which use cellulose as nutrition for survival [47]. However, hygienically important microbes can show different results regarding their adhesion.

Dantas *et al.* [48] performed an experiment of microbial transfer of 10 biofilm forming *S. enteriditis* strains from chicken meat to cucumber *via* glass, plastic and wood cutting boards. The formation of biofilm was highest on wood (60%), followed by plastic (40%) and glass (10%). Once the biofilm was formed, they are difficult to clean and disinfect on surfaces, and the microbial transfer from cutting boards to cucumbers was also highest in wood. However, in cheese making process, the presence of lactic acid bacteria counters the adherence of many pathogens including *Listeria* spp., *Salmonella* and other *enterobacteriaceae* [49] [50].

The presence of biofilms from natural wood flora may stop the growth of some harmful organisms. Therefore, this factor should be considered for microbial safety in hygienic surfaces, such as cheese ripening wooden boards and biocontrol for nosocomial pathogens in hospital environment [51]-[58]. Mariani *et al.* [59] tested the fate of two *L. monocytogenes* strains, over time as a function of the presence of a native biofilm, the farmhouse origin of cheeses, and the wooden shelves properties. In presence of a native microbial flora on the shelves, deposited populations of *L. monocytogenes* remained stable or even decreased by up to 2 log10 (CFU/cm^2) after 12 days of incubation at 15˚C in all tested conditions. By contrast, *L. monocytogenes* populations increased by up to 4 log10 (CFU/cm^2) when the resident biofilm was thermally inactivated, suggesting a microbial origin of the observed inhibitory effect. In a similar study no inhibitory compounds by biofilm microflora were observed [49]. Therefore this reduction in *L. monocytogenes* numbers can be attributed to "Jameson effect" according to the nutrient consumption and exhaustion by competitive microorganisms [49] [60] [61]. This type of effect can be used on wood for treatment with probiotic type microorganisms and their bio-surfactants, which may antagonize the growth of nosocomial pathogens on inanimate surfaces [62].

5. Hygienic Suitability of Aged Wood Surface

Wood is an organic material which undergoes changes in its structure and properties along the time under different use and weathering conditions [63]. It is anticipated that rough and cracked wood surface can entrap bacteria which may help in survival of these organisms ultimately posing a risk to contact persons [23] [64]. However, studies have shown that the weathering conditions affect other materials too and scored wood surfaces has been seen to perform better than other in use scored surfaces like plastic, regarding the survival of microbes. The electron microscopy reveals that the cuts on wood surface open in the drying process and therefore bacteria cannot survive and cleaning also becomes easier [29], at least not more difficult as compare to plastic [65] [66]. Meanwhile, under similar circumstances, the plastic surface cuts have closing structure which can provide shelter for microbial survival [29]. Koch *et al.* [20] also reported that artificially aged plastic surface supported more bacterial survival as compared to wood.

Apart from structural composition, the chemical constituents also do not change as rapidly as they are perceived. For example, in case of wooden shelves being used in cheese making, the age does not have significant impact on water activity, pH, and salt concentration, and neither on major microflora, such as, *Leuconostoc sp*., facultative heterofermentative *Lactobacilli*, *Staphylococci*, *Enterococci* and *Pseudomonads* [67].

The aging of materials also bring the wearing and tearing of surfaces which provide different conditions of survival to microbes as compared to new or unused surfaces. Gough and Dodd, [68] assessed the survival of *Salmonella* Typhimurium persistence on food preparation surfaces, wood and plastic chopping boards both new and after heavy scoring. Survival was assessed by counting the numbers of *S.* Typhimurium recovered after rinsing the inoculum off the board surface followed by contact plates. Recovery of the board inoculum from the rinse diluent was significantly greater from plastic than wood, and from untreated than scored boards. However, the disinfection was more readily carried out on plastic than both types of wood boards.

As previously described, wood has extractives which may act as antimicrobial agents. These chemical agents may degrade by some treatments, especially, high temperature processing of wood and also by washing by different liquids which may act as solvents for these chemicals and the quantities may decrease in cleaning process [69]. However, such washing and aging do not decrease the overall hygienic nature of wood material [49].

6. Contact Time and Contamination Rate from Wood Surfaces

Wood absorbs moisture and liquid microbial inoculum rapidly compared to non-absorptive materials, leading to lower recovery concentration on contact from wood surface, for example when touching wood with hand or preparing food on the surface. However, this absorption is different according to the type of contact between contaminated material and wood. For example, Miller *et al.* [70] observed that swabbing showed non-significant difference in the bacterial numbers after short contact time (0 and 90 min) of placing ground beef onto plastic and hardwood cutting boards at room temperature. However, longer contact time of microbes on wood shows different results, as Revol-Junelles *et al.* [71] observed that *E. coli* cells and *Bacillus cereus* spores became metabolically inactive faster on dry poplar wood as compared to glass surface on room temperature with prolonged contact time, which made their viable contact recovery very low. Moore *et al.* [72] reported that the number of bacteria recovered from formica and stainless steel were not only higher than polypropylene or wood, but also, regardless of application medium or holding time, the transfer to the model food was also high.

On the other hand, the transfer of microbes from wood surfaces to the contact medium may depend upon contact time, which means a longer contact time is generally linked to higher microbial contaminant/transfer to contact medium [73]. For example, Dawson *et al.* [74] reported that transfer rates of *Salmonella typhimurium* from carpet, tile and wood to bologna rose with increase in brief contact time of 5, 30 and 60 s. However, for longer contact time the transfer rate may be lesser because of antimicrobial role of wood, for example, Mohammad and Al-Taee (2014) observed that the transferrable quantities of *E. coli* and *Salmonella* spp. after 5 and 15 minutes from surface to meat and vegetables were higher on glass, plastic and steel as compared to wood [75]. Montibus *et al.* (2016) studied the transfer rate of *Penicillium expansum* from poplar crates and plastic surfaces to apples during the study period of one week. They observed that the transfer rate continued to decrease on wood surface during the study period while it was constant or increasing from plastic [5].

Goh *et al.* [76] performed an experiment regarding the contact transfer of *L. monocytogenes* from wooden and plastic cutting boards to the uncooked and cooked meat. For this study, the chicken meat was contaminated with 200 μl solution at 7 log10 CFU/ml of bacteria and contacted with test surfaces for 5 s. Later, the cooked and uncooked chicken was contacted on contaminated surfaces to determine the transfer. After 1 h of holding time, the transfer of microbes from meat to wood (6%) and wood to meat (11% and 0%) was lower than that of plastic (71.8% and 25 % respectively).

7. Are Wood Surfaces Difficult to Clean?

As a misconception, the absorbance potential and porous nature of wood is generally considered as a hindrance in cleaning process. However, many studies have shown that wood surfaces are not more difficult to clean as compared to other non-porous surfaces [66] [77] [78]. Even, the ordinary washing of wood and plastic preparation surfaces in the kitchen gives the satisfactory results regarding the elimination of hygienically important microbes from these surfaces [20]. Ak *et al.* [69] observed that lesser viable *E. coli*, *L. innocua*, *L. monocytogenes* and *Salmonella* bacteria were recovered from 9 types of wooden cutting boards as compared to plastic boards. Moreover, the cleaning with hot water and detergent eliminated these microbes on all cutting boards [78], which is contrary to the assumption that wood is difficult to clean.

Zangerl *et al.* [69] examined the effect of cleaning and heat disinfection processes of 1 year old spruce fir wooden shelves used for cheese ripening on the survival of *L. monocytogenes*. The cut boards were inoculated with a suspension containing 5.5×10^7 CFU/ml of *L. monocytogenes* and incubated for 24 h at room temperature, the boards were cleaned by soaking them for 15 min in a solution of hot alkaline detergent followed by brushing and rinsing with warm water. Some of the cleaned boards were subsequently heat treated at 80˚C for 5 min and at 65˚C for 15 min, respectively. The cleaning procedure alone was not sufficient to render *L. monocytogenes* from the upper 2 mm wood layer inactive. In the case of both temperature-time combinations for heat disinfection, however, *L. monocytogenes* was not detectable. It was concluded that the use of wooden shelves does not affect the hygienic safety of cheeses if such shelves are in good repair and are thoroughly cleaned and sanitized by heat treatment. Therefore, there is no reason to replace wood employed in cheese ripening processes with other materials. In another study, it has been reported that the steam treatment of spruce fir wood for 20 min with three different temperature programs between 70˚C and 78˚C, made the *L. monocytogenes* undetectable when tested at 7, 8 and 9 days [79].

Sometimes wood surfaces may take little bit longer cleaning time depending upon type of disinfection or cleaning method use. Deza *et al.* [80] submerged the pieces of pine-wood and plastic cutting boards in the 9 to 10 log CFU/ml solution of *E. coli*, *L. monocytogenes*, *P. aeruginosa*, and *S. aureus* and then dried the boards under laminar flow for 20 minutes. Later, these inoculated pieces were immersed in the disinfectant solutions of sodium hypochlorite (NaClO), acidic electrolyzed water and neutral electrolyzed water. They found that all the solutions decreased the microbial count to undetectable limit plastic after 1 minutes of submersion while in case of wood they there were live cells present after 1 minute of treatment which became inactive after 5 minutes of treatment. DeVere and Purchase, [81] reported the survival of *E. coli* and *S. aureus* on four different surfaces cleaned with four types of cleaning agents including wipes and sprays. The microbial solution was inoculated on all surfaces and dried for 30, 60 and 120 min before being cleaned with antibacterial products. The results showed that wood was more efficiently cleaned with all types of products as compared to glass, plastic and antibacterial plastic surfaces. Lücke and Skowyrska, [66] also reported that after proper cleaning, the microbial counts were same on polyethylene, maple and beech cutting boards, suggesting that the wood material is not worse in cleanability than commonly used plastic.

Campylobacter may survive in presence of wood [32], however, the cleaning methods can remove this hurdle. Acuff *et al.* [82] reported that washing of wooden utensils with detergent on dishwasher removed the *Campylobacter jejuni*, while hand washing did not. Therefore, attention should be given while dealing with *Campylobacter* contaminated food products on wooden surfaces. Thormar and Hilmarsson [83] observed that the viable *Campylobacter* counts were reduced below the detectable level on plastic and wooden board surfaces after treatment with monocaprin emulsions for 2 min. Al-Qadiri *et al.* [84] reported that *C. jejuni*, *Salmonella* Typhimurium, *E. coli* O157:H7, *L. monocytogenes* and *S. aureus* were significantly reduced both on wooden and plastic cutting boards after 1 to 5 minutes of treatment with neutral electrolyzed water, quaternary ammonium, and lactic acid-based solutions.

8. Do the Species and Part of Wood Have Role in Antimicrobial Behavior?

Every wood species have unique anatomy and chemistry which leads to specific action against microbes [35] [85]. The studies have shown these variations of antimicrobial properties of wood as shown in **Table 1**. Johnston *et al.* [86] tested the antimicrobial activities of essential oils extracted from the wood of Alaska cedar (*Chamaecyparis nootkatensis*), western juniper (*Juniperus occidentalis*) and Douglas fir (*Pseudotsuga menziesii*), as well as, methanol extracts of ponderosa pine (*Pinus ponderosa*) and western red cedar (*Thuja plicata*) against *Clostridium perfringens*, *Fusobacterium necrophorum*, *Candida albicans and Actinomyces bovis*, which are common cause of multiple infections in farm animals. The extracts of western juniper and Alaska cedar exhibited strong growth inhibitory activities against all tested pathogens while of the Douglas fir showed activity only against *A. bovis*. Regarding the level of beneficial lactic acid bacteria on wooden vats used in dairy processing, Cruciata *et al.* [49] reported that the level of these microbes varied depending on the type of wood species being used. For instance, the high levels were registered on the surfaces of cedar, ash, walnut and poplar vats. Within this bacterial group, enterococci were only detected on cedar and cherry woods.

Wood is a complex material having different structural and chemical composition from different parts of a tree. The studies have shown that the extractives from bark, heartwood and sapwood have different effect on microbes [4] [86] [90] [91].

9. Biochemical Profile of Wood: Antimicrobial and Safety Perspective

The wood contains many types of extractives that principally protect it against the microbial, fungal and insect degradation. The antimicrobial chemicals include tannins, phenolic acids, flavenoids and terpenoids [92]. The mode of action of different wood chemicals can be seen in **Table 2**.

The emissions from wood do not pose health risks to inhabitants and they do not reduce the antimicrobial properties of material. The wood is always stored and dried before use. That allowed the volatile organic compounds to emit until stable level. Moreover, the age and storage time of pine wood did not influence its antimicrobial behavior [87].

The antimicrobial chemicals from wood can also be questioned for their transfer to contact subjects like food [43]. However, there are no specific studies showing such migration of chemicals, causing harmful effects regarding spoilage of food or human health [93]. In fact, the migration of chemicals from wood to contact subjects is very low [94].

The pH of wood is generally acidic due to its chemical composition and this property also helps to stop the surface adhesion and survival of certain bacteria including *Clostridia*, *Staphylococci*, *E. coli*, *L. monocytogenes*, *Pseudomonas* spp., and *Salmonella* spp. [49] [53] [95].

Table 1. Ranking of wood species depending upon the hygienic suitability.

Reference	Bacteria	Ranking
[4]	*Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Enterobacter faecium*, and *B. subtilis*	Pine > larch
[17]	*E. coli* and *E. faecium*	Pine = oak = larch > maple > spruce > beech > poplar Pine = oak > larch = maple = spruce = beech = poplar
[20]	*Bacillus subtilis* and *Pseudomonas fluorescens*	Oak > spruce
[38]	Poultry manure flora	Pine > larch = maple
[70]	*E. coli* 0157:H7	White ash > red oak > black cherry > maple
[87]	*Escherichia coli* and *E. faecium*	Pine > poplar = beech
[88]	*S. aureus*, *P. aeruginosa*, and *Acinetobacter baumannii*	Oak > Douglas fir = pine > poplar
[89] [90] [91]	*S. aureus*, *E. coli*, *Enterococcus faecalis*, *Streptococcus pneumoniae*	Pine > spruce

Table 2. Antimicrobial actions of wood chemicals against microbes*.

Target	Wood chemicals
Cell wall and cell membrane	Flavonoids, tannins, aldehydes, phenolic acids, terpenoids, alkaloids, terpenes
Nucleic acid	Flavonoids, aldehydes, alkaloids
Metals metabolism	Tannins
Protein synthesis	Aldehydes, tannins
Energy metabolism	Flavonoids, phenolic acids
Adhesion and Biofilm formation	Phenolic acids, quinones

*the data is adapted from[92] [96] [97] [98].

As Table 2 shows, many of wood metabolites effect on microbial cell wall and cell membrane, the difference of membrane structure among different types of microorganisms may give them support or vulnerability to this antimicrobial effect [99]. For example, the Gram negative bacteria, *E. coli*, survives lesser on wood as compared to Gram positive, *E. faecium*, isolates [87]. However, the extractive action of wood is stronger against multiple Gram positive microbes *(S. aureus* and *E. faecium*) as compared to gram negative bacteria (*E. coli*) [4] [89], which shows that probably, the physical microbial effect of wood is stronger against Gram negative, while chemical effect is stronger against Gram positive bacteria. It might be because the Gram positive bacteria have thicker cell wall which might provide them shield against the desiccation effect of wood. Unlike Gram negative bacteria, the Gram positive bacteria lack the outer membrane containing lipopolysaccharide [99] [100], which may render them prone to chemical action of wood metabolites. Further research is needed to justify the difference of survival of different microbes on similar wood types.

10. Conclusions

The recent studies have developed our understanding regarding the natural hygienic properties of wood. Laboratory and field trials have shown a reduction in microbial counts on wood contact surfaces, indicating their importance as promising additional support to the hygienic measures to curb the number and severity of contamination/infections in healthcare and food industries.

Different species, parts, and age of wood have different action against type, intensity, and frequency of contact of microbes. Therefore, specialized studies are needed to establish the standard values to address these parameters that would be helpful in determining the most cost-effective way to optimize the safety of contact surfaces.

As the safety authorities around the globe are more focused on prevention than reaction, they have implemented the concept of environmental monitoring of hygienically sensitive places. For example, Food Safety Modernization Act in USA and some organizational repositories in European Union enforce the environmental surveillance as part of safety program. In this scenario, the antimicrobial properties of wood should be kept in mind while implementing an environmental hygiene program.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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