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# Enhancement of termite (*Reticulitermes flavipes* L.) resistance in mycelium reinforced biofiber-composites

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## ABSTRACT

The increasing demand for sustainable packaging materials with minimal ecological footprint, compatible cost and stable shelf-life has led to a growing interest in biodegradable or compostable cellulosic packaging materials. Since cellulosic fibers are prone to termite *(Reticulitermes flavipes)* attack, a study was conducted to identify natural and safe termiticides that can be applied to 100% biodegradable composites derived from lignocellulosic fibers and fungus mycelium. The composite material is a patented technology, developed by Ecovative Design LLC (Green Island, NY). Biocomposite boards of two densities were manufactured using kenaf, hemp and corn fibers and bonded by three different strains of fungi *Daedaleopsis confragosa*, *Ganoderma resinaceum*, and *Tramates versicolor*. The resultant biocomposite boards were evaluated for termite resistance using four termiticides: vetiver oil (*Vetiveria zizanioides*), guayule resin (*Parthenium argentatum*), cedar oil (*Juniperus virginiana*), and borax. The treated boards were evaluated for termite resistance in accordance with ASTM D3345-01. The results showed variable impact of different types of termiticides on fungus mycelium bonded cellulosic biocomposites. A heavy to complete mortality was observed in guayule resin and vetiver treated boards. Borax was least effective as a termiticide. Kenaf and hemp boards treated with guayule resin showed maximum repellency to termites, followed by vetiver oil. The weight loss for treated and untreated samples ranged between 17.4%–33.7%, and 19.9%–55.8% respectively. The findings of this study show that vetiver and cedar natural oils and guayule resin can be used as an effective treatment on mycelium bonded cellulosic composites to improve their termite resistance.

## 1. Introduction

The demand for sustainable packaging materials with minimum environmental impact has been growing for the last several decades. According to U.S. Environmental Protection Agency 2012 data, only 2.8 million tons (8.8%) of the total 32 million tons of plastics waste generated in the U.S. was recycled (EPA, 2012). From an ecological standpoint, synthetic plastics are essentially inert due to low chemical reactivity, and cause major pollution to the environment and ecosystem. Packaging sector is the major consumer of both rigid and flexible plastics worldwide with the market share of 46% and estimated cost of $839 Billion (Smithers, 2016). The demand for rigid and flexible plastics packaging material is expected to rise annually by 4.4% and 3.4% respectively due to growing preference for packaged food and goods in developing countries (ALL4PACK, 2016). Since most of the plastic based packaging materials are non-biodegradable and goes to the landfills, there is a growing interest in biodegradable or compostable packaging materials that leave a minimal carbon footprint on the planet. Research efforts to develop eco-friendly and sustainable packaging materials have focused largely on the use of cellulose fibers, starches, poly-lactic acid (PLA), poly-hydroxyalkanoates (PHAs), chitosan and oil based polymers (Kumar and Iwata, 2008). However one of the major challenges with this category of materials is their durability and resistance to biodeterioration and biodegradation.

The use of natural oils and bioactive chemicals to replace petroleum based insecticides and pesticides has gained much traction due to increased awareness and societal concerns for a healthy and chemical free environment. In the last several years, many studies have focused on evaluating the efficacy of natural oils against biodegradation and biodeterioration of natural materials caused by insects, fungi, bacteria,

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**Table 1**
Selected list of bioactive ingredients reported in the vetiver oil, cedar oil, guayule resin and borax (Martinez et al., 2004; Stewart et al., 2014; Schloman et al., 1988).

| Vetiver oil | Cedar oil | Guayule resin | Borax |
|---|---|---|---|
| a-vetivone | a-thujone | Guayulins A, B, C, D | Disodium octoborate hydrate |
| β-vetivone | a-Pinene | Partheniol | Sodium borate |
| Nootkatone | Camphene | Sesquiterpene | Sodium tetraborate |
| Khusimol | Sabinene | Triterpenoids | – |
| Isovalencenol | a −Fenchone | Triglyceridess, triolein | – |
| Zizanoic acid | Bornyl Acetate | Argentatin A, B | – |
| Carboxylic acid | Terpinolene | Polyphenolics | – |
| Alcohols | Sesquiterpcnoid | Polysaccharides | – |
| Carbonyl compounds | Limonene | | – |

mold and stains (Regnier et al., 2014; Singh and Singh, 2012; Thomson and Walker, 2014). It is known that brown and white rot fungi can cause decay and rot of cellulosic materials, in addition insect attach especially termites can also do a considerable damage. For insect repellency, in particular termites, natural oils from vetiver grass, cassia leaf, clove bud, cedar wood oil, eucalyptus, lemon grass germanium and guayule resin are reported to be effective (Bultaman et al., 1991; Zhu et al., 2001; Nakayama et al., 2001). Vetiver oil was found to be the most effective repellent with a major bioactive ingredient α and β vetivone (Zhu et al., 2001). In cedar oils, the main bioactive compounds include cedrol, cedrene, and thujopsene (Adams, 1991). In guayule, a combination of organic compounds such as flavonoids, cinnamic and p-anisic acid derivatives, and a variety of terpenoids act as bioactive ingredients (Bultman et al., 1998). Table 1 lists the selected bioactive compounds found in different natural oils that lend resistance to biodegradation.

Biocomposite material discussed in this study refers to a fully biodegradable novel composite product made from 100% plant-based substrates, and bonded with fungus mycelium (Holt et al., 2012a,b; Zeigler et al., 2016). Mycelium acts as matrix and lignocellulosic fibers as reinforcement. The biocomposite material is a patented technology, developed by Ecovative Design LLC (Green Island, NY). One of the primary application of this material is the packaging, since most of the packaging material is discarded after single use. Other uses include construction, furniture, and acoustics material (Evocative Design, 2017). Since majority of the biocomposite material is composed of cellulosic fibers, it is prone to termite attack (Holt et al., 2012a,b). The research is driven by the hypothesis that bioactive compounds found in natural oils should provide repellency against insect and termite attack in cellulosic materials. Therefore this work focuses on identifying and evaluating natural oil based safe termiticides that can be applied to 100% biodegradable composite materials derived from lignocellulosic fibers bonded with fungus mycelium.

## 2. Materials and methods

### 2.1. Material preparation

The biocomposite boards evaluated in this study were manufactured from three different cellulosic fibers namely, corn stover *(Zea mays)*, kenaf pith *(Hibiscus cannabinus)*, and hemp *(Cannabis sativa)* pith. The cellulosic fibers were bonded by three different fungi mycelium strains, *Daedaleopsis confragosa (D.conf.)*, *Ganoderma resinaceum (G. res.)*, and *Tramates versicolor (T.ver.)*. The biocomposite boards were manufactured by Ecovative Design LLC at their research laboratory located in Green Island, NY. The manufacturing process involved pasteurizing and sterilizing cellulosic material at 115 °C for 28 min followed by cooling below 35 °C and inoculating with fungus strain. Inoculated material is transferred to plastic mold, sealed and is incubated at 2 °C for 5 days. Mycelium colonized boards are then sterilized in a convection oven at 60 °C for 8 h to deactivate fungi growth and to prepare the final product. The details of the manufacturing process is described in an earlier published research (Holt et al., 2012a,b). Compression force was used

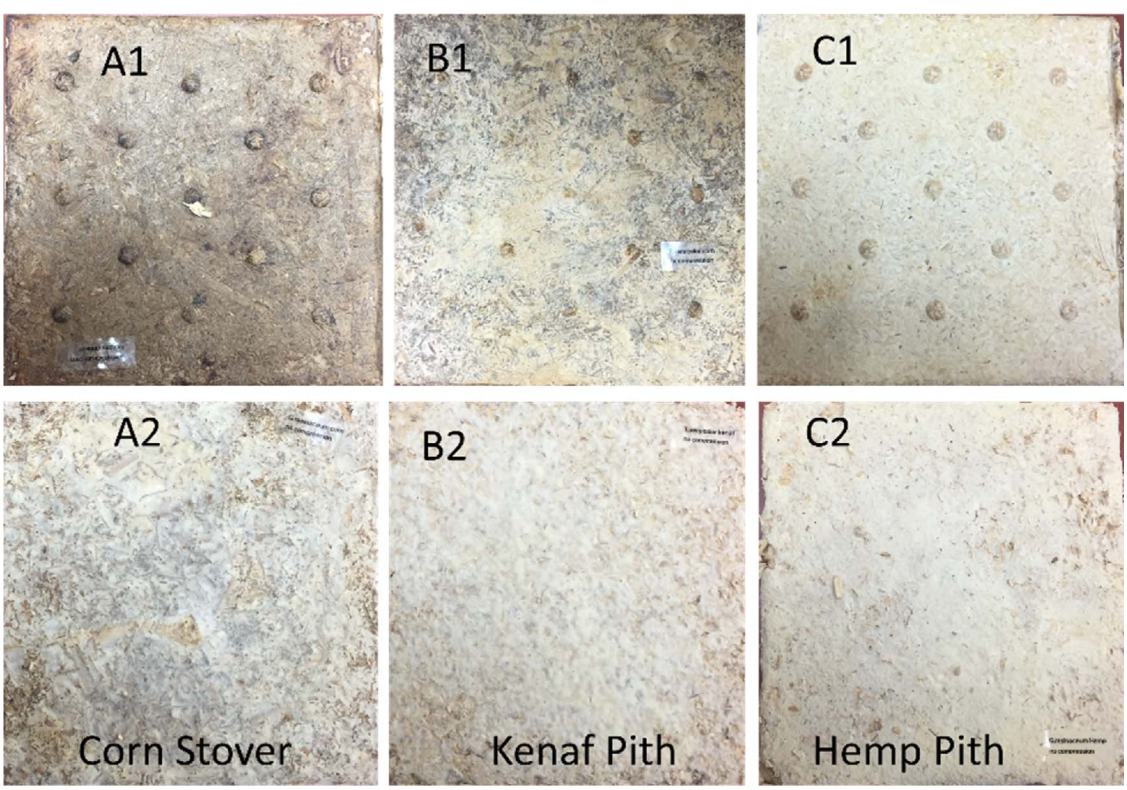


**Fig. 1.** Biocomposite samples, A1–corn compressed 4X, A2 − corn uncompressed 1X, B1 kenaf compressed 4X, B2 kenaf uncompressed 1X, C1 hemp compressed 4X, and C2 hemp uncompressed 1X.