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Review

Environmental Sustainability: A Review of Termite Mound Soil Material and Its Bacteria

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Abstract: The high quantity of nutrients accumulated in termite mound soils have placed termite mound as a 'gold mine' for bacteria concentrations. However, over the years, not much attention has been given to the bacteria present in termite mound soil. This is because many studies have focused on approaches to manage termites which they see as menace to agricultural crops and buildings. Therefore, we aimed to evaluate the potential application of termite mound soil material and its bacteria for biotechnological purposes. This review has been grouped into four key parts: The termite mound as hotspot for bacterial concentration, the degradation of lignocellulose for biofuel production, termite mound soil as a soil amendment, and the role of termite mound soil and its bacteria in bioremediation and bio-filtration. Therefore, the effective usage of the termite mound soil material and its bacteria in an ecofriendly manner could ensure environmental sustainability.

Keywords: biofuel; bioremediation; heavy metal; healthy environment; soil nutrient

1. Introduction

In the agroindustry, mound-building termites are known to have a detrimental effects on a number of crops, forest trees, and manmade structures [1,2]. Mound-building termites are a group of termite species, such as fungus-growing termites, that live in mounds [3]. Because of the destructive effect arising from the feeding habit of termites, many research studies have concentrated on the pest management of termites. However, of the roughly 2250 taxonomically well-known termite species, comparatively few—around ten to twenty percent—can negatively impact humans socially and economically [4]. Termites have been used as a biological pointer to assess soil quality and fertility. This is because they play a key part in soil transportation, methanogenesis, nitrogen fixation, acetogenesis, and nutrient circulation, thus improving the soil water content, pH, porosity, and organic carbon content [5–7]. Some termite societies like *Macrotermes* and *Coptotermes* are found in a mound (Figure 1) which they built by excavating soil particles from depths using resources from the surrounding soil [8].

Termite mound soils serve as unique natural habitats which harbor and uphold several microorganisms, of which the predominant ones are bacteria [9]. A termite mound is built by a mixture of clay components and organic carbon cemented by secretions, excreta, or saliva deposited by termites [10]. The architectural shapes of termite mounds include cathedral, dome, conical, lenticular, and mushroom-like [11]. These variations in shape depend on species type, ecological temperature conditions, clay availability, and the level of termite disturbance in the environment [12]. It has been reported that soil nutrients are accumulated in a termite mound, and their turnover plays a vital function in the ecosystem [13–15]. Research has revealed that termite mound soil is a "gold mine" of bacterial communities [16–19]. Termite mound soils could be used as a bulking agent [20] and for silo construction for short-term grain storage [21]. Furthermore, some bacteria isolated from termite mound soil could be utilized in an ecofriendly way as a potential material for antimicrobial production [10,22], biofertilizers, and biocontrol [23]. This can increase soil fertility and enhance crop production, thereby guaranteeing environmental sustainability (Figure 1) [24,25]. Environmental sustainability recognizes the need to improve and maintain the biophysical systems that sustain both the short and long-term quality of all life on Earth without compromising the health and diversity of natural ecosystems [26]. Due to the ecosystem services rendered by some bacteria present in termite mound, Miyagawa et al. [27] and Kaiser et al. [28] have called for proper research on the factors that support mound restoration by termites and further encourage practices that improve mound conservation. Though bacteria found in termite mound soils contribute to ecological services, there is scarcity of information on the possibility of using them as biotechnological products. Generally, biotechnology is seen as a fast emerging and influential field of technology for its useful role in health, food, and environmental sustainability [29]. Therefore, this review summarizes the variety of bacteria in termite mound soils and their possible contributions to lignocellulose degradation, biofuel production, bioremediation, and bio-filtration, as well as their potential to be a soil amendment.

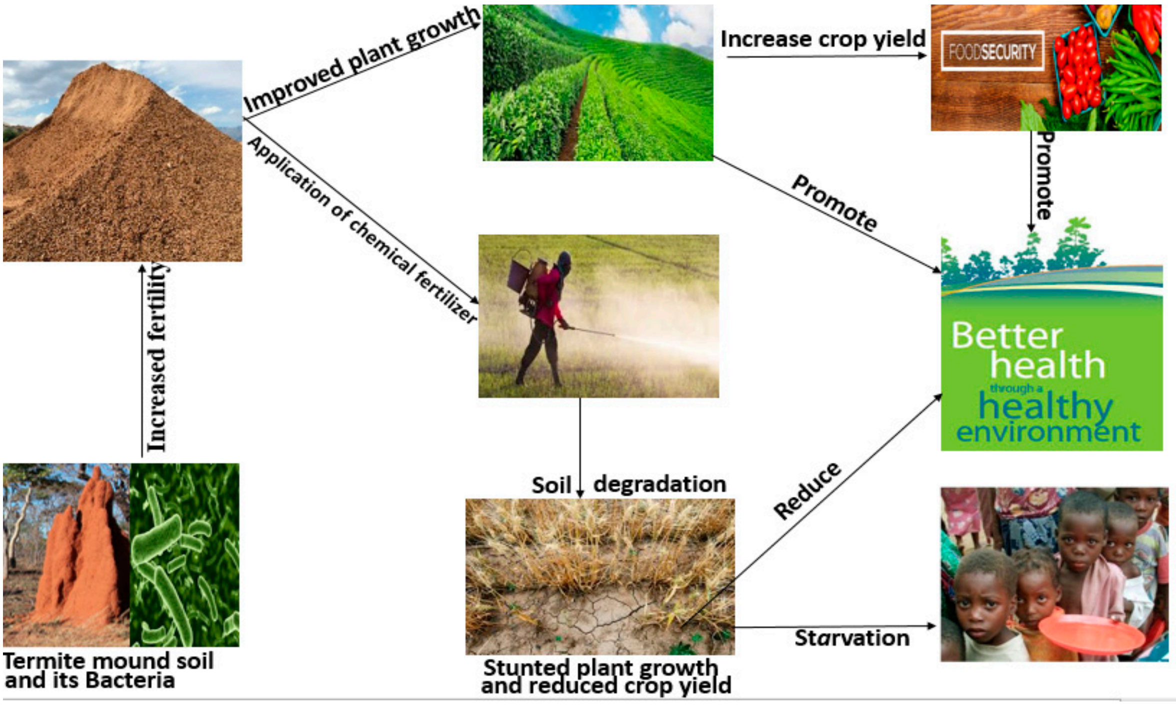

Figure 1. Termite mound soil and its bacteria's role on human health and environmental sustainability.

2. Termite Mound as Hotspot for Bacteria Concentration

Bacteria secrete extracellular hydrolytic enzymes into soil that are responsible for the breakdown and utilization of some vital elements, and, as a result, they are seen as a major driving force controlling terrestrial habitats [30,31]. The nutrient richness of termite mounds not only contributes to plant growth but also supports soil beneficial bacteria living in termite mound soil [32,33]. The little research conducted on termite mound soils have reported the existence of useful bacteria therein (Table 1) which are important for biotechnological applications. *Spirochetes*, which are capable of producing acetate from H_2 or CO_2, were observed in termite mounds [34]. Spain et al. [35] stated that there are higher populations of bacteria in termite mound soil than their surrounding soil. This was supported by the research of Kumar, Tilak, Sivakumar, and Saranya [16], who stated that bacterial populations in open and closed termite mound soils were 75.5×10^5 cfu/g of soil and 65.5×10^5 cfu/g of soil, respectively, and they were higher than the normal soil with 30.5×10^5 cfu/g of soil bacterial population. This high bacterial diversity in mound soils has been credited to the high level of humidity and accessibility of substrate.

Table 1. Bacteria reported present in termite mound soil and the method used in identifying them.

Molecular Method Used	Bacteria Reported	Reference
454-pyrosequencing based analysis of 16S ribosomal ribonucleic acid gene sequences	*Nitrospirae, Cyanobacteria, Bacteroidetes, Spirochaetes, Actinobacteria, Fibrobacteres,* Candidate division TM7, *Chloroflexi, Proteobacteria,* WCHB1-60, *Elusimicrobia, Planctomycetes, Spirochaetes, Chlorobi, Gemmatimonadetes, Armatimonadetes, Acidobacteria,* SM2F11, *Firmicutes,* Candidate division WS3	[36]
PCR-denaturing gradient gel electrophoresis analysis, cloning and sequencing of PCR-amplified 16S rRNA gene fragments	*Firmicutes, Actinobacteria, Chloroflexi*	[32]
Ion Sequencing of V3 hypervariable region of 16S ribosomal deoxyribonucleic acid	*Cyanobacteria, Proteobacteria, Chlorobi, Actinobacteria, Deinococcus-Thermus, Firmicutes, Synergistetes, Spirochaetes,* and *Bacteroidetes,*	[34]
Bacterial tag encoded amplicon pyrosequencing	*Gemmatimonadetes, Fibrobacteres, Nitrospirae, Verrucomicrobia, Bacteroidetes, Actinobacteria, Deinococcus, Planctomycetes, Chlamydiae, Firmicutes, Chloroflexi, Tenericutes, Acidobacteria,* and *Proteobacteria*	[37]
Isolation and cultivation	*Pseudonocardia, Nocardia, Micromonospora, Streptomyces,* and *Amycolatopsis*	[10]
Isolation and cultivation	*Bacillus*, *Pseudomonas*, *Nocardia*, and *Streptomyces*	[16]

3. Degradation of Lignocellulose for Biofuel Production

Currently, there are many calls for the search for renewable forms of energy resources. This is as a result of limited areas for petroleum-based fuel production, which are continually reducing [38,39]. Over the years, animal feed and plant built biological materials consisting of carbohydrate have been used as biomass energy resources for alternative fuel production, and the fuels generated from these resources are called biofuels [40,41]. A successful use of renewable fuels from biomass instead of petroleum-based automotive fuels will benefit many societies and environments [42]. Biofuel usage reduces oil reliance and the effects of greenhouse gases, improves air quality, and creates new job opportunities [43]. Plants are made up of lignocellulose, which is the principal structural component of their cell walls [44]. Lignocellulose, a major source of renewable organic biomass, is an economical source of energy that is composed of hemicellulose, cellulose, and lignin [45]. Despite lignocellulose abundances in nature, the high cost of hydrolyzing them into simpler monosaccharides has made the economics of utilizing them unattractive [46]. This has led to the search for cost-effective, biological means of hydrolyzing lignocellulose [47]. Overall, direct and indirect fermentation are the two main mechanisms (Figure 2) presently used in biofuel exploration by targeting alcohol production. Direct fermentation entails the breaking down of starting plant materials into fermentable sugars, which are later converted into alcohol. Indirect fermentation uses pyrolysis of the starting plant materials to produce a mixture of carbon dioxide, hydrogen, and carbon monoxide. Thereafter, acetogenic bacteria are used to convert the produced gas into ethanol [48].

Recently, scientific interest in termite mound soils has increased, because they accommodate vast numbers of bacteria that secrete unusual cellulolytic enzymes that are useful in biofuel industries. For example, *Glycosyl hydrolases*, a useful enzyme for bioethanol, could be obtained from a termite mound [37,39,49]. As early as 1985, Jaishree and his co-researchers reported that the *Cellulomonas* species, a cellulose degrading bacteria, was isolated in a termite mound occupied by *Odontotermes obesus* in a semi-arid region [9]. In addition, genes from the bacteria responsible for xylan and cellulose hydrolysis have been identified in bacteria isolated from termite mound soil [50]. Termite mound soils are laden with bacteria phyla like *Acidobacteria*, *Firmicutes*, *Actinobacteria*, and *Proteobacteria* [36]. Most strains of these bacteria phyla are good degraders of plant biomass polysaccharides [51], and they can also decompose phenolic composites and lignin [52].

Fermenting bacteria, which have the ability to convert complex lignocellulose polymers into monosaccharides using lignocellulolytic enzymes which are essential for several vital industrial processes, have been isolated from termite mound soils [16]. Varghese, Agrawal, Sharma, Mandhan, and Mahajan [50] reported that thirty bacterial isolates from termite mound soil showed xylanase and cellulase activities from 0.45 to 6.02 and 55 to 380 IU/mL, respectively. Simple sugar fermentation from the lignocellulose breakdown by these enzymes is a remarkable prospect in biofuel production [53]. Thus, understanding the bacterial activities and environmental conditions controlling the transformation of massive quantities of carbon materials in termite mound soils could lead to new opportunities that can benefit the environment [30,50,54].

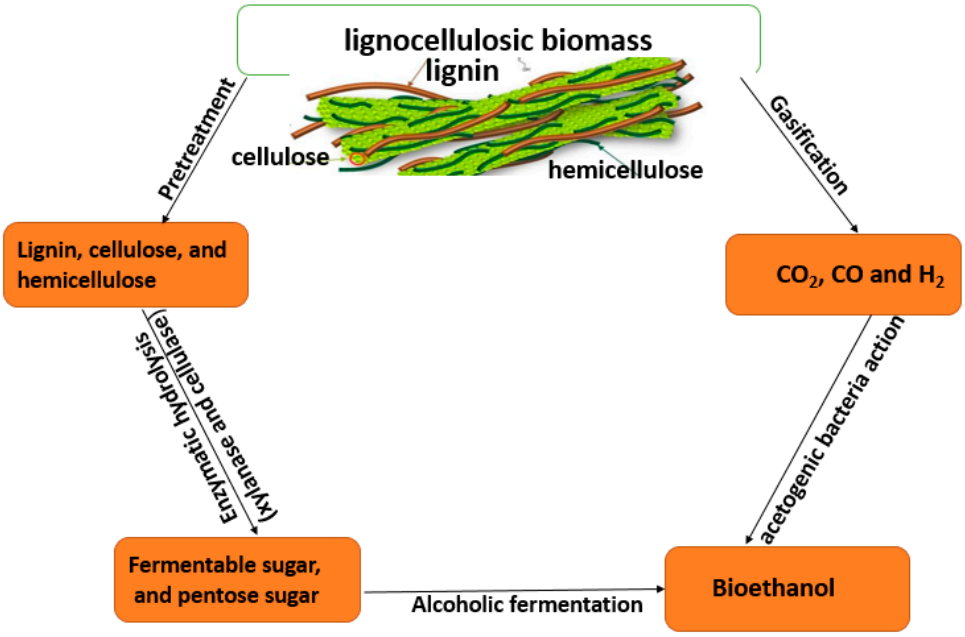

Figure 2. Direct and indirect fermentation mechanisms for biofuel production.

4. Termite Mound Soil as Soil Amendment

Soil amendments are materials combined with soil for the improvement of physical quality and, consequently, plant growth and health. Due to the unique physical and chemical properties of termite mound soils (which are brought about by termite activities), they are ‘hotspots’ for nutrient concentration in tropical and subtropical soils [15]. The physiochemical parameters of termite mounds and their surrounding soils are relatively different (Figure 3) [55]. Dhembare [13] and Deke, as well as Adugna and Fite [4], revealed that termite mound soils are richer in properties like clay content, organic carbon, copper, iron, potassium, zinc, magnesium, and phosphorus relative to their surrounding soils. The investigation of Fall et al. [56], showed that termite mound soil had approximately two-to-three times calcium and phosphorus, five times carbon and nitrogen, and 50 times ammonia and organic matter than their surrounding soil. The clay content in termite mound soils increases their soil porosity and water-holding capacity [8]. This then increases microbial activities [8,57] and therefore assists in the growth of plants [33]. Owing to the uniqueness of termite mound soils, many researchers have recommended their use as a soil amendment in low-input cropping systems, as seen in Table 2 [4,15,58].

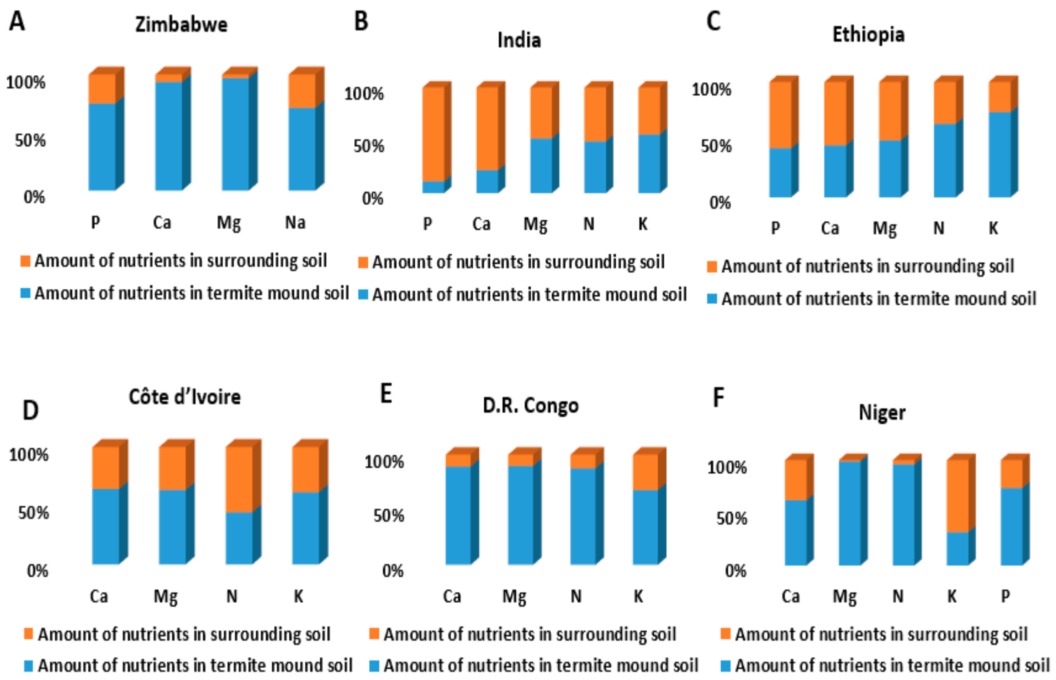

Figure 3. Some soil physiochemical parameter differences between termite mound soil and surrounding soil. References: A = [59], B = [13], C = [4], D = [60], E = [61], and F = [62].

Table 2. Termite mound soil application as a soil amendment.

Test Plant	Effect on the Plant	Reference
Solanum lycopersicum	The soil amended with termite mound soils resulted in better plant height, as well as an increase in leave number, fruits, and dry matter than those plant grown on unamended soil.	[62]
Oryza sativa L. and *Phaseolus vulgaris* L.	Improve the growth of *Oryza sativa* L. and *Phaseolus vulgaris* L.	[27]
Solatium melongena	Combined use of 200 g of termite mound material with NPK led to a substantial increase in *Solatium melongena* production.	[63]
Lolium perenne	*Lolium perenne* gave higher dry-matter yields with substrates derived from termite mounds than the comparable soil.	[64]
Zea mays	Combined use of termite mound materials and inorganic fertilization significantly increased the *Zea mays* growth and yield.	[65]
Acacia holosericea	Termite mound materials consisting of *Pseudomonas monteilii* species enhanced the ectomycorrhizal development between *Acacia holosericea* and *Scleroderma dictyosporum.*	[66]
Sorghum sudanensis	Combining sandy soil with termite mound materials at a proportion of 120 Mg/ha improved porosity and transformed the pore size distribution, thus causing a stepping up in the obtainable water content for the crop growth.	[67]

5. The Role of Termite Mound Soil and Its Bacteria in Bioremediation and Bio-Filtering

Current research has given intensive attention to bioremediation, which is a process used to treat contaminated media by altering environmental conditions to stimulate the growth of microorganisms that degrade target pollutants [68,69]. Some bacteria have the ability to directly interact and remove heavy metals from contaminated soils and increase the transfer of these metals to the above ground biomass of plants [70]. The efficacy of *Fluorescent pseudomonads* in bending heavy metals has been reviewed by Wasi et al. [71] and a lot of these *Pseudomonas* strains are found in termite mound soils [17]. For instance, *Pseudomonas monteillii* isolated from termite mound soil were inoculated to *Sorghum* bicolor, with soil amended with 560 mg Cd kg^{-1} soil in research conducted by Duponnois et al. [72]. Their findings revealed that *Sorghum bicolor* inoculated with *Pseudomonas monteillii* had a higher Cd uptake than those not inoculated. Furthermore, they also reported that soil samples inoculated with *Pseudomonas monteillii* had a higher use of hydroxybutiric and ketoglutaric against fumaric acid in soil samples not inoculated with *Pseudomonas monteillii*. They therefore recommended that *Fluorescent pseudomonads* could aid in the phyto-extraction of heavy metals from soil. The surface characteristics and mineralogical compositions of the termite mound soil materials position them as an excellent adsorbent of metals. This became evident in an experiment where Abdus-Salam and Itiola [73] used termite mound soil material as a prospective tool for removing lead metal (Pb(II)) from aqueous solutions. The results from their experiment revealed that termite mound materials adsorbed Pb(II) up to 15.5 mg/g, and they then concluded that termite mound soil material is an efficient adsorbent of oxides of metals and even manganite silicate. Additionally reported in literature is the use of termite mound materials for defluoridation [74], the removal of arsenate from water [75], Zn(II) removal from aqueous solutions [76], the removal of dyes from wastewater [77], and the removal of chromium from aqueous solutions [78].

Termites can significantly decompose plant materials, and, through the process of decomposition, a significant amount of greenhouse gases are produced [79,80]. Ho et al. [81] reported that termite-resultant methane adds roughly 3–4% to the entire global methane budget, and mound-building termites contribute less than 1% of the total global emission (although this amount depends on the type of mound-building termite species) [82]. However, termite mound soils harbor a considerable number of methane oxidizing bacteria like *Methylocystaceae* and *Methylococcaceae* that act as biofilters. This bacteria can consume the methane produced by termites [36,81,82] and therefore reduce the amount of methane finally released to the surroundings [83,84]. In an experiment to test if the bacteria in termite mound soil can mitigate methane emission, Nauer et al. [85] reported that termite mounds with the help of the methanotrophic bacteria living in them were able to oxidize half of the methane formed by termites before it was released. Methanotrophs use enzymes—mainly methane monooxygenase—as a strategy to oxidize the methane produced by termites. This is because some genes (like the *mmoX* and *pmoA* genes) which encode subunits of methane monooxygenase have a strong affinity for methane and, even at a low concentration of less than 40 ppm, can oxidize methane [86].

6. Conclusions

Globally, biotechnology is seen as a fast developing and significant field of technology for its proficient part in health, food, and environmental sustainability. With the pursuit of using natural materials for biotechnological purposes, we therefore reviewed the potentiality of termite mound soil materials as a worthy tool. This is because they host beneficial bacteria that can be useful in the bioremediation of heavy metals, the bio-filtering of gases, and biofuel production, and they can serve as soil amendments. For the optimal utilization of termite mound materials for biotechnological purposes, there is a need for further and extensive research to exploit the metabolic capabilities of the bacteria present in termite mound soils, thereby uncovering their full potential. Furthermore, to ensure a sustainable termite mound materials application in the future, research should also be carried out to improve factors that stimulate mound restoration by termites, as well as to improve termite mound conservation.

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