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REVIEW ARTICLE

Potentials of termite mound soil bacteria in ecosystem engineering for sustainable agriculture

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Abstract

The environmental deteriorating effects arising from the misuse of pesticides and chemical fertilizers in agriculture has resulted in the pursuit of eco-friendly means of producing agricultural produce without compromising the safety of the environment. Thus, the purpose of this review is to assess the potential of bacteria in termite mound soil to serve as biofertilizer and biocontrol as a promising tool for sustainable agriculture. This review has been divided into four main sections: termite and termite mound soils, bacterial composition in termite mound soil, the role of bacteria in termite mound soil as biofertilizers, and the role of bacteria in termite mound soil as biocontrol. Some bacteria in termite mound soils have been isolated and characterized by various means, and these bacteria could improve the fertility of the soil and suppress soil borne plant pathogens through the production of antibiotics, nutrient fixation, and other means. These bacteria in termite mound soils could serve as a remarkable means of reducing the reliance on the usage of chemical fertilizers and pesticides in farming, thereby increasing crop yield.

Keywords Biofertilizers · Chemical fertilizers · Environmental safety · Food security · Organic farming

Introduction

Traditional agriculture contributes a key part in meeting the demand for food of a rising human populations (Santos et al. 2012) that is currently more than seven billion people globally, and this figure is expected to rise to eight billion by 2020 (Conway 2012). The use of pesticides and inorganic fertilizers to boost the fertility of soil and control plant pests has increased food production; however, their misuse has resulted in eutrophication of water bodies, air, and groundwater pollution, thus affecting human and environmental health (Savci 2012; Alori et al. 2017). The prolonged use of these chemicals affects soil by reducing its water-holding capacity, increasing soil salt content, leading to inequality of soil nutrient distribution, and ultimately affecting the structure and fertility of soil (Savci 2012). Looking at these negative effects of chemical fertilizers and pesticides, which will certainly increase as human population increases, it is therefore paramount to produce agricultural produce in a sustainable manner without causing any harm to the environment (Pathak et al. 2018). To achieve this, eco-friendly methods like the use of biofertilizers and biocontrols need to be employed to boost soil fertility and suppress soil plant pathogens (Igiehon and Babalola 2017). Biofertilizers are substances that are made up of live microorganisms (which could be plant growth-promoting rhizobacteria (PGPR)) which when applied to soil, plant, or seeds, inhabit the rhizosphere of plants and stimulate plant growth (Malusá and Vassilev 2014). PGPR enrich the soil through potassium solubilization, phosphate mineralization, and nitrogen fixation, breaking down organic substances to a form that plants can utilize. Further, they help in the regulation of plant growth substances and the production of antibiotics that suppress soil borne plant pathogens (they are microscopic organisms that prefer to live within the soil causing harm to plants and even soil itself) such as virus, bacterium, fungus, or nematode (Liu et al. 2018; Parewa et al. 2018) that cause damaging effects on fruits and growing and stored crops of economic importance, therefore leading to plant diseases which contribute directly to losses in agriculture (Widmer 2014).

Investigations associated with soil uniqueness in controlling soil microbial community composition could enlighten our understanding of soil quality and biogeochemical processes (Li

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et al. 2015). The structures and functions of soil microorganisms are widely used as a pointer to assess the degree of soil health (Zhu et al. 2017). This is because soil microorganisms function as a means of transforming carbon-based materials, cycling minerals, and energy and also perform further roles that could advance soil health and agricultural sustainability (Choudhary et al. 2018). However, little information exists in respect to the functions and structure of soil microorganisms in termite mound soil. Termite mounds are the structures in several tropical ecosystems that are primarily built by termites (Jouquet et al. 2015). Soil from termite mounds is rich in mineral nutrients and organic matter, and these make it a suitable habitat for microorganisms (Nithyatharani and Kavitha 2018). Due to this nutrient richness of termite mound soil, small-scale farmers often improve the soil condition of their farmland by using termite mound soil, which they believe can increase crop yield (Deke et al. 2016). Microbial communities connected with termite mounds play an important role in the maintenance of the composition and fertility of soil through nitrogen fixation, acetogenesis, and lignocellulose breakdown, thus improving crop yield (Arumugam et al. 2016). Despite the contributions of termite mound bacteria in improving soil fertility, there is little research involving the assessment of the bacterial richness, abundance, and functional diversity in termite mound soil when compared to the assessment of the composition and functional diversity of bacteria in termite gut microbiota and the surrounding soil (Fall et al. 2007). Few researchers have used cultivation-dependent and cultivation-independent (like the denaturing gradient gel electrophoresis) tools to examine the composition and abundance of bacteria in termite mound soil. With the current trend in environmental microbiology, with the adoption of the high-throughput sequencing (HTS) approach to detect, identify, and monitor microorganisms in the environment, a comprehensive study of the bacterial diversity can now be realized (Ercolini 2013). This HTS approach will help to reveal all the plant growth-promoting bacteria present in termite mounds (Arumugam et al. 2016). This review is therefore aimed at assessing the potential of bacteria in termite mound soil to serve as biofertilizers and biocontrols as a promising tool for sustainable agriculture.

Termite and termite mound soils

Termites are a social insect that host a large amount of bacteria responsible for the breaking down of polyose and cellulose to a form that they can utilize (Bignell 2010). Termites are known to have a substantial effect on agroecosystems. They are referred to as “ecosystem engineers” as they can maintain, transform, and support soil fertility (Deke et al. 2016). Termites perform a significant contribution in upholding soil’s chemical and physical parameters by excavating and breaking down organic materials when constructing their mounds (Jouquet et al. 2015; Vidyashree et al. 2018). Termites feed on plant materials, fungi, and humus, and because of their feeding habit, they are considered as a big menace to agricultural produce in sub-tropical and tropical areas (Rosengaus et al. 2011; Negassa and Sileshi 2018). This is because they have the tendency of destroying growing or stored crops and farmland buildings (Ogedegbe and Ogwu 2015), and thus, many research works have centered on the pest management of termites. However, termites’ involvement as an agricultural pest is merely trivial aspect as compared to the positive contributions of termites to agroecosystems. There are about 2600 taxonomically well-known species of termites, and of this number, around 20% are destructive to agricultural crops (Sileshi et al. 2010; Deke et al. 2016). The guts of termites contain numerous microscopic single-cell organisms of which several are principally bacteria that can help in many metabolic processes like decomposition of organic matter (Brune and Ohkuma 2010; Hongoh 2010). Previously, studies on the gut ecosystem of termites concentrated on wood feeding termites, for example, the study of Mathew et al. (2012) that reported the presence of *Lactobacills*, *Peptococcus*, *Bacteriodetes*, *Clostridium*, *Peptostreptococcus*, *Bifidobacterium*, *Ruminococcus*, *Fusobacterium*, *Eubacterium*, and *Termitomyces* species (Bacteria that can break down cellulose) in termites’ gut by using a gene-specific bacterial primer.

Termites build conspicuous structures called mounds in many humid ecosystems. They are constructed primarily by a mixture of organic materials and clay components which is glued by termites’ feces, saliva, and other secretions (Jouquet et al. 2015). The mounds built by termites are solid as this makes it difficult for rain and predators to enter (Mujinya et al. 2013). The need of termite to normalize the temperature in their mound affects the shape of the mound and physicochemical components of the soil and consequently leading to diverse biological habitats (Jouquet et al. 2015). Menichetti et al. (2014) stated that the daily activities of termites that feed on litter is the key driving factor that circulates nutrients in soil occupied by them. This claim was backed by the studies on the physicochemical properties of termite mound soil by Dhembare (2013) and Jouquet et al. (2015) that showed that organic carbon, pH, electric conductivity, magnesium, potassium, zinc, iron, phosphorus, copper, and clay content were increased in soil from termite mounds when compared with the corresponding neighboring soil. Another factor that can influence physicochemical properties of termite mound soil is the parent soil type and this could also influence the shape of the mounds, although not necessary the size (Jouquet et al. 2015).

Bacterial composition in termite mound soil

Investigations into bacterial communities through various approaches like the use of metagenomics techniques (Fig. 1) have

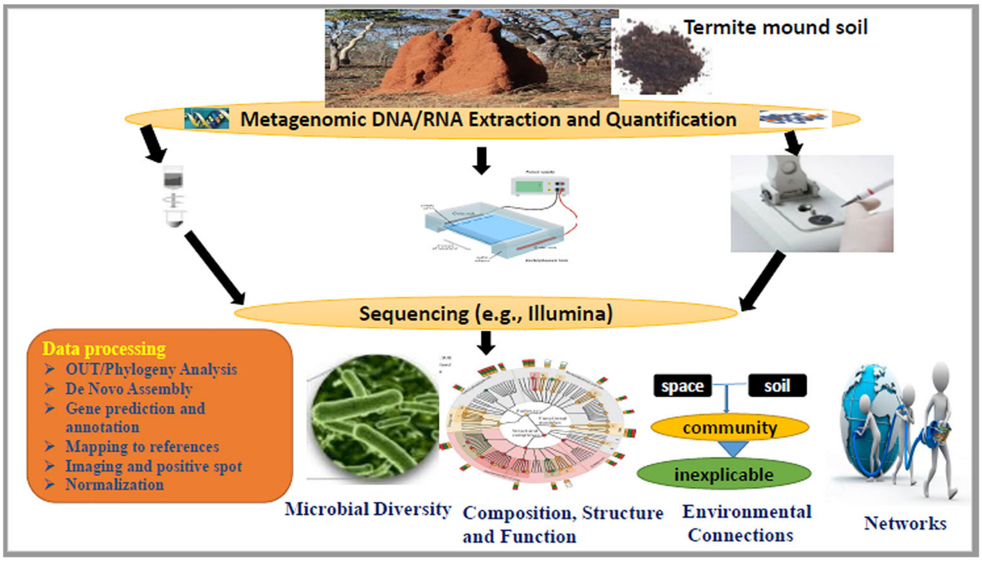

Fig. 1 Metagenomics method, sequencing-based open-format technologies, data processing, and analysis for comprehensive investigation of bacteria obtained from soil samples in termite mound

shown the diverse nature of bacteria in termite mound soil (Manjula et al. 2014). Kumar et al. (2018) reported that the bacteria population in both closed and open termite mound soil are higher than in normal soil. This high diversity of bacteria in termite mound soil could be as a result of the high amount of organic matter in the termite mound. Several researchers have reported the occurrence of *Bacteroidetes, Firmicutes,* Spirochaetes, *Chloroflexi, Nitrospirae, Planctomycetes, Proteobacteria, Tenericutes, Actinobacteria, Deinococcus-Thermus,* SM2F11, Candidate division TM7, *Verrucomicrobia, Fibrobacteres, Chlorobi, Elusimicrobia,* Candidate division WS3, *Acidobacteria*, *Synergistetes, Cyanobacteria,* WCHB1–60, *Chlamydiae*, and *Gemmatimonadetes* phyla in termite mound soil (Fall et al. 2007; Makonde et al. 2015; Manjula et al. 2016). Some strains of these bacterial phyla and their corresponding genes (Table 1) play a huge role in soil maintenance and this they do by hydrolyzing lignocellulose materials, recycling nutrients, and fighting against soil pathogens, which could increase crop yield (Manjula et al. 2016). From literature, it was observed that the type of termite that colonized the mound and the geographical location of the mound influence the kind of bacteria present in the termite mound soils (Table 2).

Underlying mechanism employed by some bacteria in termite mound soils in improving plant growth

Some bacteria such as *Achromobacter, Agrobacterium, Azotobacter, Bacillus, Burkholderia, Flavobacterium, Micrococcus, Pseudomonas*, and *Rhizobium* with numerous plant growth-promoting activity isolated from termite mound soils can support in tailoring of plant production as they instigate nutrient uptake, plant growth, and yield by a series of mechanisms (Istina et al. 2015; Chakdar et al. 2018). These mechanisms include direct solubilization of insoluble nutrients, production of growth hormones, fixating of nitrogen (Fig. 2), and through the production of lytic enzymes, siderophore, cyanides, fluorescent pigments, and antibiotics which help in alienating soil pathogenic organisms capable of affecting plants (Fig. 3) (Fuchs et al. 2001; Devi and Thakur 2018). Furthermore, these plants' growth-promoting bacteria produce indole acetic acid that regulates cell divisions, elongation, and differentiation (Khare and Arora 2010). Devi and Thakur (2018) reported that during laboratory experiment, of the 70 bacteria that belong to the genera *Bacillus* and *Alcaligens* isolated from termite mound soils 0.6–47.56 μg/mL of indole acetic acid was produced by 21 isolates, 9.27–65.48% SU of siderophores produced by 12 isolates, while 13 isolates produced ammonia in peptone broth and showed HCN production.

The role of bacteria in termite mound soil as biofertilizers

Soil fertility depends on the accessibility of stable nutrients in a form that plants can utilize (Gougoulias et al. 2014). The use of termite mound soil has been suggested as biofertilizers and inoculant in low-input cropping systems because it is rich in nutrients and plant growth-promoting bacteria (Dhembare and Pokale 2013; Menichetti et al. 2014; Deke et al. 2016). Local farmers in the plain areas of Laos and Northeast Thailand have started using termite mound soil for improving crop yield. This is because of the high cost of chemical fertilizers (Miyagawa et al. 2011; Bhardwaj et al. 2014). In areas with limited amount of mineral fertilizers, there is a need to use some bacteria from termite mound soil to increase the availability of minerals in soil (Chauhan et al. 2017; Nithyatharani and Kavitha 2018). This idea could be crucial in sustaining farming in such areas (Sánchez 2010). Termite mound soils

Table 1 Role of termite mound soil bacteria in improving soil fertility and plant growth

Bacteria	Mound	Effect on soil, crop growth, and pathogen	References
Fluorescent pseudomonads	*Macrotermes subhyalinus*	The inoculation of *Fluorescent pseudomonads* to sorghum plants significantly improved the shoot and total biomass of sorghum plants when compared to the control	Duponnois et al. (2006))
Bacillus endophyticus TSH42 and *Bacillus cereus* TSH77	Termitarium	They increased turmeric plant growth and production up to 18% in field trial when bacterized individually and in combined form in comparison to non-bacterized plants	Chauhan et al. (2017))
Flavobacterium	*Odontotermes obesus*	They have denitrification genes and carry out denitrification in soil	Sarkar (1991))
Thiobacillus and *Rhizobium*	Termitarium	They aid in nitrogen fixation therefore enhancing soil fertility	Manjula et al. (2014))
Chlorobi	*Macrotermes natalensis*, *Microtermes* sp., and *Odontotermes* sp.	They oxidize and reduce sulfur compounds for CO_2 fixation via the reverse tricarboxylic acid cycle and can perform N_2 fixation	Makonde et al. (2015))
Planctomycetes	*Cornitermes cumulans*	They oxidize ammonia to dinitrogen without oxygen and play a major part in nitrogen cycle	Costa et al. (2013))
Chloroflexi	*Cubitermes niokoloensis*	Their corresponding *nifH* genes are significant nitrogen fixer	Fall et al. (2007))

have been reported to contain phosphate-solubilizing bacteria population which through the production of organic acids, chelation and exchange reactions can mobilize vital nutritional elements in the soil by hydrolyzing both inorganic and organic phosphorus from soluble compounds (Chakdar et al. 2018). The ability of these phosphate-solubilizing bacteria to solubilize inorganic and organic phosphorus is seen as a significant feature for increasing soil fertility and their use as an inoculant concurrently increases plant P uptake and increase crop yield (Bama and Ravindran 2012). 2-Keto gluconic acid and gluconic acid (major organic acids for solubilization of phosphate) were produced by *Kosakonia, Bacillus*, and *Pantoea* isolated from termite mound soils (Chakdar et al. 2018). From an experiment, it was shown that after 24 h of incubation, strains of *Pantoea* isolated from termite mound soils solubilized tri-calcium phosphate to the tune of 1067.33 mg/L (while comparing it with the strains of *Pantoea* isolated from soils of Western Ghat forest, it only solubilized tri-calcium phosphate to the tune of 28 mg/L) (Dastager et al. 2009; Chakdar et al. 2018). Furthermore, when seeds were bacterized with *Pantoea* sp. A3 and *Kosakonia* sp. A37, it resulted in ~37% and ~53% increase in root length of tomato seedlings, respectively (Chakdar et al. 2018). *Bacillus cereus* TSH77 and *Bacillus endophyticus* TSH42 isolated from termite mound soils were used to bacterize the rhizome of *Curcuma longa.* Both strains showed remarkable plant growth-promoting (PGP) activities. This led to an increase in *Curcuma longa* growth and production by 18% when compared with non-bacterize *Curcuma longa* (Chauhan et al. 2017). This increase in plant growth and rhizome biomass was owned to the high production of the indole acetic acid (IAA), solubilization of phosphate, and production of siderophore by the bacteria. It is of importance to note that termite mound soils hold higher amount of phosphorus when compared to the surrounding soils (López-Hernández 2001). This is because of the highly efficient phosphate-solubilizing bacteria present in termite mound soils (Chakdar et al. 2018). *Pseudomonas fluorescens*—a well-known phosphate-solubilizing bacteria, was reported to dissolve rock phosphate in an experiment where termite mound soil were used as microbial inoculum to support *Acacia seyal* growth. From the result, it was observed that the leaves, height, and shoot biomass of *Acacia seyal* were better developed in the soil where termite mound soils were used as inoculant. They then concluded that termite mound soil could stimulate the growth of bacterial populations that can break down materials essential for plant growth (Duponnois et al. 2005).

Several researchers have identified bacteria phyla which are nitrogen fixers such as the *Chloroflexi, Cyanobacteria*, and *Proteobacteria* in termite mound soil (Ntambo et al. 2010; Makonde et al. 2015; Arumugam et al. 2016; Manjula et al. 2016). Strains of these phyla such as symbiotic diazotrophic bacteria belonging to *Chloroflexaceae, Methylocystaceae, Pseudomonadaceae, Enterobacteriaceae*, and their corresponding *nifH* genes are significant nitrogen fixers (Da Silva Fonseca et al. 2018). Nithyatharani and Kavitha (2018) successfully isolated four different bacteria species from termite mound soil and these bacteria contribute to soil fertility. They include *Citrobacter fruendii,* a nitrogen fixer; *Enterobacter* sp. which contribute to acetogenesis; *Paenibacillus* sp. which are capable of reducing sulfur molecules to a form which plants can utilize to enhance metabolism

Table 2 Bacteria reported present in termite mound soils and their corresponding surrounding soils

Country	Termite type	Bacteria present in termite mound soil	Bacteria present in surrounding soil	Reference
Kenya	*Macrotermes michaelseni*	*Proteobacteria*, Nitrospirae, Gemmatimonadetes, *Firmicutes*, *Fibrobacteres*, Cyanobacteria, Chloroflexi, *Bacteroidetes*, *Acidobacteria*, and *Actinobacteria*	Armatimonadetes, SM2F11, WCHB1–60 *Spirochaetes*, *Proteobacteria*, Planctomycetes, Nitrospirae, Gemmatimonadetes, *Firmicutes*, *Fibrobacteres*, Elusimicrobia, Cyanobacteria, Chloroflexi, Chlorobi, Candidate division WS3, *Bacteroidetes*, *Acidobacteria*, and *Actinobacteria*	Makonde et al. (2015))
Kenya	*Odontotermes* sp.	Candidate division, TM7, *Bacteroidetes*, Chlorobi, Candidate division WS3, *Acidobacteria*, *Actinobacteria*, Elusimicrobia, Planctomycetes, *Spirochaetes*	Armatimonadetes, SM2F11, WCHB1–60 *Spirochaetes*, *Proteobacteria*, Planctomycetes, Nitrospirae, Gemmatimonadetes, *Firmicutes*, *Fibrobacteres*, Elusimicrobia, Cyanobacteria, Chloroflexi, Chlorobi, Candidate division WS3, *Bacteroidetes*, *Acidobacteria*, and *Actinobacteria*	Makonde et al. (2015))
Senegal	*Cubitermes niokoloensis*	*Firmicutes*, *Actinobacteria*, *Chloroflexi*, and *Planctomycetes*	*Firmicutes*, *Alphaproteobacteria*, *Bacteroidetes*, *Chlorobi*, *Deltaproteobacteria*, and *Chloroflexi*	Fall et al. (2007))
India	Not specified	*Actinobacteria*, *Firmicutes*, *Chlorobi*, *Synergistetes*, *Bacteroidetes*, *Cyanobacteria*, *Deinococcus-Thermus,* *Proteobacteria*, and *Spirochaetes*	–	Manjula et al. (2014))
India	Not specified	*Nitrospirae*, *Chloroflexi*, *Bacteroidetes*, *Gemmatimonadetes*, *Tenericutes*, *Actinobacteria*, *Fibrobacteres*, *Deinococcus*, *Planctomycetes*, *Firmicutes*, *Chlamydiae*, *Proteobacteria*, *Acidobacteria*, and *Verrucomicrobia*	–	Manjula et al. (2016))
Thailand	Not specified	*Streptomyces*, *Amycolatopsis*, *Pseudonocardia*, *Micromonospora*, and *Nocardia*	–	Sujada et al. (2014))

and growth; and *Lactococcus* sp. Reasonable numbers of bacteria strains which exist in termite mound soil are capable of breaking down plant biomass polysaccharides (Koeck et al. 2014; Nithyatharani and Kavitha 2018), and they are also able to break down lignin and phenolic compounds (Bandounas et al. 2011). Paul and Varma (1993) and Sexana et al. (1993) reported the occurrence of *Bacillus* and *Cellulomonas* sp. in termite mound soil, and these bacteria are known for decomposing cellulose and xylan.

Termite mound soil was used as a soil amendment by Garba et al. (2011) in an attempt to evaluate the influence of termite mound soil on sandy soil physical parameters and on the growth characteristics of *Solanum lycopersicum* L. Their findings showed that soil mixed with termite mound material had larger clay size particles and higher organic carbon content than unamended soil. Furthermore, *Solanum lycopersicum* L. planted in amended soil had better plant height, an increase in leaf number, fruits, and dry matter when compared to *Solanum lycopersicum* L. grown on unamended soil. Combining sandy soil with termite mound materials at a proportion of 120 mg/ha improved the porosity and transformed the pore size distribution causing an increase in the obtainable water content for crop growth (Suzuki et al. 2007). The combined use of 200 g of termite mound material with NPK fertilizer led to a substantial increase in *Solatium melongena* production (Batalha et al. 1995). Watson (1977) planted perennial ryegrass on termite mound soil in pot experiments and reported that perennial ryegrass gave higher dry-matter yields with substrates derived from termite mound than the comparable soil. He then concluded that crop production can be increased by augmenting soil with termite mound materials.

The role of bacteria in termite mound soil as biocontrol

Plant rhizosphere is a very competitive region and occupied by many microorganisms because of the high nutrient availability extruded by mucilage and roots of plants (Chowdhury et al. 2015). The living and non-living factors in rhizosphere influence the growth of agricultural plants (Igiehon and

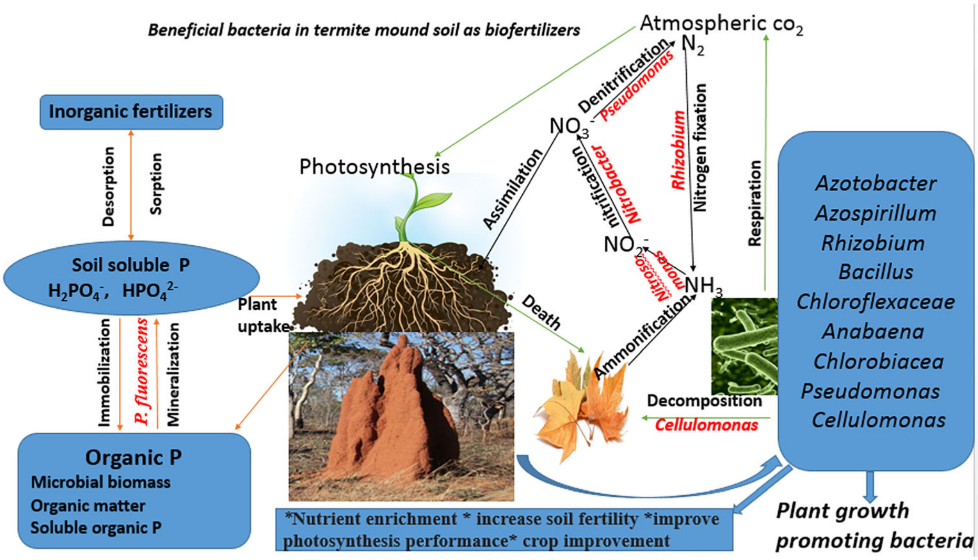

Fig. 2 Potiential use of bacteria in termite mound soil as biofertilizer in improving crop yield

Babalola 2018). Plants respond to their environment through their hormones like ethylene, gibberellin, cytokines, auxins, and abscisic acid (Alori et al. 2017). Some bacteria in the rhizosphere known as plant growth-promoting rhizobacteria influence the physiology of the plant to a large extent (Alori et al. 2017), and they can suppress soil borne plant pathogens through the stimulation of plant-induced systemic resistance and the production of nematicidal, antiviral, and antimicrobial substances (Doornbos et al. 2012). Plant growth-promoting bacteria are able to suppress pathogenic organisms by using the mechanism (Fig. 3) of producing siderophore, lytic enzymes, antibiotics, fluorescent pigments, and cyanides (Babalola 2010; Olanrewaju et al. 2017) or by consuming compounds which stimulate the pathogens and competing with the pathogens for nutrients (Berg 2009; Doornbos et al. 2012). For instance, *Pseudomonas fluorescens* WCS417 suppress flagellin triggered by immune responses through apoplastic exudation molecules of low molecular weight in *Arabidopsis thaliana.* This they do by the introduction of induced systemic resistance; thus, an immune signaling force is instigated systemically against a broad spectrum of disease-causing organisms (Millet et al. 2010; Berendsen et al. 2012).

Plant pathogens pose a prolonged threat to food production at a global scale (Devi et al. 2018). Synthetic agrochemicals are frequently used in protecting plants from disease-causing organisms. However, unselective application of the synthetic agrochemicals can cause numerous adverse effects on human and environmental health (Mahdi et al. 2010). Recently, microbial inoculants have been used as an ecologically friendly approach in suppressing or fighting plant pathogens (Ayitso et al. 2015). Termite mound material is seen as an ecologically friendly method for reducing inorganic fertilizers through biological activities, as they are loaded with microorganisms capable of suppressing soil borne plant pathogens and

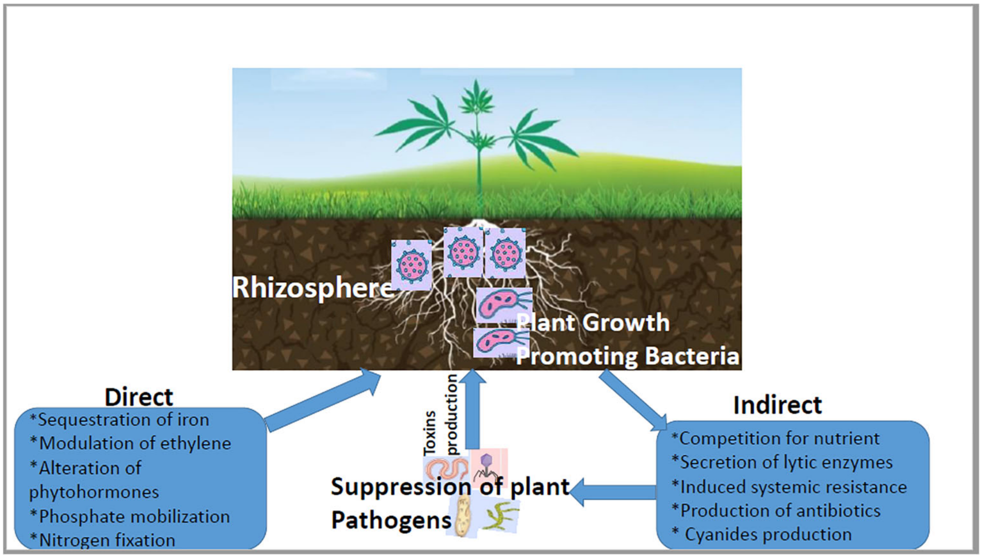

Fig. 3 Mechanisms used by plant growth-promoting bacteria to suppress plant pathogenic organisms

mobilizing vital nutritional elements in soil (Bama and Ravindran 2012; Devi et al. 2018). Chauhan et al. (2016) reported that *B. endophyticus* TSH42 and *B. cereus* TSH77 isolated from termite mound soil significantly slow down the growth of *Fusarium solani* (a plant pathogen causing rot disease in crops like potato). Investigation of the acidified cell-free culture filtrate using liquid chromatography–mass spectrometry showed that *B. cereus* TSH77 are made up of fengycin and surfactin while *B. endophyticus* TSH42 contained fengycin, surfactin, and iturin. The rhizome rot diseases in *Curcuma longa* L. were controlled, when treated with three strains of these bacteria. *Staphylococcus saprophyticus* and *Bacillus methylotrophicus* isolated from termite mound also showed antifungal activity against *Fusarium oxysporum*, *Alternaria brassicae*, *Rhizoctonia solani*, *Sclerotium rolfsii*, and *Colletotrichum truncatum* (Devi et al. 2018). Antimicrobial activity of *Streptomyces* sp. isolated from the termite mound material was tested against *Metarhizium anisopliae* (a fungal entomopathogen), and the occurrence of *Streptomyces* within the mound structure offered a substantial survival benefit to the termites when exposed to *M. anisopliae* (Chouvenc et al. 2013).

Concluding remarks and future directions

With the quest to produce more agricultural crops for the ever increasing human population, there is a need to accomplish that quest without compromising the safety of the environment or human health. As a result of the grave health and environmental problems associated with the use of chemical fertilizers and pesticides globally, there is a need for alternative safe measures. Termite mound soil contains useful bacteria that are capable of decomposing lignin and cellulose, fixing nitrogen, solubilizing phosphate, and suppressing plant soil pathogens. These have put them in a position to function as biofertilizers and biocontrol. For the future success of termite mound soil usage as biofertilizers and biocontrol, extensive research is still required to unveil their full potential.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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