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Biological Enrichment of *Hippophae rhamnoides* L. (Seabuckthorn) Through Microbial Interventions and Exploring the Probable Role of Plant Growth-Promoting Bacteria from Termite Mounds

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ABSTRACT

Seabuckthorn (Hippophae rhamnoides L.) is an economically significant shrub, renowned for its oil, containing over 100 bioactive compounds. Phytochemical studies have reported numerous constituents for biomedical applications having nutraceutical and therapeutic properties. However, oil content in the current cultivars is below optimal level. Traditional methods of breeding, employed to reach optimal level are resource-intensive and time-consuming. A sustainable alternative, organic farming has resurfaced with its integration with beneficial soil micro-fauna which provides an eco-friendly approach in enhancing crop quality and productivity conventional agricultural practices. Amidst these, Plant Growth-Promoting Bacteria (PGPB) is one promising option. PGPB enhance phytohormone production, nutrient uptake, and secondary metabolites by activating plant's natural immune response. Few bacteria have been explored in the rhizospheric soil of *Hippophae* sp. to enhance its metabolite production. This paper reviews researches done on the PGPB associated with *Hippophae* sp. and explores the novel idea of using termite mound or termite gut bacteria that could catalyse the production of bioactive content. Termites and their mounds foster a diverse and underexplored microbiota of PGPB which could promote production of phytohormones and act as a biocontrol agent against pathogens of *Hippophae* sp. The role of such microbes being used as bio-fertiliser in several plant species gives a new prospect in improving the livelihood of high-altitude farmers, simultaneously contributing to sustainable agricultural practices.

Keywords: *Hippophae*; Seabuckthorn; Termite; Plant growth-promoting bacteria

1. INTRODUCTION

Seabuckthorn (*Hippophae rhamnoides L.*) is a winter, deciduous shrub of Elaeagnaceae family which is native to Europe and Asia. It is a cold desert shrub found in the north western Himalayas at an altitude of 3200-5400m asl and is considered as eco-economic plant in China[1]. It is known for its high valued oils which contains more than 100 bioactive compounds of unsaturated fatty acids, flavonoids, sterols, vitamin C and E, carotenoids, omega-3,6,7 tocopherols, tocotrienols derivatives etc[2-3]. These bioactive compounds have significant effects in digestive problems, cardiovascular diseases, neural issues and cancer treatment[2]. The oil content in the seeds varies across different species and varieties. This makes it useful in nutraceutical, therapeutic and cosmeceutical properties and hence, it is also known as "plateau holy fruit"[3]. The global annual market requirement of oil is more than 1200 tonnes per year. This makes market of Seabuckthorn (hereafter referred as to as SBT) an emerging one as multi-nutritional food, nutraceutical and therapeutic drug. To overcome this gap between production and utilisation, increment of the oil content is the main aim of SBT breeding.

Researches are bent towards exploring the various aspects that can facilitate processes that could develop elite cultivars. Indulging in studying the genetic makeup is essential for this aspect. This mainly includes targeting anti-oxidant pathways to upregulate its bioactive compounds. However, these studies are time-consuming and resource intensive which makes it inefficient. Limited studies have been done with the rhizospheric bacteria having plant growth promoting properties that could naturally enhance the yield of bioactive content of the cultivar and help in combating pathogenic disease[4]. Exploring plant growth promoting bacteria for improving the quality of SBT is an eco-friendly and sustainable alternative. But the limitations of conventional breeding and genetic studies, has paved way of exploring biological approaches to enhance the cultivation of SBT. One underexplored

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avenue is application of Plant Growth-Promoting Bacteria (PGPB) associated with termites. There have been several studies done on the inoculation of PGPB isolated from rhizospheric soil. Termite associated PGPB are diverse, untapped and novel, unlike rhizospheric bacteria, which have been exploited quite a lot over the time. Moreover, termites are decomposers, of the organic matter in their habitation like microorganisms which naturally provides availability of the organic compounds in their simple forms.[5] Termites and their mounds harbours rich microbial diversity including PGPB that improve nutrient availability and uptake, phyto-hormone production, solubilisation of phosphate and other minerals and synthesis of secondary metabolites. These bacteria have shown good effects on the studied plants in which they were inoculated. Using these termite- associated bacteria is an eco-friendly, sustainable and promising strategy to enhance phytochemical yield and environmental resilience of SBT while maintaining its genetic fidelity.

This paper reviews the researches done on the plant growth promoting bacteria in *Hippophae* and explores prospects of deliberate introduction of termite associated PGPB to be used as bio-inoculants in SBT farming. It also attempts to evaluate interaction between insects, plant and micro-organisms.

2. PHYTOCHEMICAL PROFILE OF SEABUCKTHORN

All parts of SBT have bioactive compounds that includes vitamin A, C, E, K, carotenoids, flavonoids–isorhamnetic, quercetin, myricetin, kaempeferol, fatty acids, omega-3, 6, 7, organic acids- malic acid, ascorbic acid, oxalic acid, steroids e.g., ergosterol, stigma-sterol, lanosterols, amyrins, tannins. Carotenoids include carotene-lutein, β-cryptoxanthin and zeaxanthin and xanthophyll-lycopene, gamma-carotene and beta-carotene. Lycopene and beta-carotene are present in major amount. Vitamin E of SBT has α, β, γ, δ- tocopherol and tocotrienols derivatives[2,6]. Table 1 provides the list of bioactive compounds present in Seabuckthorn. α - tocopherol is the most abundant of all tocopherol and constitutes 70-80 % in soft parts, 40-50 % in seeds and 96 % in pulp oil[7]. Comparative study of SBT seed pulp and skin oil in different sub-species of SBT. Gas Chromatography technique showed higher constituent of unsaturated fatty acids (USFA; 70.2 %) than saturated fatty acids (SFA; 29.798 %). Maximum total to cotrienols was found in seed oil (290 mg in 100 gm) followed by skin oil (260 mg in 100 gm) and pulp oil (190 mg in 100 gm). However, α -tocopherol was found maximum in skin oil (120 mg in 100 gm), seed oil (100 mg in 100 gm) and pulp oil (80 mg in 100 gm).[7] Pulp oil had highest percentage of omega -7 FA (51.78 %) followed by skin oil (47.17 %). Seed oil had 41.5 % omega-6 FA and 22.42 % omega -3 FA[2]. However, this composition varied across different species and cultivars. Oil content in soft fruit tissue of *H. rhamnoides* ssp. *mongolica* Rousi was studied. It was observed that oil content is accumulated first in seed than fruit. Variability of oil content accumulated in SBT was also analysed. The average oil content in fruit has been found from 5.38 % to 34.15 % of dry weight and 3.5 % to 6.5% of wet weight in eight populations of SBT in sub-species *mongolica*. The wet weight was compared to that of sub-species population of Russia which was 1.6 % to 6.6 %. Average oil composition was found more in smaller fruit-3.7 % - 7.2 % of wet weight as compared to 2.4 % to 5.8 % in the bigger fruit[8]. This analysis pars with the previous literature studies of fruit size. For sub-species *mongolica*, oil content in soft tissue of fruit increases from the beginning of ripening and then declines from mid to end of August before it spikes to its maximum range in September to October. Oil content in seed gets constant after November. Oil content has been found 3.5 % subspecies *rhamnoides* than 2.1 % in sub-species *sinensis*. Oil content of 93.5 mg in 100 gm and 93.6 mg in 100 gm in pulp of *H. rhamnoides* ssp. *turkestancia*. But its seed oil constituted 144.1 mg in 100 gm of α- tocopherol stated the presence of 20 fatty acid (FA) from C14:1 - C24:1[9-10]. Physico-chemical characteristic analysis of pulp and seed oils in petroleum ether and n- hexane extract has showed that tocopherol (vitamin E) content was more in seed oils than pulp oils and that too highest in n- hexane extract than petroleum ether. Tocopherol content in petroleum ether extract of seed oil was 186±2.5 mg in 100 gm and in n- hexane was 196 ± 3.9 mg in 100 gm. However, in pulp oil, tocopherol content in petroleum ether extract was 147 ± 1.7 mg in 100 gm and n- hexane extract was 158 ± 2.2 mg in 100 gm.[11] Plant age and starch accumulation also effects the oil content in plants. Plants of nine to twelve years of age have higher oil accumulation except for the Bulgangol population which is above 13 years of age[8]. Delving into phytochemistry of SBT gives practical reasons for applications and need for its diversity in day to day life. These compounds make it a multipurpose plant with nutraceutical, therapeutic, anti-microbial, anti-oxidant, and cosmeceutical properties.

SBT has been used in the traditional medicine of South Asian countries for lung and skin ailments[12]. Carotenoids and tocopherol are anti-oxidants that neutralises reactive oxygen species and prevent lipid peroxidation[13-14]. These tocopherols and their derivatives are better because they get penetrated rapidly in the stratum corneum of the skin and do faster free radical neutralisation. Tocopherols and tocotrienols are preferred because of their quicker penetration in the skin and faster neutralisation of free radicals[2]. They prevent damage to the cell and other organic compounds- proteins, nucleic acid and lipid of the body which could cause diseases. They play role in inhibiting the lipid peroxidation that plays role in initiating several neuro-degeneratory, Coronary Artery Disease (CAD) etc. There exists a linear co-relation between the total phenolic content and anti-oxidant content isolated from the berries of *H. rhamnoides* L.[6]. Polyphenols from ether extracts of leaves and waste products from the post-harvest treatment of SBT consists of 5 % berries. These berries are anti-hyperintensive and effective in treatment of stomach ulcer, skin burns and interferon induction activity[15]. Oils have shown significant effects in cancer treatments[3], tumour and cardiovascular diseases, digestive issues. Leaves of the plant are efficient in treating burns, cardiac disorders, eczema and radiation injury[16]. SBT leaves are novel source for the production of wide spectrum anti-viral phytochemical drug Hiporamin. This drug has anti-viral activity against pathogenic issues in humans, animals and even plants[17-18]. Oil of its seeds and fruits have been used in the skin and digestive disorders for both humans and animals.

Several studies of biomedical research have been done studying and understanding the therapeutic efficacy of SBT oil in humans and animals. A study has been conducted on mongrel dogs to compare the efficacy of SBT seed oil with misoprostol and sucralfate in Gastric Ulcer & Erosion (GUE). Dogs which were treated with sucralfate in combination with SBT oil (1g + 1ml) healed in 8.25 days followed by 9.75 days in combination treatment of misoprostol and SBT oil.[19] Another study was conducted on nine weeks inbred male Swiss albino mice for 30 days to study the effects of SBT leaf extract (SBL-1). A dose of SBL-1 as 30 mg per kg of body weight was given to the mice half an hour before lethal dose of ^{60}Co-γ- irradiation (10Gy). Their tissue histology showed a significant decrease in villi number, height, crypts, cellularity apoptotic cells and cryptal paneth cells in the jejunum of mice as compared to the affected mice[20]. Healing activity of SBT is found better than silver sulfadiazine. It decreased the stress levels of biomarkers and enhanced hypoxic tolerance in animals indicating its anti-stress adpatogenic activity. Topical ointment with SBT extract has healing properties in repair of chronic wounds[21]. Anti-diabetic and anti-oxidant effect of SBT was studied in streptozotocin-nicotinamide induced type-2 diabetic rats. SBT was orally administered in rats. Induced rats in histopathological examination showed significant reduction in blood glucose levels and Thiobarbituric Acid Reactive substances (TBARS) levels[22]. Evaluation of adpatogenic activity of aqueous extract of *Hippophae salicifolia* (Aq-HS) was observed and studied in muscle and heart samples. Muscle samples showed 47 % increase in the Reactive Oxygen Species (ROS) in multiple stress condition. Administering Aq-HS showed 21 % decrease in the ROS and 36 % reduction in superoxide dismutase

Tablr 1. List of bioactive compounds in Seabuckthorn

S. No.	Bioactive compounds		Composition
1.	Vitamins	Vitamin A	
		Vitamin C	
		Vitamin E (tocopherols and tocotrienols)	70-80% in soft parts, 40-50% in seeds and 96% in pulp oil
		Vitamin K	
2.	Carotenoids	Lutein	
		B-cryptoxanthin	
		Zeaxanthin	
3.	Xanthophylls	Lycopene	
		γ-carotene	
		β-carotene	
4.	Flavonoids	Isorhamnetic	
		Quercetin	
		Myricetin	
		Kaempeferol	
5.	Fatty acids	Omega-3	22.42% in seed oil
		Omega-6	41.5% in Seed oil
		Omega-7	51.78% in Seed oil
6.	Organic acids	Malic acid	
		Ascorbic acid	
		Oxalic acid	
		Ergosterol	
7.	Steroids	Stigma-sterol	
		Lanosterols	

(SOD) levels. Simultaneously, heart samples showed 46 % increase in ROS and 79 % increase in SOD levels in the exposed control rats. ROS was reduced by 5 % and SOD levels were reduced by 33 % in exposed control rats. These results show its potential as nutraceutical drug.

3. LIMITATIONS OF TRADITIONAL APPROACHES

SBT is an actinorhizal plant that has symbiotic association with the nitrogen-fixing actinobacteria *Frankia* in its root nodules. It is capable of fixing 45 kg of nitrogen in a hectare of land. This number is twice the amount fixed by the leguminous soyabean plant.[23] It increases the composition and availability of nitrogen, potassium, phosphorus and other organic elements establishing its ecological significance in the high altitude regions. Excellent nitrogen fixing property of SBT and presence of an extensive root system that improves it binding to the soil and in better absorption of nutrients and in increasing the quality of the soil in Hilly areas sustaining other flora. Consequently, this affects the oil content in the plant. Seeds have 7-10 % and fresh pulp has 1-5 % of oil content[3]. Despite all these, its cultivation is often being challenged by altitudinal variations, extreme climatic conditions of extreme snow and frost along with accelerated soil erosion, landslide, and limited agronomic inputs in the tough topography of Himalayas and low yield of oil in the seeds with 7-10 % and 1-5 % oil from the pulp of the fruit. All these factors make it difficult for the plant to thrive, affecting the content of bioactive compounds.

The aim is to combine traits of resistance to harsh weather condition with fruit quality and other desired factors of absence of thorns, low mortality in winters due to snow and frost tolerance. However, combining all these traits in a single cross makes the breeding process complex[23]. Conducting hybridisation experiments on SBT varieties have shown that maternal plant and seed size influence the hybridisation process. There has been no significant genetic effect on traits of thorniness, number of lateral shoots, and stem straightness. Further, open-pollinated progenies do not give precise estimation of genetic parameters and recommended controlled crosses for accurate analysis. Furthermore, emphasis has to be made on the need for doing more comprehensive hybridisation studies to obtain reliable genetic parameter estimates. This clearly states that until precise genetic parameters are established, effective breeding strategies for SBT will remain limited.

Traditional agriculture system involves the use of the chemicals based products which increases degradation of the ecosystem. Relying on biological additives such as compost, green manure, bio-inoculants, bio fertilisers, crop rotation and pest management is healthy alternative to sustain the biodiversity and avoid any unintentional disruption of the ecosystem. With all this in consideration, organic systems performs better than conventional farming practices because of reduced chemical load that allows microbes to thrive. Further presence of rich microbial biodiversity improves the secondary metabolite levels of phenolic and anti-oxidants, improving the plant-microbe interactions[24].

4. ROLE OF PGPB IN SBT IMPROVEMENT

Production of secondary metabolites in plant is attributed to its immune response, which often gets triggered by the influence of microflora of the plant, including bacteria. Plants detect receptors like bacterial flagella by their Pathogen Recognition Receptors (PRR), and activate Pathogen-Associated Molecular Pattern Triggered Immunity (PTI). After pathogen recognition, plants transduce signal via Ca^{2+} influx, production of ROS, H_2O_2, NO, and activation of Mitogen Activated Protein Kinase (MAPKs) which trigger transcription of defence related genes. After this, the plant deploys immediate local defences, which includes secondary metabolites like flavonoids, lignin, phyto-alexins, etc. Secondary metabolites like salicylic acid trigger Systemic Acquired Resistance (SAR), which prepares uninfected tissues for immune response. The uninfected tissues resist infection by producing more protective compounds including secondary metabolites[25].

Organic farming is one of the key components of resilient farming systems, which contributes to long-term agricultural viability, which is an eco-friendly alternative to increase the quality of crop. In this regard, integrating micro-organisms can help in improving the bioactive composition while simultaneously improving the livelihood of the farmers. Microbial diversity benefits the soil in combating root and soil borne pathogens, accelerated decomposition of the organic matter, nutrient content etc. Further, rich microbial diversity harbours richer and stable microbiome to ensure crop vigour and improving the productivity of the crop[26]. Plant-microbe interactions, symbiotic relationships (such as rhizobacteria and Arbuscular Mycorrhizal Fungi (AMF) in organic farming practices helps plants in combating pathogenic microbes more naturally and creating effortless adaptations in plants at phenotypic and genotypic levels. This aids in improving the genetic quality of the species naturally.

PGPB offer a sustainable and eco-friendly approach to enhance growth and productivity of desired plants. These beneficial microbes can improve nutrient uptake, fix atmospheric nitrogen, solubilize phosphates, produce phytohormones, and enhance stress tolerance. PGPB also play a role in suppressing phytopathogens through siderophore production and Induced Systemic Resistance (ISR). Phytohormones such as gibberellins, Indole-3-acetic acid (IAA) and cytokinins enhance the signalling pathways and regulate growth and development of plant[27]. These bacteria regulate the expression of 1-aminocyclopropane-1-carboxylate (ACC) deaminase which reduces ethylene levels to alleviate stress in plants. Siderophore production helps in the chelation and transport of iron into plant cells and constrain any growth

Table 2. List of mechanism of PGPB

S. No.	Mechanism	Description	Example Organisms / Strains	Reference
		Direct Mechanisms		
1.	Biological Nitrogen Fixation	Conversion of atmospheric N_2 to ammonia via nitrogenase enzyme, providing nitrogen to plants.	*Azotobacter chroococcum CL13*, *Rhizobium pusense*	Chandran[32], *et al*
2.	Phosphate Solubilisation	Solubilisation of inorganic phosphate into plant-available forms via organic acids and phosphatases.	*Bacillus safensis*, *Pseudomonas plecoglossicida*, *Bacillus cereus*, *Azotobacter*	Dinesh[33], *et al*; Jagtap[34], *et al*
3.	Siderophore Production	Chelation of Fe^{3+} to form soluble iron complexes, enhancing iron availability to plants and reducing pathogen access to iron.	*Bacillus cereus*, *Pseudomonas aeruginosa*, *P. fluorescens*	Vinayarani[35], *et al*
4.	Zinc Mobilisation	Solubilisation of zinc via organic acids and chelators.	*Pseudomonas plecoglossicida*, *Enterobacter hormaechei*	Jagtap[34], *et al*; Dhondge[36], *et al*
5.	IAA (Indole Acetic Acid) Production	Promotes root elongation and branching, enhancing nutrient absorption.	*Kocuria turfanensis*, *Bacillus thuringiensis*, *Pseudomonas fluorescens*, *Klebsiella sp.*	Goswami[37], *et al*
6.	Cytokinin & Gibberellin Production	Promotes shoot growth, chlorophyll biosynthesis, and flowering.	*Agrobacterium*, *Pseudomonas*, *Bacillus sp*, *Herbaspirillum*, *Azospirillum*	Tsukanova[38], *et al*
		Indirect Mechanisms		
7.	ACC Deaminase Production	Degrades ethylene precursor ACC, reducing stress ethylene levels in plants under abiotic and biotic stress.	*Pseudomonas sp*., *Pseudomonas oryzihabitans*, *Burkholderia gladioli*	Pandey & Gupta[39], Mellidou[40], *et al*
8.	Antibiotic Production (Antibiosis)	Inhibits phytopathogens through the production of antimicrobial compounds.	*Bacillus cereus* (zwittermicin), *Pseudomonas sp* (phenazine, DAPG), *Streptomyces sp*, *Serratia sp*.	Gross & Loper[41]
9.	Synthesis of Lytic Enzymes	Produces enzymes like chitinase, β-1,3-glucanase, protease, and cellulase to degrade fungal cell walls.	*Serratia marcescens*, *Paenibacillus spp*., *Streptomyces spp*., *Pseudomonas fluorescens*	Karthika[42], *et al*; Compant[43], *et al*
10.	Induced Systemic Resistance (ISR)	Activates plant defense mechanisms through signaling pathways involving salicylic acid, jasmonic acid, or ethylene.	*Pseudomonas aeruginosa*, *Bacillus subtilis*, *Azospirillum sp*, *Serratia sp*	Vinayarani[35], *et al*
11.	Biocontrol of soil-borne pathogens	Suppresses diseases like rhizome rot and leaf blight through antagonism and ISR.	*Pseudomonas aeruginosa*, *Bacillus safensis*, *Trichoderma asperellum*, *Pseudomonas plecoglossicida*	Praveena[44], *et al*
12.	Abiotic Stress Resistance	Enhances plant tolerance to drought, salinity, and heavy metals via antioxidant compounds, IAA, siderophores, and biofilm formation.	*Bacillus velezensis*, *Bacillus cereus*, *Pseudomonas aeruginosa*, *Burkholderia gladioli*	Abd El-Daim[45], *et al*; Mukhtar[46], *et al*

of any pathogen[28]. For an instance, PGPB like, *Bacillus velezensis* releases Volatile Organic Compounds (VOCs) and cyclic lipopeptides that promote Induced Systemic Resistance (ISR) and inhibit pathogenic bacteria in plants aiding to their defence mechanism and secondary metabolite production[29-30] (Refer Table 2). PGPB increases production and accumulation of secondary metabolites in plants which further enhance the resilience of plants to abiotic factors. These functions of PGPB also helps in exploiting the secondary metabolites of the plants for the use by mankind. Introduction of bacteria will eventually augment the biomass and growth of plant. Research done on the bacteria isolated from the Trans-Himalayan region showed their resistance and resilience to the abiotic stresses that are prevalent in the colder regions and simultaneously contributing to the growth and development of *Hippophae rhamnoides*. They have shown good siderophore activity, IAA production and increase phosphate solubilisation. They show promising results as bio-inoculant in the ecosystem. There have been limited studies reported in PGPB isolated from rhizospheric soil of *Hippophae*. Phosphate-solubilizing bacteria has been isolated and it possessed high level of IAA and siderophore production potential[31].

Formulation of a carrier based good bio fertiliser that can maintain the viability of microbes and is effective in stress tolerance, nutrient solubilisation and can maintain the viability of microbes is a good option. Integration of PGPB in the formulation can increase resilience of the soil ecosystem and nutrient cycling. Since, PGPB increase the morphological parameters of the plant. We can expect increase in size of fruit and yield due to availability of nutrients and its uptake, improved phytochemical content due to plant- microbe interactions. Integrating termite-associated PGPB in the organic farming practice will can boost the resilience of soil ecosystem in degraded terrains of the Himalayas.

Though limited studies have explored their application in SBT, the introduction of PGPB especially those isolated from unique ecological niches such as termite mounds holds great potential in improving plant vigor, yield, and bioactive compound accumulation. Further research and field validation are essential to harness the full potential of PGPB in SBT cultivation systems.

5. TERMITE MOUNDS AS NOVEL MICROBIAL RESERVOIRS

Termites and their mounds harbours a variety of microbial diversity. Fig. 1 show Schematic illustration showing the relationship between termite and their mounds, microbial diversity, Plant growth-promotion in Seabuckthorn bioactive enhancement. Multifaceted functions provided by them as ecosystem services such as improving soil porosity, aeration and cation exchange capacity which alters the chemical properties of the soil increases the productivity of the ecosystem. Their endo-symbiotic relationship helps them break down hard organic compounds into simple elements in their residing soil. Ingestion of organic material and mixing of their saliva in the ingested material breaks down the matter into simpler substances increasing the availability of nutrients (carbon, hydrogen, nitrogen, phosphorus) in the soil. This increases the nutrient recycling of the soil promoting plant growth. Their mimicking of tilling promotes colonisation and sustenance of microbes in the soil improving the physico-chemical property of the soil[47]. Bacteria isolated from the termites and mounds have root and soil borne pathogenic potential. Several studies have shown exogenous application of isolated micro-organisms in plant growth promotion, accumulation of secondary metabolites and act as biocontrol agents. Therefore, use of such microbes as bio-fertiliser and bio-pesticide can be a good alternative for improving the resilience and resistance of the ecosystem. Termite and their habituating mounds sustains PGPB that produces phytohormones-Indole-3-Acetic Acid (IAA), siderophore, nitrogen fixing (nif) genes etc[48-49].

SBT is susceptible to disease such as Fusarium wilt and powdery mildew[50]. Bacterial strain isolated from the termite mound have shown antagonistic activity against Fusarium wilt in cucumber[51]. This demonstrates their potential application as biocontrol in SBT faming as well. Significant augmentation has been observed in length and dry weight of root and shoot, and biomass of plants by *Bacillus subtilis*. Interestingly, many bacteria isolated from the termitarium soil are *Bacillus* species.

PGPB are reported as contributing factor in augmentation of various bioactive compounds of many medicinal plants. For example, inoculation of rhizospheric bacteria like, *Bacillus tequilensis* increased the quantity of sterols and polysaccharides in *Rehmannia glutinosa* (Chinese Foxglove). While inoculation of *Bacillus subtilis* in the rhizosphere of *Chamomilla recutita* (Chamomile) increased the content of flavonoids in the plant[26]. Similarly, consortium of various bacteria including *Bacillus* sp. increased flavonoid content in *Curcuma longa* (Turmeric)[27]. Interestingly, *Bacillus* sp. has been isolated from termite and, sterols and polysaccharides are the group of major bioactive compounds reported in SBT (Refer Table 1). Hence, there is a potential of PGPB isolated from termite in augmentation of bioactive compounds of SBT as a bio-fertiliser.

Termite-associated microbes are good option in improving the quality of soil in the high-altitude regions which have poor organic content, pathogen suppression, bioactive enhancement, and unfavourable abiotic factors such as cold tolerance. These studies suggest that termite mounds are an understudied niche which offers a rich pool of microbiota. Its integration in the SBT cultivation can boost the profile of its bioactive compounds and provide a domain wide insights in contributing to a resilient, eco-friendly agroecosystem.

The table 3 represents the details of some studies that have shown plant growth promoting potential of termite associated bacteria.

Table 3. PGPB isolated from termite and termitarium soil

S. No.	Source	Bacterial strain	Property	Reference
1.	Termitarium soil	*Bacillus siamensis* YC-9	Antagonistic activity against cucumber *Fusarium* wilt caused by Fusarium oxysporum f. sp. cucumerinum (FOC). It suppressed disease incidence with 73.2% efficacy and increased its growth efficiency. Induced systemic resistance in roots by upregulating disease resistance enzymes- peroxidase (POD), polyphenol oxidase (PPO), and phenylalanine ammonia-lyase (PAL).	Zhou[50], *et al*
2.	Termitarium soil	*Pantonea* sp. A3, A34, *Kosakonia* sp. A37, B7 and *Bacillus* sp. AH9	Seed bacterisation with *Pantoea* sp. A3 and *Kosakonia* sp. A37 enhanced tomato seedling growth, 37% and 53% increases in root length, respectively.	Chakdar[51], *et al*
3.	Termitarium soil	*B. endophyticus* TSH42, *B. cereus* TSH77	Turmeric production increased upto 18% field trials, HPLC showed 13.6% increase in curcumin content.	Chauhan[52], *et al*
4.	Termitarium soil	*B. endophyticus* TSH42, *B. cereus* TSH77	Showed antagonistic potential against *Fusarium solani* causing Rhizome rot of turmeric and reduced disease incidence in plant. LC-MS analysis confirmed the presence of antifungal lipopeptides-surfactin and fengycin in both strains, with TSH42 additionally producing iturin.	Chauhan[53], *et al*
5.	Termitarium soil	-	Synergistic effect of termitarium soil when combined with sandy soil increased the water consumption efficiency in *Solanum lycopersicum.* It enhanced the growth and yield of the plant by better moisture rentention and utilisation.	Garba[54], *et al*
6.	Termitarium soil	-	Improved growth of *Oryza sativa* due to increase pH of soil with water consumption efficiency acting as fertility hotspot and improved physical chemical properties	Miyagawa[55], *et al*
7.	Termitarium soil	*Trinervieus trinervoides* and *Odontotermes*	Tripartite application of isolates with urea and superphosphate improved maize height to 78.32 cm, leaf area to 159.2 cm^2, dry matter to 123.67 g, and chlorophyll content to 2.10 mg/g. It increased *Azotobacter* (3.12×10^3 CFU/g) and dehydrogenase activity (6.44 µg TPF g^{-1} d^{-1}).	Bama & Ravindran[56]
8.	Termitarium soil	*Staphylococcus saprophyticus*, *Bacillus methylotrophicus* and *Bacillus* sp.	Anti-fungal activity against pathogens - *Sclerotiumrolfsii*, *Alternaria* sp., *Colletotrichumtruncatum*, *Rhizoctonia solani* and *Fusarium oxysporum was* observed.	Devi[57], *et al*

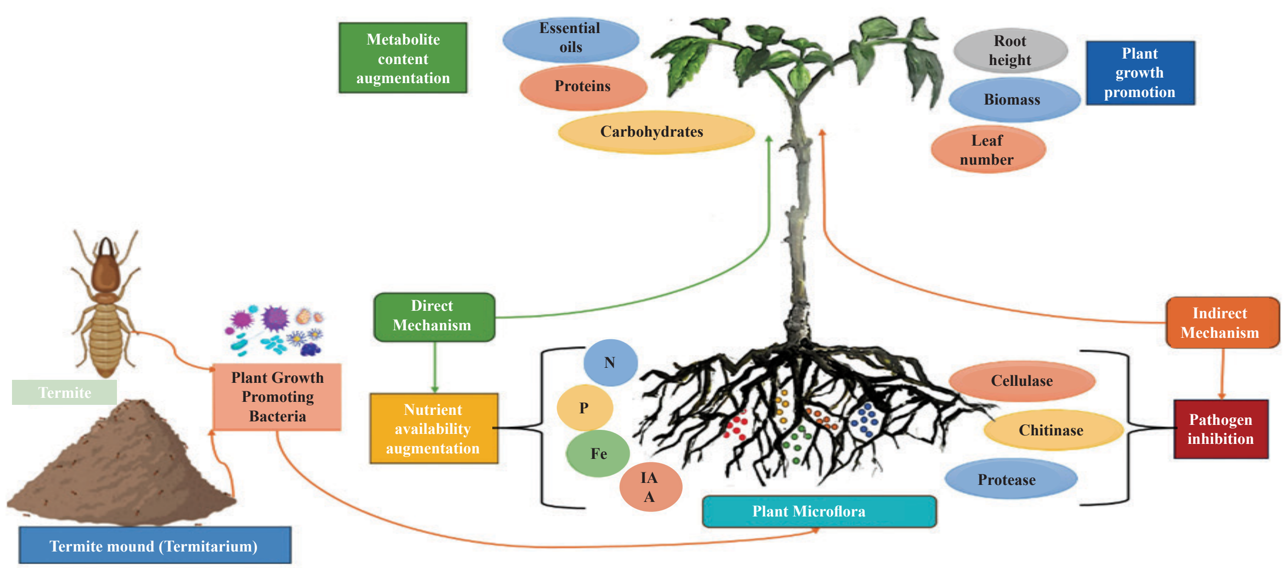

Figure 1. Schematic illustration showing the relationship between termite and their mounds, microbial diversity, Plant growth-promotion in Seabuckthorn bioactive enhancement.

6. FUTURE DIRECTIONS AND RESEARCH GAPS

SBT being capable of establishing itself in harsh conditions where nutrients are deficient. In these conditions microbial support can be crucial for its growth enhancement and secondary metabolite production. These PGPR are capable of upgrading nutrient uptake and can be a sustainable approach for complementing nitrogen fixing capability and nutrient solubilisation of phosphorus, zinc, potassium, production of phytohormones in SBT. The use of synthetic fertilisers helps in plant growth but causes a negative impact on edible fruits and soil physiology as well as microflora. More reliable and eco-friendly method such as using bio-fertiliser over the usage of synthetic chemicals for plant improvement aids in sustainability approach. Termite being an inhabitant of enriched microbial diversity is a source of several undiscovered PGPR which can be isolated from termite gut and termite mound soil, can be used as a bio-inoculum in SBT for enhancing the adaptability of *Hippophae* in harsh conditions and accumulation of more bioactive compounds. The study can give rise to some novel findings and could establish a foundation among microbial-insect-plant interaction which can be potentially impactful. The rhizospheric biota can be employed for the betterment of environment health and sustainable solution in agriculture productivity. Further much more studies such as metagenomics, CRISPR/Cas, NGS can be used for non-culturable microbes for better studies.

7. CONCLUSION

Plant growth promoting bacteria increases the acquisition of the essential nutrients in soluble and available forms for easy absorption by the plants e.g., phosphates through organic compounds, nitrogen through nitrogenase enzymes, potassium etc. this results in nutrient enriched soil and thus better crop yield. Integration of micro-organisms in the conventional farming practices might be a new phase in the farming of this low maintenance crop. Using microbes in the cultivation of SBT is a promising option in improving its productivity. Exploring the bacterial symbionts will help in continuing low maintenance farming practices done on SBT while strengthening the mountain farmers to rely on the traditional farming and make livelihood out of it. This will emphasise both economic and commercial advantage of crop. Ecological benefits of SBT agriculture can strengthen the the mountain farmers to rely on the traditional farming and make livelihood out of it. Future researches should aim at exploring microbial interventions in organic practices to make it an economically viable crop.

REFERENCES

1. Li G, Du S, Guo KE. Evaluation of limiting climatic factors and simulation of a climatically suitable habitat for Chinese Seabuckthorn. PloS One. 10(7);e0131659:2015.
2. Acharya D, Joshi P, Srikanth CK, Menon V, Paul J. Seabuckthorn -a rich source of bioactive tocopherols and tocotrienols. In proceedings of the 7th conference of the International Seabuckthorn association on Seabuckthorn: Emerging Technologies for Health Protection and Environmental Conservation, NASC Complex, New Delhi, India. 2015.
3. Zhao Y, Ruan C.-J, Li Y, Ding GJ. Rumpunen K. Dynamics of oil content in dry pulp of Seabuckthorn berries in half-sib family and different berry ripe period. In Proceedings of the 7th conference of the International Seabuckthorn association on Seabuckthorn: Emerging Technologies for Health Protection and Environmental Conservation, NASC Complex, New Delhi, India. 2015.
4. Khan S, Ambika Rani K, Sharma S, Kumar A, Singh S, Singh Y. Rhizobacterial mediated interactions in curcuma longa for plant growth and enhanced crop productivity: A systematic review. Frontiers in Plant Science, 14, 1231676. 2023.
5. Bignell DE, Eggleton P. Termites in ecosystems. In termites: Evolution, sociality, symbioses, ecology, edited by T. Abe DE, Bignell & M. Higashi. Springer Netherlands, 2000. pp. 363–387.
6. Anjum N, Tripathi YC. Flavonoid constituents, total polyphenol and antioxidant efficacy of Hippophae rhamnoides L. berries. In proceedings of the 7th conference of the International Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015.
7. Kallio H, Yang B, Peippo P. Effects of different origins and harvesting time on vitamin C, tocopherols, and tocotrienols in Seabuckthorn (Hippophaë rhamnoides) berries. J of Agricultural and Food Chemistry. 2002;50(21):6136-6142.
8. Enkhtuul TS,Tsendeekhuu TS. A study on geographical variation of features of Hippophae rhamnoides L. spp. mongolica rousi in mongolia. In proceedings of the 7th conference of the International Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015.
9. Rongsen L. The correlation between Seabuckthorn berry quality and altitudes of its growing location. In Seabuckthorn association conference. 2007.
10. Venugopalan VV, Ranjith A, Sarinkumar K, Arumughan C. A green technology for the integrated processing of fresh Seabuckthorn berries. 2006.
11. Barik CR, Sahoo L, Goud VV. Physico-chemical characterisation of pulp and seed oils of Seabuckthorn (Hippophae salicifolia D. Don) from Tawang district of Arunachal pradesh, North-Eastern India. In proceedings of the 7th conference of the International Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015. .
12. Ahani H, Attaran S. Therapeutic potential of

Seabuckthorn (Hippophae rhamnoides L.) in medical sciences. Cellular, molecular and biomedical reports. 2022;2(1):22-32.

13. Ranjith A, Kumar KS, Venugopalan VV, Arumughan C, Sawhney R.C, Singh V. Fatty acids, tocols, and carotenoids in pulp oil of three Seabuckthorn species (Hippophae rhamnoides, H. salicifolia, and H. tibetana) grown in the Indian himalayas. J of the Am Oil Chemists' Society. 2006;83(4):359-364.
14. Parimelazhagan T, Chaurasia OP, Ahmed Z. Seabuckthorn: Oil with promising medicinal value. Current Science. 2005;88(1):8-9.
15. Pomerantseva TY, Rysbaeva DD. Avakumov VM. Reparation activity of definite fraction, isolated from fruits and leaves of Seabuckthorn. Biology, chemistry, introduction and breeding of Seabuckthorn. Transactions of Gorky Agricultural Institute. 1986 (Russian).
16. Sharma P, Suryakumar G, Ganju L, Mishra K. Future prospects of Hippophae salicifolia as a nutraceutical drug. In proceedings of the 7th conference of the International Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015. .
17. Shipulina LD, Sheichenko OP, Sheichenko VI, Tolkachev ON, Morozov VI, Bykov VA. Seabuckthorn study as the source for production of antiviral drug Hiporam. 2008.
18. Sheichenko OP, Tolkachev ON, Shipulina LD, Krepkova LV, Vichkanova SA, Mineeva MF, Bykov VA. Seabuckthorn (Hippophae L.) A Multipurpose Wonder Plant. 2014.
19. Thakur D, Tyagi SP, Kumar A, Gupta S, Singh V. The comparative therapeutic efficacy of the combination of Seabuckthorn seed oil and misoprostol or sucralfate in gastric ulcer and erosion in dogs. In proceedings of the 7th conference of the international Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015.
20. Bala M, Gupta M, Beniwal CS, Abdin MZ, Prasad J. Seabuckthorn leaf extract counters jejunum pathology in whole body ^{60}Co-gamma-irradiated mice-a study on tissue histology and microbiota towards development of safe and non-toxic radiation countermeasure. In proceedings of the 7th conference of the international Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015.
21. Gupta A, Keshri GK. Wound healing and anti-stress prospective of Seabuckthorn (*Hippophae rhamnoides L.*). In proceedings of the 7th conference of the international Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015.
22. Sharma M, Akhter MS, Shukla G, Pillai KK, Jairajpuri ZS. Protective effect of Seabuckthorn (*Hippophae rhamnoides L.*) in STZ-induced lipid peroxidation and β-cell damage in rat pancreas. In proceedings of the 7th conference of the international Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015.
23. Demidova N, Eriksson G, Lundkvist K. Genetic variation in growth characteristics of Hippophae rhamnoides L. grown in controlled conditions. In proceedings of the 7th conference of the international Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015.
24. Mäder P, Fliessbach A, Dubois D, Gunst L, Fried P, Niggli U. Soil fertility and biodiversity in organic farming. Science. 2002;296(5573):1694-1697.
25. Dangl JL, Jones JD. Plant pathogens, integrated defence responses to infection. Nature. 2001;411:826-833. doi:10.1038/35081161 (accessed on 14 June 2025). 6839.
26. Negi S, Pathak D, Kushwaha D, Sharma A, Khan S, Agarwal U, *et al.* Role of rhizospheric microflora in medicinal plants metabolite production." In genetic improvement and conservation practices of medicinal plants. pp. 242-263. CRC Press. 2025.
27. Khan S, Negi N, Pal A, Rana D, Thaplyal M, Thapliyal A, Agarwal U, Singh Y. Preliminary isolation and biochemical characterisation of plant growth promoting rhizobacteria from Curcuma longa from the high-altitude region of Uttarakhand. Environ Conserv J. 2025;26(1):45-51. doi: 10.36953/ECJ.2025.26106
28. Vaghela N, Gohel S. Medicinal plant-associated rhizobacteria enhance the production of pharmaceutically important bioactive compounds under abiotic stress conditions. J of Basic Microbiology. 2023;63(3-4):308-325.
29. Borriss R, Wu H, Gao X. Secondary metabolites of the plant growth promoting model rhizobacterium Bacillus velezensis FZB42 are involved in direct suppression of plant pathogens and in stimulation of plant-induced systemic resistance. Secondary metabolites of plant growth promoting rhizomicroorganisms: Discovery and Applications. 2019;147-168.
30. Mehnaz, S. Secondary metabolites of Pseudomonas aurantiaca and their role in plant growth promotion. In plant microbe symbiosis: Fundamentals and advances (pp. 373-393). New Delhi: Springer India. Kumar A, Guleria S, Mehta P, Walia A, Chauhan A, Shirkot CK. (2015). Plant growth-promoting traits of phosphate solubilizing bacteria isolated from Hippophae rhamnoides L.(Sea-buckthorn) growing in cold desert Trans-Himalayan Lahul and Spiti regions of India. Acta physiologiae plantarum. 2013;37:1-12.
31. Jouquet P, Traoré S, Choosai C, Hartmann C, Bignell D. Influence of termites on ecosystem functioning.

Ecosystem services provided by termites. European J of Soil Biology. 2011;47(4):215-222.

32. Chandran SJG. Isolation and characterisation of N_2 fixing bacteria from Curcuma rhizosphere soil of Western Ghats. Int J Res Anal Rev. 2019;6:487491.
33. Dinesh SN, Saminathan R, Patil MM, Baviskar PR, Hadidi H, Vignesh S, Kumar PM. Investigating the single pass baffled solar air heater (SAH) with an organic PCM (OPCM). Mater. Today: Proc. 2022;62:5245–5249.
34. Jagtap AB, Yadav IS, Vikal Y, Praba UP, Kaur N, Gill AS, Johal GS. Transcriptional dynamics of maize leaves, pollens and ovules to gain insights into heat stress-related responses. Front Plant Sci. 2023;14:1117136.
35. Vinayarani G, Prakash HS. Fungal endophytes of turmeric (Curcuma longa L.) and their biocontrol potential against pathogens Pythium aphanidermatum and Rhizoctonia solani. World J Microbiol Biotechnol. 2018;34:1–17.
36. Dhondge H V, Pable AA, Barvkar VT, Dastager SG, Nadaf AB. Rhizobacterial consortium mediated aroma and yield enhancement in basmati and non-basmati rice (Oryza sativa L.). J Biotechnol. 2021;328:47–58.
37. Goswami L, Sengupta S, Mukherjee S, Ray S, Mukherjee R, Lahiri Majumder A. Targeted expression of L-myo-inositol 1-phosphate synthase from Porteresia coarctata (Roxb.) Tateoka confers multiple stress tolerance in transgenic crop plants. J Plant Biochem Biotechnol. 2014;23: 316-330.
38. Tsukanova KA, Meyer JJM, Bibikova TN. Effect of plant growth-promoting Rhizobacteria on plant hormone homeostasis. South African J Bot. 2017;113:91–102.
39. Pandey S, Gupta S. Evaluation of Pseudomonas sp. for its multifarious plant growth promoting potential and its ability to alleviate biotic and abiotic stress in tomato (Solanum lycopersicum) plants. Sci Rep. 2020;10(1):20951.
40. Mellidou I, Ainalidou A, Papadopoulou A, Leontidou K, Genitsaris S, Karagiannis E, Karamanoli K. Comparative transcriptomics and metabolomics reveal an intricate priming mechanism involved in PGPR-mediated salt tolerance in tomato. Front Plant Sci. 2021;12:713984.
41. Gross H, Loper JE. Genomics of secondary metabolite production by Pseudomonas spp. Nat. Prod. Rep. 2009;26(11):1408-1446.
42. Karthika S, Varghese S, Jisha MS. Exploring the efficacy of antagonistic rhizobacteria as native biocontrol agents against tomato plant diseases. 3 Biotech. 2020; 10(7):320.
43. Compant S, Duffy B, Nowak J, Clément C, Barka EA. Use of plant growth-promoting bacteria for biocontrol of plant diseases: Principles, mechanisms of action, and future prospects. Applied and Environmental Microbiology. 2005;71(9):4951-4959.
44. Praveena R, Dinesh R, Srinivasan V, Sarathambal C, Priya George. PGPR consortium involving Pseudomonas aeruginosa, Bacillus safensis, Trichoderma asperellum and Pseudomonas plecoglossicida for suppression of soil borne pathogens. ICAR Indian Institute of Spices Research, Kozhikode. 2022.
45. Abd El-Daim IA, Bejai S, Meijer J. Bacillus velezensis 5113 induced metabolic and molecular reprogramming during abiotic stress tolerance in wheat. Sci Rep. 2019;9(1):16282.
46. Mukhtar A, Manzoor M, Gul I, Zafar R, Jamil HI, Niazi AK, Arshad M. Phytotoxicity of different antibiotics to rice and stress alleviation upon application of organic amendments. Chemosphere. 2020;258:127353.
47. Ohkuma M. Termite symbiotic systems: Efficient bio-recycling of lignocellulose. Applied Microbiology and Biotechnology. 2003;61(1):1-9.
48. Chouvenc T, Efstathion CA, Elliott ML, Su NY. Extended disease resistance emerging from the faecal nest of a subterranean termite. Proceedings of the royal society B: Biological Sciences. 2013; 280(1770):20131885.
49. Tsar'kova TF, Isaev ON, Sheichenko OP, Sheichenko VI, Shipulina LD, Morozov VI, Tolkachev ON. Green grassy shoot cuttings of Seabuckthorn for propagation-prospective varieties of plants for tannin production. In proceedings of the 7th conference of the international Seabuckthorn association on Seabuckthorn: Emerging technologies for health protection and environmental conservation, NASC Complex, New Delhi, India. 2015.
20. Zhou L, Wang J, Wu F, Yin C, Kim KH, Zhang Y. Termite nest associated Bacillus siamensis YC-9 mediated biocontrol of Fusarium oxysporum f. sp. cucumerinum. Frontiers in Microbiology. 2022; 13:893393.
51. Chakdar H, Dastager SG, Khire JM, Rane D, Dharne MS. Characterisation of mineral phosphate solubilising and plant growth promoting bacteria from termite soil of arid region. 3 Biotech. 2018;8(11):463.
52. Chauhan AK, Maheshwari DK, Kim K, Bajpai VK. Termitarium-inhabiting Bacillus endophyticus TSH42 and Bacillus cereus TSH77 colonising Curcuma longa L.: Isolation, characterisation and evaluation of their biocontrol and plant-growth-promoting activities. Canadian J of Microbiology. 2016;62(10):880-892.
53. Chauhan AK, Maheshwari DK, Dheeman S, Bajpai VK. Termitarium-inhabiting Bacillus spp. enhanced plant growth and bioactive component in turmeric (Curcuma longa L.). Current Microbiology. 2017;74:184-192.
54. Garba M, Cornelis WM, Steppe K. Effect of termite mound material on the physical properties of sandy soil and on the growth characteristics of tomato (Solanum lycopersicum L.) in semi-arid Niger. Plant and Soil. 2011;338:451-466.
55. Miyagawa S, Koyama Y, Kokubo M, Matsushita Y,Adachi Y, Sivilay S, Oba S. Indigenous utilisation of termite mounds and their sustainability in a rice growing village of the central plain of Laos. J of Ethnobiology and Ethnomedicine. 2011;7:1-6.

56. Bama PS, Ravindran AD. Influence of combined termite mound materials and inorganic fertilisers on growth parameters of maize under non sterilised pot culture study. Elixir Applied Zoology. 2018;125:52303-52305.
57. Devi R, Thakur R, Gupta M. Isolation and molecular characterisation of bacterial strains with antifungal activity from termite mound soil. International Journal of Current Microbiology and Applied Science. 2018;7:1-7.

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