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Review Article

Unleashing the Biocontrol Potential of Compost-inhabiting and Rhizobacteria for Sustainable Plant Health

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ABSTRACT

Microbial populations play a vital role in plant health, protecting them from pathogens and diseases. They boost the growing up plant by protecting it from different harmful microbes and diseases. Beneficial microorganisms in compost and rhizobacteria suppress diseases through mechanisms like competition, antibiotic production, parasitism, and induced resistance (ISR, SAR). Compost promotes the growth of crops particularly by controlling the diseases. They do this by the activities of the beneficial microorganisms reside in it and their competition dominance for energy. Other mechanisms of disease suppression are through production of antibiotic compounds, parasitism/ predation, activation of disease-resistant genes and through improving the defensive capacity of plant through. They perform as disease controlling agents and suppress the diseases by stimulating the beneficial symbiosis and protecting the plant by the degradation of harmful compounds in growth suppressing soil. Augmentation of rhizosphere with rhizobacteria, isolated from the same environment, provides better control of diseases because they are acclimatized in the proposed rhizospheric conditions. The disease suppression mechanism is same as that of compost inhabiting bacteria. PGPR and compost inhabiting bacteria must survive, colonized, ecologically fit and function in the specific environmental conditions to act as biocontrol agents. Varied microbes showed diverse antagonistic activity under different environmental conditions. Plant growth-promoting rhizobacteria (PGPR) and compost-inhabiting bacteria can act as biocontrol agents, promoting sustainable plant health. The objective of this review is to critically evaluate the current understanding of these microorganisms, highlighting their potential and identifying future research avenues**.**

Keywords: Biocontrol, compost inhabiting bacteria, disease suppression, PGPR.

INTRODUCTION

The world faces critical issues pollution, fueled by population growth and natural resource exploitation. The quest for improving the yield of crops has led to indiscriminate use of chemical fertilizers and pesticides (Basu et al., 2021) Chemical fertilizers and pesticides in agriculture contaminate soil, while excessive pesticide use to control plant diseases has devastating residual effects, threatening the environment and human well-being. The effectiveness of chemical controls against plant pathogens has been compromised as many pathogens have developed resistance (Lucas, 2011). During the past couple of decades the use of biostimulants and biofertilizers have gained wide attention owing to their environment friendly nature and imparting beneficial effect on crop yield and quality. Consequently, controlling economically significant plant diseases has become increasingly challenging due to a nonexistence of active material (Bailey, 2014). Intensified production of crop and market of food around globe have exacerbated this issue (Fones et al., 2020). Climate change presents additional obstacles in plant pathogen control, including shifting geographic disseminations of pathogens (Fones et al., 2020; Chaloner et al., 2021). However, beneficial microbes like Bacillus spp. have emerged as key players to suppress the disease in peas (Miljaković et al., 2020). *Macrophomina phaseolina*, *Sclerotium rolfsii*, and *Harpophora maydis*. Specifically, Fusarium pseudo graminearum, trigger seedling blight, scab, and crown rot in cereals (Khan et al.,, 2006, Li et al., 2022). Infection caused by *Fusarium* can significantly reduce wheat seed germination and seedling emergence, leading to seedling death in cereal crops (Charles, 2007). Furthermore, Fusarium head blight causes demage in grains, a major issue in global cereal production (Pirgozliev et al., 2003).

However, excessive pesticide use not only harms the environment but also fosters pest resistance (Lucas, 2011). To address this challenge, it's essential to explore eco-friendly and cost-effective alternatives for controlling plant pathogens. In sustainable agriculture, biological control methods have emerged as viable substitutes for chemical control, offering a promising solution for managing plant diseases (Abaidoo et al., 2011; Chaloner et al., 2021). Finally decomposed organic matter has been employed in agriculture since ancient times as a valuable organic amendment. Its efficacy stems from the diverse microbial populations it harbors, which confer numerous benefits, including: Plant growth promotion through hormone production, Disease suppression via antibiotic production, pathogen predation, and induced systemic resistance, Enhanced plant self-defense mechanisms. The structure and dynamics of compost's inhabitant microbes vary throughout the composting process, influencing its disease-suppressive capabilities. Strategic inoculation with beneficial microorganisms can augment disease control efficacy (Wang et al., 2004; Clercq, 2004). As a rich carbon source, compost supports a diverse array of bacteria with potential pathogen-suppressive properties (Saeed et al., 2021). Moreover, manure derived from municipal wastes has demonstrated substantial disease-control activity (Pugliese et al., 2008).

PGPR control pathogens indirectly, by producing siderophore. Microorganism] plays a dual role in plant health, sequestering iron to limit phytopathogen growth and simultaneously promoting plant growth through increased iron availability (Argenziano et al., 2020). Siderophore-producing Pseudomonas bacteria show suppressive effect against Fusarium and Sclerotium species (Manwar et al.,, 2004). Systemic resistance induced by rhizosphere residing microbes in various crops, protecting against nematodes, viruses, and pests in Chilli and eggplant (Bharathi et al., 2004), paddy (Nandakumar et al., 2001), Mango (Vivekananthan et al., 2004). Root exudates, comprising various biochemicals like phenolics are released by plants into the surrounding soil. These exudates play a decisive role in regulating soil microorganisms, modifying soil characteristics, and preventing the spread of phyto pathogens. The root zone, densely populated with microbes actinomycetes, fungi, and insects, benefits from root-secreted proteins and high-molecular-weight compounds (rhizodeposition), serving as a nutrient source for beneficial microbes (Saeed et al., 2021). Root exudates, including ions, water, and oxygen, facilitate interactions between roots and rhizobacteria, acting as repellents against pathogens or attractants for beneficial microbes. Research highlights the diversity of root exudate composition among plant species and ages, creating tailored nutritional opportunities for rhizospheric microorganisms (Santoyo et al., 2021). Moreover, secondary metabolites within these exudates foster symbiotic partnerships with (Pang et al., 2021). Additionally, ethylene production surges in response to stressors like pathogens, drought, and heavy metal toxicity, warranting its classification as a "stress hormone" (Devarajan et al., 2021).

Objectives

This review aims to consolidate existing research on the biocontrol efficacy of compost-inhabiting and rhizobacteria, with a focus on their applications in maintaining sustainable plant health and mitigating plant diseases.

Review of literature

Biological control is of two types, general and specific. Disease control in plant ecosystems is achieved through the collective synergistic effects of (Stone et al., 2014). This phenomenon, known as general suppression, effectively controls plant pathogens like *Pythium* and *Phytophthora* spp. by utilizing broad-spectrum antifungal compounds (Avilés et al., 2011; Benítez et al., 2009). Compost-based media enhance this suppression, inhibiting pathogen growth (Noble & Coventry, 2005; Litterick et al., 2004). The large scale production of bio fertilizers is not so simple and certain constraints i-e biological, technical regulatory etc needs to be kept in mind before mass scale production (Figure 1).

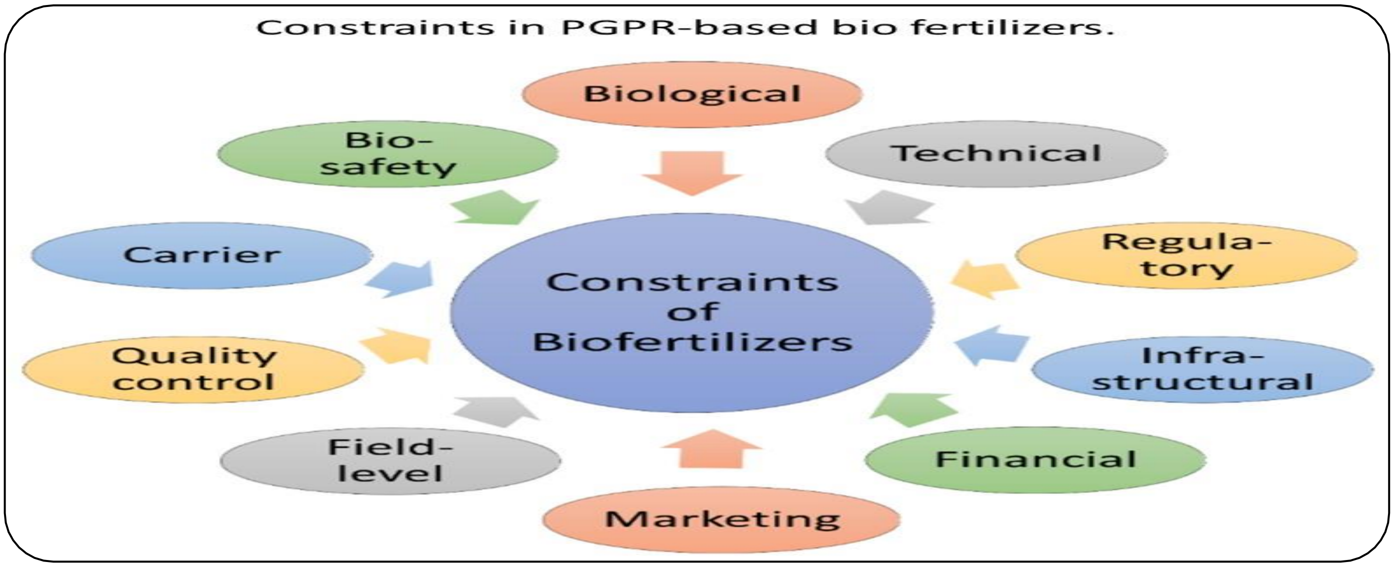

Figure 1. Constraints in the production, utilization and commercialization of PGPR-based bio fertilizers (Basu et al., 2021).

In contrast, specific suppression involves targeted antibiotic production by specific microorganisms, effective against particular pathogens (Stone et al., 2004). Although less effective than general suppression, examples include, Trichoderma spp. suppressing Rhizoctonia solani growth in compost-amended soil (Scheuerell et al., 2009). Trichoderma asperellum's antifungal activity against *Fusarium oxysporum* (Cotxarrera et al., 2002). Strategic selection of biocontrol agents from compost can enhance disease suppressiveness (Carisse & Provost, 2024), with specific suppression mechanisms involving targeted antibiotic production (Raaijmakers et al., 2010; Mazurier et al., 2009 ; Thomashow, 1999).

Impact compost on soil and plant health

The use of compost can also increases the pH, porosity, moisture, aggregate stability, organic content, and P and K content as well as reduce the bulk density of the soil. The addition of compost significantly improves soil chemical and physical properties; although at the low rate there was effect**.** It also enhances soil structure, boosts biological activity, and improves water retention, providing a sustainable pathway to restore degraded (Surya et al., 2022)

Mechanism of disease control

Disease control by Plant Growth Promoting Rhizobacteria PGPR and compost dwelling biocontrol microbes is obtained through the following four mechanisms:

- Competition (Masalha et al., 2000)
- Antibiotic compounds production (Mavrodi et al., 2006)
- Parasitism / predation (Cohen-Kupiec & Chet, 1998)
- Instigation of disease-resistance genes (Induced systemic Resistance (ISR), Systemic Aquired Resistance (SAR) (Mitter et al., 2013; Wang et al., 2004).

Competition

Plants need Iron for chlorophyll synthesis and pathogen survival/pathogenicity. PGPR produce siderophores, which sequester iron, rendering it available to plants (Masalha et al., 2000; Whipps, 2001). Deprive pathogens of iron, inhibiting growth (Arora et al., 2005), Facilitate plant growth by eliminating Fusarium (Dey et al., 2004). Siderophores produced by PGPR suppress plant pathogens in gram (Verma et al., 2010) and wheat (Silini et al., 2012).

Chelate iron and other metals, restricting pathogen access (Miethke & Marahiel, 2007), Enhance bacterial production of antimicrobial compounds (Sayyed et al., 2005). Pseudomonas spp. exhibit resilience to abiotic stresses via catalase activity (Joseph et al., 2007). Plant pathogens, characterized by weak saprophytic capabilities, are outcompeted for resources in composted soils (Wang et al., 2004).

Antibiotic compounds production

Compost-inhabiting and plant growth-promoting rhizobacteria employ antibiosis to hinder pathogens, synthesizing antibiotic compounds such as Phenazines (Mavrodi et al., 2006). D-gluconic acid (Kaur et al., 2008), 2-hexy 1-5propyl resorsinol (Cazorla et al., 2014).These compounds exhibit efficacy against Phythium spp (Perneel et al., 2008). Rhizobacteria produce diverse antibiotics, including, Volatile and nonvolatile compounds (Ahmad et al., 2008), Lipopeptide biosurfactants (Ongena et al., 2007), Heterocyclic nitrogenous compounds (de Souza et al., 2003). Fluorescent pseudomonads present in compost and rhizosphere effectively combat soil-borne diseases. Pseudomonas spp. produce antibiotic compounds with antifungal properties, 2, 4-diacetylphloroglucinol (Raaijmakers et al., 2002 ; Notz, 2005; Koch etal., 2002; Thompson et al., 2002). Hydrogen cyanide (Ryall, 2009; Duffy, 2003; Ramette et al., 2003). Mesorhizobium ciceri's HCN promotes plant growth either directly or by using other means (Joseph et al., 2007). Compost-dwelling Pseudomonas spp. produce 2, 4-diacetyphloroglucinol, effectively inhibiting Fusarium wilt, take-all disease, soft rot, and cyst nematode.

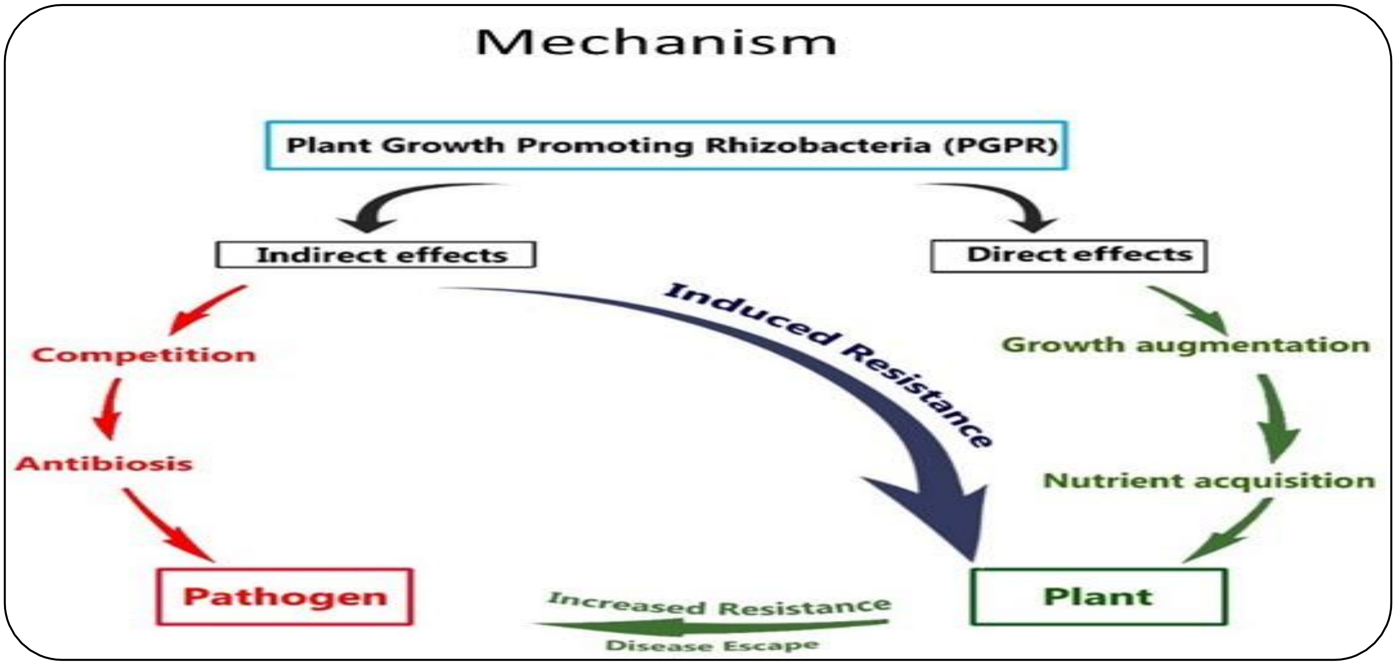

Figure 2. Main overview of interactions between plant growth promoting *Rhizobacteria* (PGPR), plants, and pathogens. PGPRs directly promote plant growth by improving nutrient acquisition by the plant and growth augmentation via regulating phytohormones levels. The indirect effects of PGPRs include suppression of phytopathogens and inducing systemic resistance in plants against a wide range of pathogenic microbes (adopted from Basu et al., 2021).

Parasitism/Predation

Rhizobacteria involved in growth promotion of plant, exhibit antagonistic action against soil-residing pathogens through parasitism, mediated by the manufacturing of chitinase enzymes that damage pathogen cell walls (Cohen-Kupiec & Chet, 1998). Specific PGPR strains demonstrate efficacy contradicted to Rhizoctonia, Fusarium, Macrophomina (Özkoç & Deliveli, 2001). Serratia plymuthica's chitinase inhibits germination of spore and elongation of germ-tube in Botrytis cinerea (Frankowski et al., 2001). Certain microbes synthesize enzymes capable of destroying oospores of phytopathogenic fungi (El-Tarabily, 2006). Compost application effectively controls Monilinia fructicola growth, causing brown rot in apple orchards (Brown et al., 2004). Synergistic interactions between bacterial and fungal biocontrol agents result in enhanced suppression of soil-borne pathogens (Garbeva et al., 2004). Specific metabolites, including NH4, Oomycin A, and phenazine-1-carboxylic acid, exhibit fungicidal properties (Whipps, 2001). PGPR hyper-parasitize pathogens through the production of cell wall hydrolases (Chernin & Chet, 2002). Combining bacteria which produce enzymes to other biocontrol agents achieves synergistic pathogen suppression (Someya et al., 2007).

Instigation of disease-resistance genes (ISR, SAR)

Biologically induced resistance confers disease protection in plants (Van Loon, 2007). Composts elicit resistance, providing an additional mechanism of biocontrol against soil and air-residing diseases (Ntougias et al., 2008). Microorganisms stimulate plant defense mechanisms, triggering systemic signaling pathways (Boehm et al., 2009); (Durrant & Dong, 2004). Plants control pathogens by secreting specific proteins and salicylic acid, the pathway leading to Systemic acquired resistance (Van Loon, 2007), whereas jasmonic acid and ethylene induced systemic resistance ((Segarra et al., 2013 ;Trillas & Segarra, 2009). Specific compost-inhabiting microorganisms colonizing roots initiate biochemical pathways, conferring resistance to soil and air-borne infections (Khan, 2020). Pseudomonas fluorescens enhances plant capacity to be defensive against air-borne pathogens (Pieterse et al., 2001). Compost extracts induces systemic resistance against anthracnose in roots (Kim et al., 2011). Inoculation of tomato plants with Bacillus subtilis, via seeds, roots, or foliar spray, confers substantial resistance against bacterial spot disease through the making of some defensive enzymes (Sharma et al., 2024) Pseudomonas spp. effectively controls: Gluey rot in watermelon stem (Lee et al., 2001), Late blight in tomato (Yan, 2002) by inducing systemic resistance. Rhizobia in non-legumes induce systemic resistance against pests through the release of stimulatory compounds, such as lipo-polysaccharides, which activate signal transduction pathways (Mishra & Ma, 2005; Sing et al., 2008). Specific Rhizobium species produce antioxidants in rice, triggering systemic resistance in response to pathogen-induced stress (Mishra et al., 2006). Inoculating seeds and seedlings with diverse PGPR strains enhances systemic confrontation against a wide array of pathogens (Ramamoorthy et al., 2001).

Contradictory observation

The suppressive efficacy of compost against plant pathogens is variable. For instance, Compost failed to suppress Rhizoctonia solani, with isolated microorganisms ineffective against the pathogen (Pugliese et al., 2008).

Research has shown varying levels of disease suppression by compost microorganisms against *Pythium ultimum*-induced damping-off in cucumber (Carisse & Provost, 2024). However, specific compost amendments can enhance suppressive activity, such as *Verticillium biguttatum* enrichment, which effectively controls Rhizoctonia solani in sugar beet and tomato (Postma et al., 2003). Additionally, *Trichoderma asperellum* supplementation reduces *Rhizoctonia solani* prevalence (Trillas et al., 2006). Interestingly, compost successfully controls *Pythium* damping-off and Phytophthora root rot in cucumber, but not in tomato (Diánez et al.,, 2007).

CONCLUSION

Investigations into natural disease suppression by compost-inhabiting bacteria and PGPR should consider the following parameters:

Microbial application included utilizing less than recommended amendment doses, as microorganisms exhibit optimal performance under nutrient-limited conditions.

Laboratory evaluation of microbial inocula as biocontrol agents: repeated assessments for growth promotion of plants and disease suppression prospective, with statistical validation.

Microbial consortia: verifying individual strain efficiency and compatibility for co-inoculation. Performance evaluation under controlled and ambient conditions to integrate plant, rhizospheric, and environmental factors.

The factors projected to suppress the disease by PGPR and/or compost inhabiting bacteria, are different for each pathogen and it cannot be generalized for all the pathogens under all environmental conditions.

FUTURE DIRECTIONS

Identify and characterize PGPR strains with enhanced biocontrol activity against specific plant pathogens.

Develop effective formulations and delivery methods for PGPR-based biocontrol agents, ensuring their survival and efficacy in various environmental conditions.

Conduct large-scale field trials to evaluate the efficacy and consistency of PGPR-based biocontrol agents in different agricultural settings.

Investigate the potential for integrating PGPR-based biocontrol with other sustainable agricultural practices, such as organic farming and integrated pest management.

COMPETING OF INTEREST

Each author have reviewed and approved the content of the submitted manuscript. And it is declared by all the Authors that they have no conflicts of interest.

AUTHOR CONTRIBUTION

All authors contributed equally.

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