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Review article

Biofortification of Vermicompost: Advancing crop nutrition and plant disease suppression in organic farming system- A comprehensive review

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ABSTRACT

Biofortified vermicompost is an organic fertilizer enriched with vital micronutrients and beneficial microorganisms, has gained attention as a valuable asset for sustainable agriculture. This review delves into the methods of production, nutrient profile, and agronomic advantages of biofortified vermicompost, along with its potential role in managing crops diseases. The production process incorporates mineral supplements, microbial inoculants, and PGPR during composting, leading to a nutrient-rich end product with enhanced macro- and micronutrient levels. Biofortified vermicompost foster plant growth by enhancing root and shoot development and boosting nutrient absorption. It also assists in controlling crop diseases through mechanisms like SAR,ISR, and generation of antimicrobial compounds, effectively suppressing soil-borne pathogen and foliar diseases. Nonetheless, challenges remain in standardizing its production, integrating it with other farming practices, and ensuring economic viability and scalability. Future research should aim to tackle these challenges and investigate the mechanisms involved in the vermicomposting process. Future research should also focus on optimizing parameters, and elucidate the composition of bacterial communities in the final product. Furthermore, studies on the sociocultural aspects of vermicompost adoption and the formulation of policies to support its use in agricultural system are necessary to fully realize the potential of biofortified vermicompost in sustainable agriculture and environmental management.

Aabbreviations

PGPR Plant Growth-Promoting Rhizobacteria
SAR Systemic Acquired Resistence
ISR Induced Systemic Resistance
Spp Species
INM Integrated Nutrient Management

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1. Introduction

Over two billion individuals worldwide suffer from deficiencies in micronutrients, such as iron (Fe), zinc (Zn), and vitamin A, resulting in major health issues and economic setbacks (Bouis and Saltzman, 2017 ; Singh and Prasad, 2014). These nutritional gaps can lead to stunted growth, hindered cognitive development, a higher risk of infection, and other negative health effects (Muthayya et al., 2013). Biofortification is the process which involves enhancing the nutritional content of crops using traditional breeding, genetic modification, or agronomic techniques, has become a sustainable and cheap method to overcome this worldwide issue (Bouis and Saltzman, 2017; Nestel et al., 2006). Vermicompost is recognized as a nutrient-dense organic fertilizer, and it is produced through the degradation of organic matter using earthworms and associated microbes and has gained considerable attention in the realm of sustainable agriculture (Gabru et al., 2024). The addition of biofortified elements to vermicompost could potentially enhance the nutritional profile of crops, thereby presenting a comprehensive strategy to strengthen food security and improve health (Yatoo et al., 2021; Singh et al., 2020). Moreover, biofortified vermicompost may enhance plant disease resistance due to presence of beneficial microorganisms and bioactive compounds inherent in vermicompost, it can inhibit plant pathogens and strengthen the plant's natural defense system (Hussain et al., 2017; Ozturkci and Akkopru, 2021).

Biofortified vermicompost has emerged as a sustainable agricultural input, with significant potential for enhancing crop productivity and managing plant diseases. It offers several agronomic benefits, primarily by improving disease resistance in crops through the action of beneficial microorganisms and bioactive compounds that suppress pathogens and boost plant defense mechanisms (Hussain et al., 2017; Ozturkci and Akkopru, 2021). In addition, biofortified vermicompost increases soil health by improving the soil structure, water retention capacity, and microbial activity, all of which create a conducive environment for plant growth. The application of compost has also been associated with an increased crop yield and improved nutritional quality, that supports to better food security and health outcomes (Yatoo et al., 2021; Singh et al., 2020). Furthermore, biofortification techniques enable the enrichment of vermicompost with required micronutrients, such as Zn, Fe and Se. Potentially addressing micronutrient deficiencies in crops and by extension in human diets. From an environmental perspective, the use of organic waste in the production of biofortified vermicompost supports sustainable waste management by reducing landfill accumulation and greenhouse gas emissions.

Despite the numerous advantages of biofortified vermicompost, its widespread adoption faces several obstacles. One major challenge is scaling up production while maintaining quality and optimizing composting conditions, which is crucial for obtaining consistent results. Additionally, absence of standardized guidelines for the production, quality assessment, and application of biofortified vermicompost poses significant regulatory challenges. Concerns regarding the economic feasibility of this product also exist as its cost-effectiveness and market competitiveness have not been thoroughly explored. Moreover, there are notable research gaps, particularly in refining biofortified techniques and studying the long-term effects of these amendments on soil and plant health. Technological constraints further hinder production efficiency because the existing systems for monitoring and control may not ensure consistent quality and nutrient levels. To fully realize the potential application of biofortified vermicomposting in sustainable agriculture, it is essential to address these issues through focused research, policy formulation, and technological innovation.

2. Biofortified Vermicompost: Composition and Production

2.1 Definition and characteristics of biofortified vermicompost

Biofortified vermicompost is an organic amendment rich in nutrients created through vermicomposting, in which earthworms break down organic waste. This process is enhanced by the addition of beneficial microbes or mineral supplements to increase agricultural value. Unlike standard vermicompost, it includes components such as phosphate-solubilizing bacteria, nitrogen-fixing bacteria, rock phosphate, and micronutrients, such as Zn, Fe and Cu (Singh et al., 2023). This fortification not only improves the macro-and micronutrient content but also boosts microbial biomass and enzymatic activity, making nutrients more accessible to plants (Hafez et al., 2025). Fig. 1. Illustrates the desirable characteristics of biocontrol agents used in biofortified vermicompost, including their modes of action against plant pathogens. This vermicompost exhibits superior physical and chemical characteristics such as reduction in C:N ratio, improved aeration, higher humus level, and also increased water retention capacity (Mulatu and Bayata, 2024). Recent advancements have incorporated nanomaterials and agro-industrial waste to further promote plant growth and resistance to disease (Yadav et al., 2024). These attributes make biofortified vermicompost a valuable resource for sustainable agriculture, particularly in nutrient-poor or acidic soils.

2.2 Production methods and techniques

Biofortified vermicompost is produced through the integration of mineral enrichment, microbial inoculation, and the incorporation of PGPR, each contributing in an increase in the nutrient content and biological activity in the final product. A common method involves the addition of mineral supplements, such as Fe, Zn, Se, Mn and Cu, which are vital for plant functions such as chlorophyll synthesis, enzyme activity and stress resistance (Mulatu and Bayata, 2024). These minerals may be introduced by directly mixing them with the composting material, applying a mineral solution during the composting process, or blending them with finished vermicompost (Yadav et al., 2024). Another strategy involves the utilization of beneficial microorganisms such as *Trichoderma*, *Bacillus*, and *Pseudomonas* species, which expedite the decomposition of organic matter, suppress plant pathogens, and enhance nutrient solubilization (Singh et al., 2023). These microbes can be introduced by pre-inoculating the feedstock or periodically applying a microbial spray during the composting cycle (Hafez et al., 2024; Singh et al., 2023). These bacteria can be applied by inoculating earthworm bedding, enriching feedstock with PGPR-rich materials, or spraying them during vermicomposting (Mulatu and Bayata, 2024). The integration of these methods results in a potent biofertilizer that not only enhances soil health but also sustainably increases crop yield (Yadav et al., 2024).

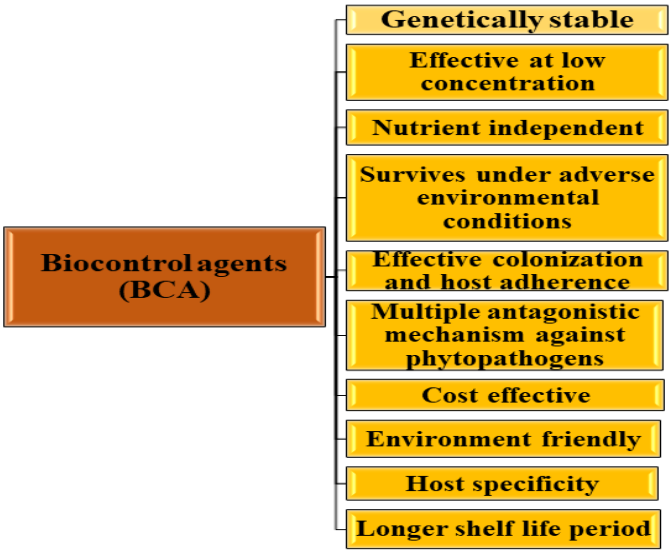

Fig 1. Schematic diagram showing desirable characteristics of bio-control agent

2.3 Nutrient composition and bioavailability

Biofortified vermicompost is gaining attention for its enhanced nutrient profile compared to conventional vermicompost. By adding specific mineral additives such as zinc (Zn), iron (Fe), selenium (Se) and manganese (Mn) during the composting process, biofortified vermicompost can achieve higher concentrations of both macro and micronutrients (Dhaliwal et al., 2022). These nutrients are vital for plant physiological functions as mentioned elsewhere .Additionally, the presence of beneficial microorganisms and PGPR in biofortified compost enhances nutrient solubilization and bioavailability, enabling plants to absorb nutrients from the soil more effectively (Pathma and Sakthivel, 2012). For example, zinc and iron, which are often not readily available in soil, become more accessible through chelation and microbial interactions when they are included in biofortified vermicompost. Consequently, plants not only receive a more abundant nutrient supply but also experience improved uptake efficiency, leading to better growth, productivity, and nutritional quality of the produce (Dimkpa and Bindraban, 2016). Several works has been done to observe the key difference between different types of vermicompost to know their biological and chemical properties like here Table 1. provides a comparative analysis of the key characteristics of biofortified vermicompost versus traditional vermicompost, highlighting differences in nutrient content, microbial diversity, and effects on plant growth.

3. Effects of biofortified vermicompost on plant growth

3.1 Impacts on plant root growth and biomass accumulation

Biofortified vermicompost has been proven to positively affect plant growth, particularly by enhancing root development and structure. Its application significantly increases root biomass, extends root length, and promotes more extensive branching patterns in a variety of crop species. These improvements in the root system led to better nutrient and water absorption, ultimately promoting healthy and vigorous plant growth. For instance, Karnwal (2020) observed that tomato plants treated with two strains of zinc-solubilizing bacteria (VBZ17 and VBZ4 strains of Pseudomonas) demonstrated a notable increase in root length, with the longest root 33 cm in plants, underscoring the potential of microbial biofortification.

3.2 Impact on plant shoot and biomass accumulation

Studies show that biofortified vermicompost greatly improves shoot development and biomass yielding in a range of agricultural crops. Recent research has indicated that vermicompost enriched with micronutrients can improve plant growth parameters and yield. For example, biofortified vermicompost has been found to enhance shoot length, stem thickness, leaf area and total biomass of the tomato plant (Akef et al., 2024). Similarly in cereal crops, such as wheat and rice, the addition of nutrient-enriched vermicompost has led to better tillering, increased leaf expansion, and higher dry matter accumulation (Oyege and Bhaskar, 2023). These enhancements in plant growth metrics are due to the balanced nutrient composition of the biofortified vermicompost.

3.3 Effect on nutrient uptake and utilization

Biofortified vermicompost can be produced by combining free-floating macrophyte biomass with cow manure and organic nutrient additives, such as eggshells, bone meal, banana peels, and tea waste. The process of enrichment greatly boosts the nutrient content of the vermicompost, leading to increased levels of total nitrogen (2.87%), phosphorous (0.86%), and potassium (3.74%) (Yatoo et al., 2022). Such nutrient-dense vermicompost is a sustainable method for improving plant nutrition and soil fertility. It supplies vital nutrients, beneficial microorganisms, and growth hormones that aid nutrient absorption and utilization in crops (Rehman et al., 2023). By enhancing soil quality and boosting nutrient availability, biofortified vermicompost can increase crop yield while decreasing reliance on chemical fertilizers (Oyege and Bhaskar, 2023). However, it is crucial to recognize that vermicomposting alone might not supply all necessary nutrients, and its application should be part of an integrated nutrient management strategy (Walia et al., 2024). Hence Table 2 represents works of various researchers and scientist on combine action of nutrient rich vermicomposting with several useful microbes to know it's impact on enhancing plant nutrition and growth capacity.

4. Biofortified vermicompost in crop disease management

Vermicompost and its derivatives have emerged as promising tools for the management of crop diseases, providing eco-friendly alternatives to conventional synthetic pesticides and fungicides. The bioactive compounds in vermicompost, derived from earthworm secretions and associated microorganisms, exhibit antifungal properties that combat a variety of soil borne pathogens (Gudeta et al., 2022). Vermicompost tea, derived as a liquid from vermicompost, has been demonstrated to effectively shield plant by creating a protective layer on leaf surfaces, thus decreasing the potential sites for pathogen invasion. Additionally, it boost microbial diversity, which contributes to the suppression of harmful pathogen (Yatoo et al., 2021). The use of vermicompost has been observed to enhance the diversity and activity of antagonistic microbes and nematodes, which assists in managing the diversity and activity of antagonistic microbes and nematodes, which assists in managing pests and diseases caused by soil-borne pathogen (Rehman et al., 2023; Yatoo et al., 2021).

4.1 Mechanisms of disease suppression

Disease suppression can be achieved through various mechanisms such as SAR, ISR, and production of antimicrobial compounds. SAR is initiated by mobile signals originating from the primary site of infection, which then move to distant tissues to activate defense mechanisms (Bisen et al., 2023). Interestingly, ISR represents another defense strategy that strengthens the host plant's physical or chemical barrier without directly targeting or inhibiting the invading pathogen (Kamle et al., 2020). In addition to SAR plants are capable of producing antimicrobial substances to combat pathogens.

4.2 Effects on soil -borne pathogens

Vermicompost has demonstrated notable effects on soil-borne pathogens, especially when it is biofortified or enhanced by beneficial microorganisms. Its application can inhibit a range of soil pathogenic fungi such as *Rhizoctonia solani*, *Alternaria solani*, *Aspergillus niger*, *A. flavus*, *Fusarium oxysporum*, and *F. graminearum* (Gudeta et al., 2022). This inhibitory effect is due to the combined action of bioactive compounds found in the coelomic fluid, mucus and skin secretions of earthworms, and metabolites from decomposer bacteria associated with vermicompost. Interestingly, while vermicompost generally supports beneficial microorganisms, some studies have identified DNA from potentially harmful bacteria such as *Salmonella* spp., *Escherichia coli*, *Enterobacter spp.*, *Enterococcus spp.*, *and Clostridium spp*. in the vermicompost samples (Blomström et al., 2016). For instance, certain PGPR can generate compounds, such as benzoic acid derivatives, cyclotetrasiloxanes, and phthalates, which aid in suppressing pathogens (Roy et al., 2025).

4.3 Impact on foliar diseases

Vermicompost, enriched with vital nutrients, such as zinc, plays a vital role in boosting plant health and ability to resist leaf diseases. For instance, the application of Zn to foliage has been found to increase Zn levels in plant tissues, which may enhance growth, development, and defense against pathogens (Rugeles-Reyes et al., 2019). Vermicompost tea, a liquid derived from vermicompost, has shown considerable promise in protecting plants from foliar diseases. When sprayed on leaves, they can decrease the area susceptible to pathogen infection and increases microbial diversity, thereby effectively managing disease causing pathogen (Yatoo et al., 2021). This indicates that biofortified vermicompost tea could be an effective approach for controlling foliar diseases.

4.4 Influences on plant defense responses

Vermicompost was prepared from the decomposition of organic residue by the activities of the earthworms, it may enhance soil biodiversity and supports the proliferation of beneficial microorganisms, thereby promoting plant growth and health (Pathma and Sakthivel, 2012). This organic amendment can affect defense-related enzymes and secondary metabolites in plants through multiple mechanisms. The application of vermicompost may trigger the production of Reactive Oxygen Species (ROS) in plants, which function as signaling molecules to activate defense responses. This results in increased activity of enzymatic antioxidants, such as Guaiacol peroxidase, Catalase and Phenylalanine ammonium lyase, as well as non-enzymatic antioxidants, such as phenols and flavonoids (Kaur et al., 2021; Kaur et al., 2022).The mechanisms of action of biocontrol agents in suppressing plant pathogens are depicted schematically in Fig. 2, showing key processes like antibiosis, competition, and induced systemic resistance. Furthermore, vermicompost can enhance the production of secondary metabolites, including phenolics, flavonoids, and other bioactive compounds, which are vital for plant's defense against both biotic and abiotic stresses (Caretto et al., 2015). This ultimately reduces the risk to some plant diseases as shown in Table 3.

Table 1-Comparative analysis Biofortified vermicompost vs Traditional vermicompost

Parameter	Traditional Vermicompost	Biofortified Vermicompost	References
Nutrient content (Macronutrients)	The levels of N,P,K vary moderatly, influenced by the type of raw materials	The NPK levels were either similar or slightly enhanced, depending on additives employed	Oyege and Bhaskar (2023)
Micronutrient enrichment	Often there are deficient or inconsistent trace element like iron, zinc, copper and selenium	Intentionally fortified with Fe, Zn, Cu, Se and Mn to cater to specific plant needs	Kaur et al, (2020)
Nutrient bioavailability	Nutrient availability depends on decomposition level and raw inputs	High nutrient solubility and plant uptake due to chelation and microbial interaction	Thakur et al, (2022)
Microbial diversity	It includes native microorganisms such as Actinomycetes, Bacillus and Pseudomonas but limited diversity	Contains intentionally added beneficial microbes like Trichoderma , Azobacter, PGPR	Pathma and Sakthivel, (2012)
PGPR	May have PGPR if present in raw feedstock	Deliberately inoculated with PGPR strains for enhanced growth and nutrient uptake	Yadav et al, (2024)
Biocontrol potential	Limited disease suppression potential	Includes microbial agents (e.g., Trichoderma) that suppress plant pathogens.	Aira et al, (2016)
Stress Tolerance Induction	Minimal effect on plant stress tolerance	Enhances plant tolerance to drought, salinity and pathogens	Hafez et al, (2024)
Consistency of quality	Varies greatly depending on raw material and composting method	More consistent and tailored quality due to standardization of inputs	Mulatu and Bayata, (2024)

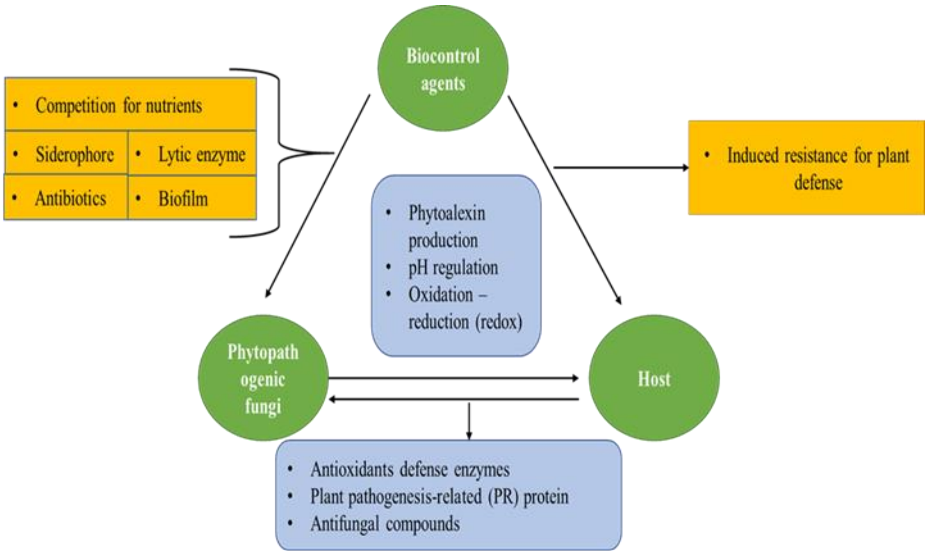

Fig. 2. Mechanism of action of Bio-control agent

5. Environmental and ecological considerations

From an environmental standpoint, biofortified vermicompost enhances soil quality by increasing organic matter levels, improving water retention, and enhancing soil structure (Matisic et al., 2024). It also plays a significant role in carbon sequestration, which can help mitigate the effects of climate change (Badagliacca et al., 2024; Matisic et al., 2024). Additionally, using vermicompost reduces reliance on synthetic fertilizers, thereby lowering the environmental impact associated with their production and application (Badagliacca et al., 2024). Ecologically, biofortified vermicompost has a positive effect on the soil microbial diversity and its functions. It increases the presence of beneficial microorganisms such as diazotrophs and phosphate solubilizers, which are important for nutrient cycling and plant growth (Suyal et al., 2021). Notably, organic practices incorporating vermicompost have been found to suppress certain soil-borne pathogens, potentially decreasing the need for chemical pesticides (Suyal et al., 2021). However, it is crucial to note that the effects of biofortified vermicompost can differ depending on soil type, application rate, and cropping system (Matistic et al., 2024). high concentrations of vermicompost may hinder plant growth owing to the presence of excessive soluble salts (Lim et al., 2014). Therefore, careful consideration of the application rates and methods is essential to maximize benefits while minimizing potential adverse effects.

6. Challenges with current use of biofortified vermicompost

6.1 Standardization and quality control

The application of biofortified vermicompost encounters obstacles related to standardization and quality assurance. Although vermicompost is nutrient-rich and improves soil health (Pathma and Sakthivel, 2012), the absence of standardized production and quality evaluation methods presents a major challenge. Variations in the raw materials, earthworm species, and environmental conditions can result in inconsistent nutrient profiles in the final product (Vuković et al., 2021). Future efforts should aim to create standardized production protocols and establish quality control measures to ensure consistent nutrient content and safety for agricultural application.

6.2 Integration with other agricultural practice

Merging biofortified vermicompost with current agricultural practices presents both challenges and opportunities. The Integrated Nutrient Management (INM) approach advocates the combination of vermicompost with other organic manures and chemical fertilizers for optimal outcomes (Sande et al., 2024). However, the main challenge is determining the correct balance and application techniques for various crops and soil types. Future research should investigate the synergistic effects of vermicompost with other sustainable practices, such as crop rotation and precision agriculture, to enhance its benefits while reducing environmental impact (Oyega and Bhaskar, 2023; Zaman and Yaacob, 2022).

6.3 Economic feasibility and scalability

The economic viability and scalability of biofortified vermicompost production are crucial for widespread adoption. Although vermicomposting is considered economically advantageous (Vukovic et al., 2021), the initial setup costs and labor demands may pose challenges for small-scale farmers. Future perspectives should focus on developing cost-effective production methods and exploring community-based vermicomposting initiatives to improve the scalability. Additionally, research into the long-term economic benefits of vermicompost use, such as reduced reliance on chemical fertilizer crop yield is necessary to encourage its adoption (Kaur, 2020; Mohite et al., 2024).

7. Conclusion

Biofortified vermicompost is an organic fertilizer produced by enriching traditional vermicompost with essential micronutrients and beneficial microorganisms. This enhanced compost has the potential to combat micronutrient deficiencies in crops and strengthen plant resistance to disease. The production process involves the addition of mineral supplements, microbial inoculants, and plant growth-promoting rhizobacteria during vermicomposting. Compared to standard vermicompost, biofortified vermicompost boasts a higher concentration of both macro- and micronutrients, and the presence of beneficial microbes aids in nutrient solubilization and bioavailability. It supports plant growth by promoting better root and shoot development, and improving nutrient uptake. Furthermore, biofortified vermicompost aids in managing crop diseases through mechanisms such as SAR ISR and production of antimicrobial compounds. It has been proven to be effective in suppressing soil-borne pathogens and foliar diseases. Nonetheless, challenges persist in standardizing its production, integrating it with other agricultural practices, and ensuring economic feasibility and scalability. Future research should focus on overcoming these challenges and exploring the role of biofortified vermicompost in the environmental management.

8. Research gaps and future directions

Several research gaps must be addressed to fully harness the potential of biofortified vermicompost. These include understanding the mechanisms involved in the vermicomposting process, optimizing the factors affecting vermicompost application, and clarifying the composition of bacterial communities in the final product (Vukovic et al., 2021). Future research should also focus on the effects of vermicompost on specific nutrient deficiencies in crops, its potential to mitigate soil degradation, and its role in pest management (Oyege and Bhaskar, 2023). Additionally, studies on the sociocultural aspects of vermicompost adoption and the development of policies to support its use in agricultural systems are needed (Sande et al., 2024). Exploring the potential of vermicompost in the remediation of organic contaminants and microplastics could open new avenues for its application in environmental management (Oyege and Bhaskar, 2023).

Table 2 Synergistic impacts of vermicompost and various microbes on plant growth

S.No	Base compost	Biofortified Agent	Target crop	Observed impacts	References
1.	De-oiled herbaceous residues of fragrant grasses	Azotobacter Chroococcum	Maize	Increase in chlorophyll content (chl a 1.44 mg/g , chl b 0.86), increase in carotenoid content, protein content (8.42%), calcium(21.96 mg/kg), phosphorous (19.94 mg/kg), iron (1.76 mg/kg)	Moeinnamin et al, (2024)
2.	Cow dung, vegetable waste, wheat straw and leaf litter	Rhizobium	Lentil	Increase in shoot length (43.83 cm), root length (43.83 cm),root length (19.52 cm), number of branches per plant (23.53)	Khalid et al, (2023)
3.	Kitchen scraps, yard waste, livestock manure, shredded paper, and cardboard	PSB, Arbuscular mycorrhizal fungi (AMF) , PGPR	Rice, cowpea, wheat, pepper, tomato, lentil, sunflower, maize, soybean, potato, chickpea, groundnut, marigold and rapeseed	Increase in crop yield seen (wheat 21.2%, chickpea 27.43%, maize 103%, rice 25%), nutrient uptake (phosphorous intake 71%, nitrogen uptake 114 % , total phosphorous 67%)	Sande et al, (2024)
4.	-	Pseudomonas spp. (Species), VBZ4 and Stutzeri VBZ17	Tomato	Increase in shoot length (58 cm), root length (33 cm), number of fruits (38.1) per plant, number of branches (28.9) per plant, Zn content (2.87 mg/ 100g) in fruits	Karnwal et al, (2021)
5.	Rice straw, *Eichhornia crassipes*, *Ipomoea carnea*, and their mixed biomass	*Azotobacter*, *chroococcum* , *Azospirillum brasilense*, *Pseudomonas fluorescence*	Rice	Increase in nitrogen content, shoot height (13.9%), leaf chlorophyll (11.9%), grain yield(27.3%), significant improvement in NPK	Mahanta et al, (2012)

Table 3 Impact of some beneficial microbes enriched vermicompost on crop diseases

S.N.	Crop	Pathogen/ Diseases	Treatment	Key findings	References
1.	Red onion (*Allium cepa L.*)	Fusarium basel rot in onion	*Eisenia foetida* *Trichoderma viride* *Pseudomonas fluoresences*	Biofortified vermicompost enhenced superior nutritional qualities, high growth and yield, low incidence of fusarium basel rot	Pakeerathan et al, (2023)
2.	Rice variety (Chor khing)	*Rhizoctonia solani*	*Trichoderma asperelloides*	Enhanced seed germination and seedling growth, increased root and shoot length, reduced incidents of sheath blight disease caused by *R. solani*	Wonglom et al, (2024)

3.	Tomato (*Solanum lycopersicum*)	Fusarium wilt disease	Bacillus spp., Pseudomonas spp., Lactobacillus spp., Aspergillus spp., and Trichoderma spp.	Low incidence and severity of fusarium wilt (31%)	Haruna and Gombe, , (2021)
4.	Tomato	Fusarium wilt disease	Bacillus spp. , Clostridium spp., and antibiotic producing microorganisms	Low incidence of fusarium wilt (35-60 %) , improved plant height (30.74 %), number of leaves (20.70%) , number of fruits (29.05%) and enhanced root development	Yatoo et al, (2024)
5.	Cowpea (*Vigna unguiculata*)	Root rot/ charcoal rot disease in cowpea	*Trichoderma herzianum* , *Trichoderma viride*	Trichoderma herzianum showed maximum disease inhibition (80%)	Subashini and Chithambaram, 2021
6.	Tomato	Vascular wilt in tomatoes	*Trichoderma asperellum* , *Bacillus subtilis* , *Pseudomonas aeruginosa*	T. asperellum showed highest antagonistic activity (87.38 %) ,	Raman et al, (2023)

Author's contribution

Roshni Bajaj (Research scholar): Review literature, Writing and Format analysis. **Jiwan Singh** (Asst. Professor): review, editing and validate the article. **Shikha** (Professor): review, editing and validate the article.

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Conflict of interest

The authors have disclosed no conflict of interest

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