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Review Paper

Microbial consortium-based biocontrol technologies for pulse crops

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ABSTRACT

Micro organisms linked to plants are crucial to agricultural output. Even though numerous studies have demonstrated that individual bacteria can benefit plants, it is becoming more and more clear that additive or synergistic effects are possible when two or more interacting microorganisms are involved in a microbial consortium. This happens partly because, in an ecosystem such as the rhizosphere, several species can carry out different duties. Thus, this review focuses on the plant growth stimulation that is exerted by various microbial players within the rhizosphere, including PGPB and fungi. These mechanisms include enhanced nutrient availability, phytohormone modulation, biocontrol, and biotic and abiotic stress tolerance. As a sustainable and environmentally benign substitute for traditional chemical pesticides or fungicides, the use of bioagents in pulse crop agriculture has attracted a lot of interest. Due to their high protein content, nitrogen-fixing capacity, and contribution to soil health, pulse crops such as beans, lentils, chickpeas, and peas are essential to global agriculture; however, maximizing their yield requires efficient management of pest diseases, in which biocontrol agents consortium are play crucial role.

Key words: Biocontrol, Microbial Consortium, PGPB, Pulse Crop

INTRODUCTION

India is the world's largest producer of pulses, with more than 35 Mha of cultivated land (Annual Report-2022-23, DPD, Bhopal). Pulse crops, including beans, lentils, chickpeas, and peas, play an essential part in world agriculture due to their high nutritional content and capacity to boost soil health with biological nitrogen fixation (Vessey 2003 and Bhattacharyya *et al.* 2012). Pulses are an important part of the agricultural economy (Choudhary 2009). These crops are abundant in protein and important amino acids, hence they are a staple in the Indian vegetarian diet. India's pulse production is lower than other countries due to factors such as marginal and sub-marginal land use, improper use of biopesticides and biofertilizers, insufficient availability of quality seeds, poor crop management practices, and abiotic and biotic stresses.

Crop production relies significantly on pesticides to manage diseases and pests (Sivasakthi *et al.* 2014) and chemical fertilizers to provide adequate nutrients for crop yield optimization (Gruhn *et al.* 2000). Concerns have been raised about the use of pesticides and chemical fertilizers, which can lead to pathogen resistance (Georghiou 2012), environmental pollution (Zhang *et al.* 2011), contamination of surface and ground waters (Savci 2012) and negative effects on humans, beneficial soil microorganisms, insects, birds, and fishes (Muñoz-Leoz *et al.* 2013). One strategy to address these problems is to develop and deploy alternative crop protection management methods, such as biopesticides and biofertilizers containing plant-growth-promoting rhizobacteria (PGPR) (Banerjee *et al.* 2005, Chandler *et al.* 2011, Subba Rao 1993). PGPR is a collection of beneficial bacteria that regulate plant growth (Huang *et al.* 2016), yield (Liu *et al.* 2016) and nutrient uptake (Calvo *et al.* 2016), as well as biological disease control (Xiang *et al.* 2017b).

Microbial consortia consist of two or more microbial species that coexist (Ram *et al.* 2022). In nature, microbial species linked with plants or animals rarely interact with their hosts in isolation; rather, their effects reflect co-evolved relationships with other microorganisms. These consortia interact with plants in both biotic and abiotic ways, frequently as symbiotic interactions and their co-adaptation may serve key agroecological roles (Bhatt *et al.* 2021). Recently, there has been an interest in mixing microbial species that do not naturally inhabit the same biological niche (Arif *et al.* 2020).

These artificial microbial consortia were first created for the pharmaceutical and food industries (Ergal *et al.* 2022). Probiotics, for example, have recently attracted attention for their therapeutic effects on human and animal health, such as regulating gut microbiota and immune function (Wang *et al.* 2021).

In agriculture, the application of various microorganisms has garnered attention because of their ability to fulfill ecological tasks, including soil bioremediation (Rajpal *et al.* 2023, Siripattanakul-Ratpukdi *et al.* 2014), plant growth promotion (Chen *et al.* 2021, Kaur *et al.* 2022) and pest and disease suppression (Muthuraja and Muthukumar 2022, Upamanya *et al.* 2020). Despite the favorable results described in the preceding examples, single PGPR strains have not been employed on a diverse range of plant hosts and have frequently demonstrated variable field efficacy for a variety of reasons (Pal and Gardener 2006). First, a single PGPR strain does not often provide biological control against numerous diseases (Backman *et al.* 1997). Second, a single strain is unlikely to be sufficiently active against various diseases given the field's different environmental circumstances (Elmqvist *et al.* 2003). The development of PGPR mixes is one technique for dealing with numerous mechanisms of action and biocontrol of multiple diseases (Jetiyanon and Kloepper 2002). *Mesorhizobium*-based inoculant technology, the creation of non-rhizobial plant-associated bacteria can increase chickpea productivity while lowering the requirement for synthetic fertilizers (Nysanth *et al*. 2024).

Several studies have shown that PGPR combinations can boost biological control activity for numerous plant diseases by inducing systemic resistance (Raupach and Kloepper 1998), as well as for a specific plant disease through antagonism (Xiang *et al.* 2017$_a$). A few studies have been undertaken to examine whether combinations of PGPR strains can improve the biological control activity of several plant diseases through antagonism (Domenech *et al.* 2006). This paper looks at recent applications and prospects for microbial consortia in sustainable agriculture.

MICROBIAL CONSORTIUM

A microbial consortium is typically defined as a collection of various microorganisms capable of cooperating as a community. Microbial communities are abundant in their natural environment and play important roles in the global carbon and nitrogen cycles (Massot *et al.* 2022). Microbial communities' interactions can be broadly characterized as cooperative or non-cooperative (Zapalski 2011). Symbiosis, mutualism, and commensalism are examples of cooperative (positive) microbial interactions (Bhatia *et al.* 2018). Non-cooperative (negative) interactions include parasitism, amensalism, and predation (Jagmann and Philipp 2014).

Microbial consortia are classified as artificial, synthetic, or semisynthetic. According to Massot *et al.* (2022), artificial consortia are made up of microbial strains that do not normally cohabit but are chosen for specific purposes. Synthetic consortia are made up of two or more genetically modified microorganisms, whereas semi-synthetic consortia include bacteria from both natural and genetically modified populations. This approach allows for the formation and management of consortia that can be strategically used in agricultural applications (Padmaperuma *et al.* 2020). To create viable microbial consortia, both prior knowledge and empirical testing are required (Gehlot *et al.* 2021, Ghosh *et al.* 2016).

MAJOR PEST AND DISEASES OF PULSE CROPS

Changes in cropping practices, fungicide and pesticide treatment patterns, and the introduction of high-yielding cultivars have all contributed to a substantial alteration in the pest-disease complex of pulses over the last two decades. The primary pest diseases, which have grown increasingly difficult to control as a result of pesticide/fungicide resistance, resurgence, and secondary outbreaks caused by indiscriminate use of chemicals, constitute a serious threat to pulse crop output (Table 1).

Table 1. Major pests and diseases infesting different pulse crops

Name of pulses	Pest	Diseases
Gram	Gram pod borer, Cutworm, Termite	Fusarium wilt, Ascochyta blight, Botrytis grey mould, stunt virus
Greengram, Blackgram and Cowpea	Whitefly, Stemfly, Spotted pod borer, Galerucid beetle	Yellow mosaic virus, Cercosora leaf spot
Pigeon pea	Pod borer, Pod fly, Spotted pod borer, Plume moth	Sterility mosaic virus, Fusarium wilt, Phytophthora stem blight, Alternaria leaf spot and powdery mildew
Fieldpea	Pea leafminer, Stem fly	Powdery mildew
Lentil	Black aphid, Spiny pod borer	Rust, wilt

BUILDING A CONSORTIUM OF MICROORGANISMS

The selection of microorganisms comprises various processes, including selecting strains with the required function, evaluating compatibility and synergism between the strains, and performing evaluation under field settings (Behera *et al.* 2021, Roell *et al.* 2019). The following things need to be considered while preparing a microbial consortium:

- Choose chassis strains: Select strains with low mutation rates, nontoxic byproducts, and high tolerance.
- Consider coexistence: Ensure that the strains are compatible with one another.
- Divide the deterioration pathways: Divide long degradation routes into several strains.
- Consider spatial distribution: An orderly distribution of strains can increase the consortium's efficiency.

They may be endosymbiotic, ectosymbiotic or both. Consortiums can respond to environmental stress as a single organism and maintain plants more effectively than separate strains.

Microbial consortium in pulse crops

Control of major diseases

Many examples of microbial consortia established in agriculture target plant diseases. Some research implies that microbial management of plant diseases is improved with multiple strains of microorganisms containing diverse mechanisms of action (Table 2).

The synergy between diverse microbial taxa can provide multiple agricultural benefits. Siddiqui and Akhtar (2009) discovered that combining the filamentous fungus *Purpureocillium lilacinum* with soil nitrogen-fixing bacteria *Rhizobium* sp. provides greater protection against the root-knot nematode *Meloidogyne javanica* and plant growth than strains applied separately. In this example, the authors claimed that while *P. lilacinum* parasitized the females and eggs of *M. javanica*, antibiotics and phytoalexins produced by *Rhizobium* had suppressive effects on the worm. Guetsky *et al.* (2007) found that combining *Pichia guilliermondii* and *Bacillus mycoides* yeast had a synergistic effect on grey mold. In this example, disease suppression was achieved by a combination of mechanisms, including nutrition competition, germination inhibition, and conidial damage. The authors indicated above discovered that a combination of *Pichia guilliermondii* and *Bacillus mycoides* had additive activity when compared to separate applications using multiple regression analysis. Yadav *et al*. (2024) assess the effectiveness of biocontrol agents such as *Trichoderma viride*, *T. harzianum* and *Pseudomonas fluorescens*, against *Sclerotinia sclerotiorum* in vitro and found that every biocontrol agent inhibited *S. sclerotiorum*'s mycelial growth. In this example, disease suppression was achieved by a combination of mechanisms, including nutrition competition, germination inhibition, and conidial damage. Arif *et al*. (2023) isolated seven isolates of *Trichoderma* out of them three isolates were found to be extremely effective in preventing the growth of *Alternaria alternata*, *Fusarium ciceris*, *Sclerotium rolfsii*, *Macrophomina phaseolina*, *Fusarium udum* and *Fusarium ciceris*.

Botanical extracts are used in several plant pathogen-targeting consortiums. Panpatte *et al.* (2021) used a consortium of *Providencia vermicola* AAU PR1 and two *Pseudomonas* spp. (*P. putida* AAU PR2 and *P. fluorescens* AAU PR3) to suppress *M. incognita*. The consortium was supplemented with extracts of *Azadirachta indica*, *Ipomoea carnea*, and *Brassica juncea*. The fortified consortium demonstrated the most effective suppression of M. incognita eggs, which the scientists attributed to the botanical extract's synergistic action with bacterial strains.

Table 2. Different microbial consortium and their targeted pathogens.

Microbial consortium	Pathogen
Trichoderma sp., *Bacillus* sp. and *P. fluorescens*	*Sclerotinia sclerotiorum*
Sphingomonas paucimobilis, Microbacteria sp., *Brevundimonas vesicularis, Pseudomonas rubrisubalbicans* and *Alcaligenes eutrophus*	*Xanthomonas campestris*
Pseudomonas fluorescens and *Enterobacter cloacae*	*Phytophthora infestans*
Pseudomonas fluorescens and *Beauveria bassiana*	*Rhizoctonia* spp.
Trichoderma viride and *P. fluorescens*	*Pythium aphanidermatum*
T. harzianum, B. bassiana and *Metarhizium anisopliae*	*Phomopsis, Alternaria* and *Fusarium*
Funneliformis mosseae, Glomus fasciculatum and *Bacillus* sp.	*Fusarium oxysporum*

Use of Trichoderma in consortia

The ubiquitous soil fungus *Trichoderma* spp. has been widely generated and improved for commercial use in agriculture to prevent plant diseases (Lorito and Woo 2015, Monte and Hermosa 2021). *Trichoderma* inhibits plant diseases directly by parasitism, competition, antibiosis, and the generation of enzymes, volatile organic compounds, and secondary metabolites, as well as indirectly through resistance induction (Lorito and Woo 2015, Monte and Hermosa 2021, Woo *et al.* 2014). Although largely employed to inhibit root infections, *Trichoderma* can provide additional functions, such as enhancing nutrient availability through mineralization and solubilization and promoting soil structure and plant growth (Bononi *et al.* 2020).

Trichoderma spp. is used in a wide range of products worldwide. Bettiol *et al.* (2019) identified 246 registered items containing *Trichoderma*. 28% of these were formulated with mixed *Trichoderma* species strains or with other microorganisms, such as *Arthrobacter*, *Azotobacter*, *Bacillus*, *Pseudomonas*, *Azospirillum*, *Rhizobium*, *Beauveria*, *Metarhizium*, *Saccharomyces*, *Purpureocillium*, *Streptomyces*, *Agrobacterium radiobacter* and *Pochonia chlamydosporia*.

Control of pests

Numerous crop losses have resulted from pests infected pulses, making it more difficult to sustain and boost crop yield and production, range of insect pests has evolved, with several once-minor pests now becoming serious dangers (Bhowmik and Yadav 2025). In the late 20th century, *Metarhizium anisopliae* was shown to effectively manage Japanese beetles (*Popilia japonica*) (Faria, 2001). Recent studies (Aynalem *et al.* 2022, Biryol *et al.* 2022) have employed entomopathogenic microorganisms to manage various pests. However, some studies have demonstrated that combining diverse microorganisms can improve control by increasing virulence-associated metabolites and other compounds with antioxidant and anti-inflammatory characteristics. Such components have been shown to depress the insect immune system and allow infection by entomopathogenic bacteria (Metwally *et al.* 2022, Nawaz *et al.* 2020, Soth *et al.* 2022, Wu and Duncan 2022).

Several studies have shown that combining microorganisms improves insect pest control when compared to single-strain applications. When treated separately, four *Beauveria* species showed rather low pathogenicity. However, when combined as a consortium, these species caused 100% mortality in *Plutella xylostella*, showing a synergistic impact (Soth *et al.* 2022). Stuart *et al.* (2022) found that combining two strains of *Bacillus bassiana* (Bov 2 and Bov 3) boosted virulence against *Duponchelia fovealis* larvae compared to using either strain alone. In this case, higher chitinase and lipase activity in the mixture, discovered via a metabolomic technique, were hypothesized to depress host immunity, increasing vulnerability to fungal infection.

In the field, entomopathogens used for pest management may compete with local bacteria. Iwanicki *et al.* (2019) used microsatellite markers to track the impact of the ESALQ1604 strain of *Metarhizium anisopliae* on sugarcane spittlebugs, *Mahanarva* spp. The findings revealed that native strains of *M. anisopliae* accounted for up to 50% of all affected insects, considerably contributing to the overall biocontrol of this pest. The use of molecular markers to follow the fate and persistence of entomopathogens in the field is an important technique for understanding their interactions with native microorganisms, as it is unclear how such interactions affect biological control.

There are rare reports of microbial consortia that include more than two phyla. Spescha *et al.* (2023) tested a soil bacteria (*Pseudomonas chlororaphis*), nematode (*Steinernema feltiae*) and fungus (*Metarhizium brunneum*) against the soil-dwelling pest, the *Delia radicum*. Based on laboratory, greenhouse and field studies, the scientists discovered that all three species were compatible and did not hinder each other's infectivity or survival in soil or roots. Furthermore, they found that mixtures of bacteria, nematodes and fungi could have synergistic effects.

Soil health

Microbial activity is critical for soil health (Fierer *et al.* 2021). Soils with significant microbial biomass, for example, have the ability to accumulate and cycle organic and inorganic nutrients (Gregorich *et al.* 2011). Microorganisms have a crucial role in soil biogeochemical processes, such as lignin and cellulose breakdown and carbon storage (Lei *et al.* 2018, Sun *et al.* 2017).

The use of microbial consortia to increase soil health is very new and understudied. However, preliminary research suggests that this strategy may have a number of advantages, including increased soil fertility, nutrient uptake and crop yields (Anshu *et al.* 2022, Lei *et al.* 2018, Vishwakarma *et al.* 2020). For example, using the fungi *Trichoderma harzianum*, *Gluconcetobacter diazotrophicus* and *Pseudomonas fluorescens* (109-10 CFU/mL liquid culture) resulted in a 50% reduction in NPK requirements due to improved cation exchange capacity between soil and roots (Shukla *et al.* 2020). Because they can develop symbiotic partnerships with nitrogen-fixing bacteria, legume vegetables, are essential for improving soil health and human nutrition (Santhiya *et al*. 2024). Bacterial consortia can speed composting of green wastes by promoting lignocellulose degradation (Oviedo-Ocana *et al.* 2022).

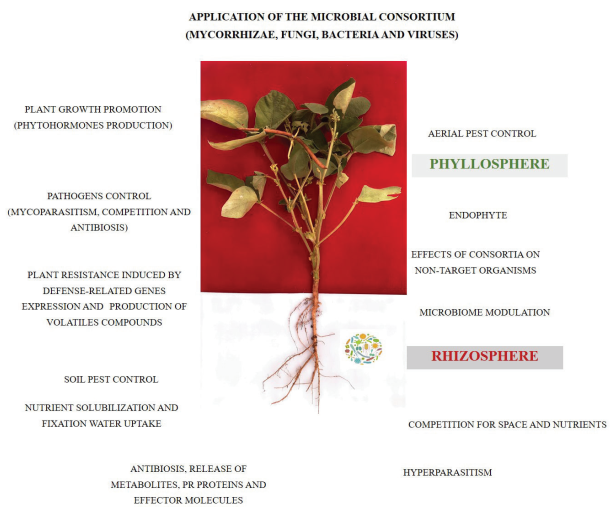

Fig. 1. The effects of using microbial consortiums.

LIMITATIONS

When biocontrol chemicals are used, they frequently fail to compete with the local microbial population and begin to establish themselves in the soil. Biocontrol agents provide effective control when their growth is maintained in the formulation; however, mismanagement can disrupt their growth, preventing them from controlling infections and promoting plant growth.

FUTURE PROSPECTS

The usage of microbial consortium is a new and promising subject nowadays. In affluent countries, they are being used quite well to increase pulse output. As a result, underdeveloped countries must consider using consortiums for biocontrol practices. Using microbial consortium requires rational thinking, such as

1. Select an effective strain for consortium production.
2. Identifying host genes that influence efficiency and competitiveness.
3. We should hold informal workshops in communities to teach farmers about the long-term use of microbial products and the negative impacts of chemicals.
4. Agronomic practices, soil conditions and socioeconomic factors should all be considered when assessing microorganisms effectiveness.
5. Microbial consortia can be tailored to individual crops and environmental circumstances, enabling precision agriculture. Tailoring microbial communities to match the particular needs of different plants could increase overall pulse crops productivity.

CONCLUSION

Microbial consortiums provide significant benefits to agriculture and have minimal input costs. As per the many results, microbial products yielded promising results in both controlled and field environments. Soils in India are nutrient-depleted, thus we need to supplement them so microorganisms play an important role as a biofertilizer and improve pulse output. The future of microbial consortia in plant care and protection looks promising, with creative options for sustainable agriculture. However, tackling the associated problems is critical to realizing their full potential and ensuring appropriate deployment in the agricultural landscape. As a result, we should all make significant efforts to raise awareness about the use of microorganisms-based products in India. Microbiologists, environmentalists, soil chemists, and agronomists must work together to support the efficient development and application of microbial consortiums.

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