International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; SP-8(4): 129-132
www.biochemjournal.com
Received: 08-01-2024
Accepted: 15-03-2024

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Biocontrol potential of *Trichoderma* and *Pseudomonas:* A review

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DOI: https://doi.org/10.33545/26174693.2024.v8.i4Sb.933

Abstract
Trichoderma and *Pseudomonas* are both well-known biocontrol agents used in agriculture to combat various plant diseases. These beneficial microorganisms employ distinct mechanisms to suppress pathogens and promote plant health. *Trichoderma* spp. are fungi that establish symbiotic relationships with plant roots. *Trichoderma* species are renowned for their antagonistic properties against various soil-borne pathogens. They compete for resources, produce antifungal metabolites, and stimulate the plant's defense mechanisms. *Trichoderma* also forms mycoparasitic interactions, directly attacking and degrading pathogenic fungi.
Pseudomonas spp., particularly *Pseudomonas fluorescens* and *Pseudomonas putida*, are bacteria with potent biocontrol capabilities. They produce antibiotics and secondary metabolites that suppress pathogen growth. Pseudomonas also colonize plant roots and form a protective barrier against pathogenic invasion. These bacteria can solubilize phosphates and fix atmospheric nitrogen, providing essential nutrients to plants. *Pseudomonas* strains stimulate plant defense responses, activating systemic acquired resistance.
In sustainable agriculture, the use of *Trichoderma* and *Pseudomonas* as biocontrol agents offers an environmentally friendly alternative to chemical pesticides. When applied as inoculants or through seed treatments, *Trichoderma* and *Pseudomonas* establish a beneficial presence in the rhizosphere, creating an environment unfavorable for pathogenic organisms. Their multifaceted approaches to disease management contribute to improved crop yields, reduced chemical input, and enhanced soil health, paving the way for more resilient and ecologically balanced farming systems.

Keywords: *Trichoderma, Pseudomonas*, biocontrol

Introduction
In the current global scenario with a constant increase in the world population one of the major challenges is to intensifying agriculture production. Due to which use of chemical fertilizers and pesticides (DDT, Urea, Ammonium Chloride) are increasing and causing harmful effects like accumulation of toxic residues in environment and resistance of pathogens to such chemicals (Jorge Poveda. 2021) [24]. So, to reduce these we need to adopt stable and sustainable methods for plant disease management and thus the use of biocontrol agents came into limelight. Biocontrol agents can be defined as the use of natural efficient strain of any microorganisms or modified organisms that helps to reduce the severity of diseases caused by plant pathogens, or toxicities caused by fertilizers and pesticides (Panpatte *et al*. 2016) [2]. There are different types of biocontrol agents like *Bacillus* sp., *Pseudomonas* sp., *Trichoderma* sp., *Beuveria* sp. Among all of them the most effective biocontrol agents are *Trichoderma* sp. and *Pseudomonas fluorescens*. They have the ability to colonize the rhizosphere and are persistence throughout the growing season. They also help to enhance plant growth and control plant pathogenic microbial population.

Biocontrol mechanisms of *trichoderma* against different plant pathogens
Trichoderma a genus of filamentous fungi has gained significant attention for its potential as a bio control agent against various plant pathogens. Its effectiveness can be attributed to several bio control mechanisms such as
i) Antibiosis Production
ii) Competition
iii) Mycoparasitism (Fig. 1)

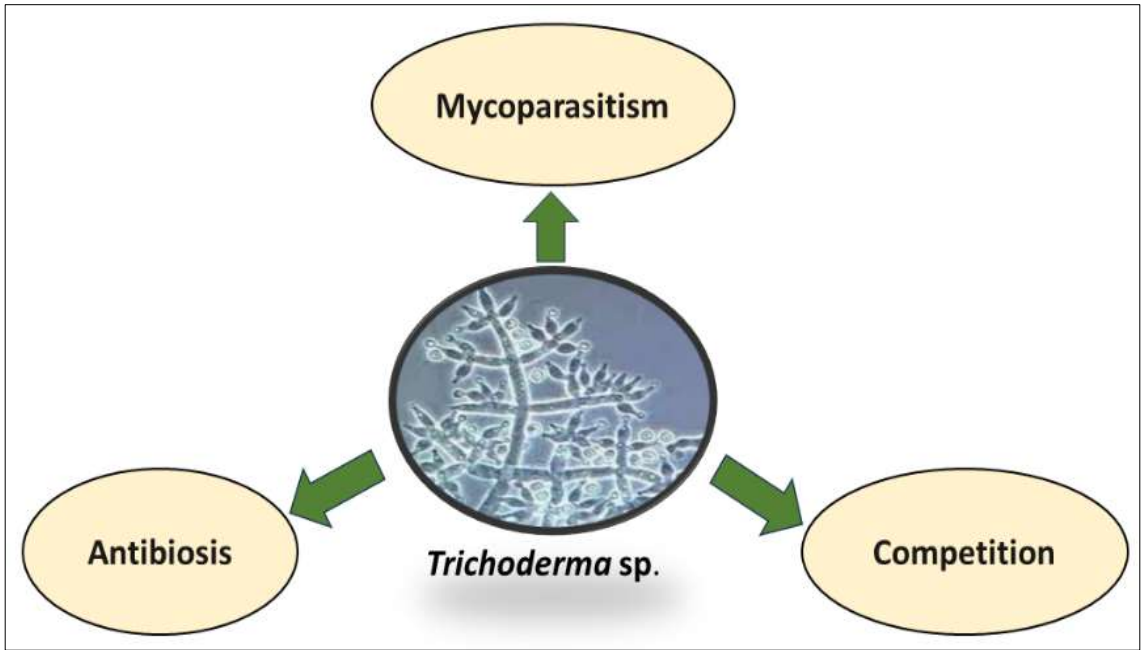

Fig 1: Biocontrol mechanism of *Trichoderma* sp.

Antibiosis Production

It is one of the primary mechanisms through which *Trichoderma* exerts its bio control activity. *Trichoderma* species produce a diverse range of secondary metabolites, such as antibiotics, volatile organic compounds (VOCs) and lytic enzymes. The production of low molecular weight, non-polar, volatile compounds result in a higher concentration of antibiotics in the soil environment that have relatively long distance range of influence on the microbial community.

Volatile antibiotics i.e. 6-pentyl apyrone and most of the isocyanide derivates. Water soluble compounds ie heptelidie acid or koningic acid. Peptaibols, which are linear oligopeptides of 12-22 amino acids rich in a-amino sobutyric acid, N- acetylated at the N-terminus and containing an amino alcohol at the C- terminus. (Mukherjee *et al*. 2010) [23].

Competition

Trichoderma is an aggressive saprophyte that efficiently colonizes various ecological niches. Competition for nutrients is the important factor for fungi as its competition for light in case of evolution of plants (Garrett 1956). Root exudates and rhizosphere are rich source of nutrients such as sugar amino acid, iron, vitamins, organic acid etc. Production of organic acids such as gluconic, citric and fumaric acid which decrease soil pH and allow the solubilization of phosphates, micronutrients and mineral cations like iron, manganese and magnesium (Vinale *et al*. 2008) [21].

In the aerobic environment (with oxygen and neutral pH) iron exists mainly as Fe3+ and tends to form insoluble ferric oxide making it unavailable for root absorbtion and microbial growth (Miethke 2013) [25].

Mycoparasitism

It is a specialized mechanism where *Trichoderma* directly attacks and parasitizes other fungi including plant pathogens. Antagonist fungi parasitize other pathogenic fungi such as hyphae of *Trichoderma* either grow along the host hyphae or coil around it. Mycoparasitism is very effective against soil borne pathogens and significantly to disease suppression (Mukhopadhyay and Kumar 2020) [14].

Biocontrol mechanisms of *pseudomonas fluorescens* against plant pathogens

Over the last few years, a great diversity of rhizosphere microorganisms has been described, characterized and in many cases tested for activity as bio control agent against soil borne plant pathogens. For achieving biological control, antagonists should have the ability to colonize root system effectively (Weller 1988; Parke 1990) [12, 15] and to produce certain antagonistic secondary metabolites (Defago and Hass 1990) [3] (Fig. 2). The major mechanisms by which *Pseudomonas* exerts its biocontrol effects are:

i) Antibiotic Production
ii) Competition for Root Niches and Nutrients
iii) Induced Systemic Resistance
iv) HCN Production
v) Siderophore Production

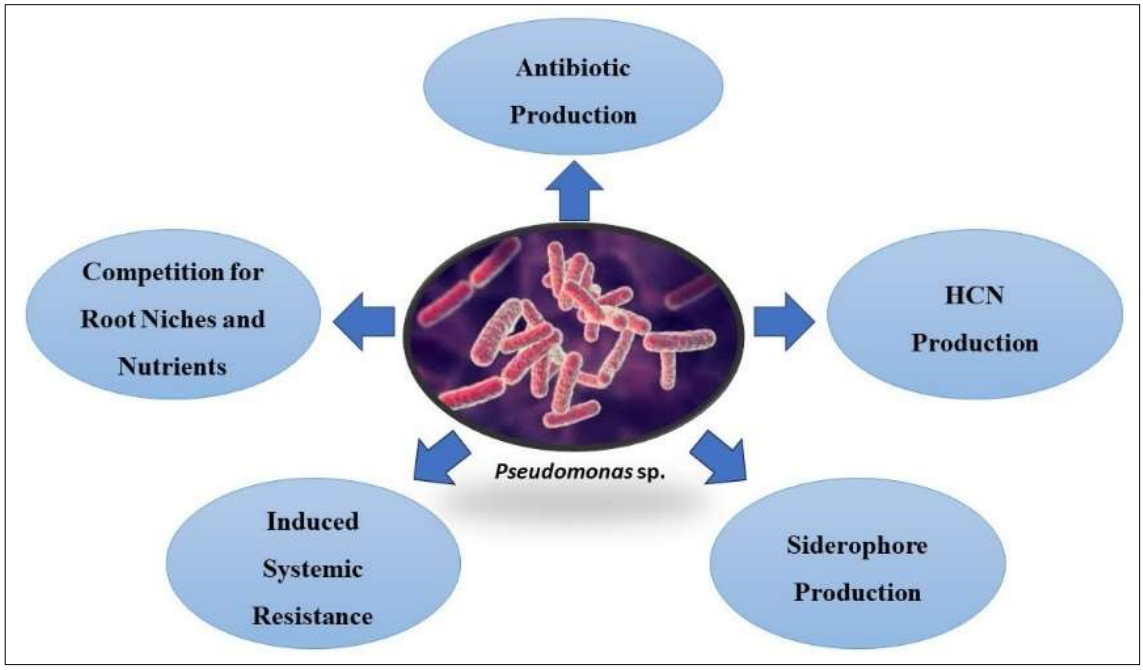

Fig 2: Biocontrol mechanism of *Pseudomonas* sp.

Antibiotic Production

Antibiotics are heterogenous group of low-molecular weight organic compounds that are harmful for the growth of other microorganisms. Production of antibiotics is the important mechanisms which helps the plant growth promoting rhizobacteria to facilitate antagonistic action against phytopathogens (Glick *et al*. 2007) [7]. There are six classes of antibiotics which are associated with bio control of plant disease like - Phloroglucinal, phenazines, pyrrolnitrin, pyoluteorin, cyclic lipopeptides and hydrogencyanide (Hass and Defago 2005) [3]. The most important antibiotic is 2,4-diacetylphlroglucinol (DAPG) which is produced by *Pseudomonas*. It helps to suppress disease of roots and young seedlings of various crops e.g. -suppression of fusarium wilt, crown and root rot of tomato (Duffy and Defago 1997; Tamietti *et al*. 1993) [4, 19].

Competition of Root Niches and Nutrients

The highly microbial diversity, competition that are occurring in the rhizosphere are challenging the biological buffering (Keel *et al*. 1996) [11]. Therefore, introduction of *Pseudomonas* is very important so that it can colonize the roots and can provide protection against all soil borne pathogens. Biocontrol agents are used in soils so that it can compete with harmful microorganisms and pathogens for limiting the availability of nutrients in root exudates and suitable for colonizing the niches. By increasing the competition for nutrients like iron helps to remove fungal pathogens from soil (Sahu *et al*. 2018) [17].

Induced Systemic Resistance

ISR can be defined as the spectrum plant immune response activates by beneficial plant bacteria that lives in together with plant root. ISR has many mechanisms like plant growth promotion, physiological tolerance induction of all wall reinforcement and also increase in production of phytoalexins, defense enzymes, lignin deposition (Jain *et al*. 2012; Jain *et al*. 2013; Jain *et al*. 2015; Singh 2014) [10, 9, 8, 18]. Such immunized plants express responses faster and stronger after pathogen attack which enhance the level of protection (Van Peer *et al*. 1991) [20].

HCN Production

Plant growth promoting rhizobacteria produce chemical compound with different benefits for the plants. The production of HCN is one of the most important mechanisms produced by *Pseudomonas fluorescence* and was found effective against *Thielaviopsis basicola* on tobacco (Laville *et al*. 1992) [13]. According to Ellis *et al*. (2000) [5], there is a strong correlation between production of HCN and biological control of fluorescent *Pseudomonas*. In the pathosystems of the tomato/*Fusarium oxysporum* f. sp. *radicis-lycopersici* and cucumber/*Pythium ultimum*, it was discovered that in vitro HCN generation and plant protection were positively correlated (Ramette *et al*. 2003) [16].

Siderophore Production

Iron is one of the most essential and abundant components but, microbes cannot obtain iron enough as they are present as insoluble ferric hydroxide, which cannot be easily transferred into cell. By adding metal chelating compound such as siderophore which are produce by *Pseudomonas*, it plays an important role in iron metabolism. Siderophore helps in promotion of plant growth and for controlling phytopathogens and diminishing the toxic effects of heavy metal in soil (Panpatte *et al*. 2016) [2].

Conclusion

In recent years plant disease control depends heavily upon variety of chemical pesticides which not only threaten agricultural crops but are also harmful for human health. The versatility of biocontrol agents makes strategies which are making them a promising alternative to chemical pesticides and it also offering sustainable and environment friendly solution for disease management. Biocontrol agents helps to reduce reliance on chemical treatment and gives a more balanced and sustainable ecosystem. *Pseudomonas* and *Trichoderma* are the important biocontrol agents which

have different mechanisms to work effectively against pathogens and contributes significantly to disease suppression. Apart from disease suppression they help in plant growth promotion, higher yield and production. Many research centres also started studying with a aim of replacing chemical pesticides with environment friendly methods. This scientific interest in biocontrol against plant pathogens is for growing public concern over chemical pesticides.

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