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BIOLOGICAL CONTROL OF PLANT PATHOGENS BY USING ANTAGONISTIC BACTERIA: A REVIEW

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ABSTRACT

The application of synthetic pesticides viz fungicide, bactericide, and nematicide to control the harmful phytopathogens that have a terrible impact on all living environments. Therefore, the developing countries have banned the further application of pesticides and usage of an alternate approach than synthetic pesticides, which have no side effect on plant health, human health, and on the living environment that are more cost-effective and eco-friendly behavior. The term biological control through beneficial microorganisms is an alternative approach to control the phytopathogens, which causes severe loss to important crops worldwide. This review article has focused on the antagonistic behavior of bacteria against fungal plant pathogens, bacteria, and nematodes. The bacterial species, especially *Bacillus, Pseudomonas,* and *Streptomyces* applied as antagonists against bundles of phytopathogens by a different mode of action. The antagonistic bacteria produce different antimicrobial compounds to suppress the growth of targeted pathogens. To suppress the growth of pre and post harvested fungal and bacterial pathogens, the biocontrol (BC) bacteria produce siderophore, antibiosis, parasitism, competition for space and nutrients, and biofilm formation. Induction of resistance in host plants also generated by biocontrol bacteria through the production of Indole acetic acid (IAA) and activities of the effector genes in host. The commercial products prepared by using the antagonistic bacteria such as *Cryptococcus albidus, Pseudomonas syringae, Bacillus subtilis, Candida oleophila' and Aureobasidium pullulans* used to control the different phyto-fungal pathogens. This review article covers the three-parts, in the first part, we discussed the antagonistic potential of bacteria against fungal pathogens, in the second part, we discuss the antagonistic potential of bacteria against bacterial pathogens and third part contain the antagonistic potential of bacteria against plant-parasitic nematodes.

Keywords: Biocontrol agent, antagonistic bacteria, bacteria against bacteria, biological control of phytopathogen, biofilm formation, siderophore, antibiosis, commercial product.

INTRODUCTION

Plants are indeed connected in different ways with assorted microorganisms(Yadav *et al*., 2017). Among these microorganisms, antagonistic bacteria are one that colonizes the aboveground part, seeds, and roots of plant without any damaging to host cell. (Liu *et al.*, 2017). Bacteria testified as endophytes consist of momentous gram-positive along with gram-negative bacteria naturally belongs to three significant genera (*Alpha*, *Beta,* and *Gamma proteobacteria)*. Even though findings related to endophytic bacteria have not much dedication, it's the most beneficial trait of microbiological studies. Plant growth was significantly indorsed by the endophytic bacteria, retain the capability of phosphate solubilization as well as distribute the nitrogen to plant. Additionally, phytohormones production is linked with

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plant-growth promoting action and enzymes entangled with growth metabolism (Taghavi *et al.*, 2009). Bacteria as plant pathogens can inhabit and colonize the ecological region of plant and have broadly recognized mechanisms regarding biocontrol activity like competition on an ecological region for space, assembly of general inhibitory chemicals, and systemic resistance brought against pathogens in the host plant (Zhuang *et al.*, 2007). The process of ecosystem restoration in a real manner helped the plant in growth with the comfort of plant and bacteria interaction. Bacterial endophytic species can survive on different host plant species.

In the past few decades, chemical fungicides have had a critical role in controlling plant diseases and increasing crop yield. Until now, suppression of soil-borne pathogens mainly relied on chemical pesticides. However, recently, scientists have reported that long-term use of chemical agents can cause adverse effects, including environmental contamination, resistant-plant pathogen outbreak, progressively higher production costs owing to the over-expenditure on these chemicals, and even toxicity in humans. Fortunately, biological control, using antagonistic bacteria as biocontrol agents (BCAs) that interfere with plant pathogens, could be an alternative to chemical control measures and could avoid the problems caused by chemical methods for plant protection(Tan *et al.*, 2006). Biological control agents (also called biocontrol agents or BCA) can play an essential role in suppressing root pathogens in soilless systems. Biocontrol agents are those products that control plant pathogens or pests or reduce their amount or their effect by one or more organisms other than a man (i.e., viruses, bacteria, fungi, and insects). Among the action mechanisms proposed is Mycoparasitism, with the concomitant production of enzymes by the microbes that degrade cell walls. Chitinolytic enzymes, together with ß-glucanases or cellulases, are the enzymes most frequently considered critical in biocontrol (Wang *et al.*, 2019). These antifungal proteins such as chitinases, glucanases are of great biotechnological interest because of their potential use as food and seed preservative agents and for engineering plants for resistance to phytopathogenic fungi. As antifungal activity is the most common feature for bacterial species, thus antagonistic bacteria are considered as an ideal biological control agents. The bioactive compound produced by bacteria may act as suppressors or/and inhibitors in the development of phytopathogens (Feichtmayer *et al.*, 2017).

Mechanism of action used by antagonistic bacteria against fungal plant pathogens: Bacteria follow a minimum of two methods of antagonism for the hindrance of various microscopic organisms, which have characteristics of controlling various fungal diseases(Safdarpour and Khodakaramian, 2019). Through parasitism and competition method, bacteria species compete with other fungal pathogens. Mostly the biocontrol bacteria are applied against the post harvested fungal pathogen and sometimes applied against the pre-harvested fungal pathogen in field condition. Here are a few examples of bacteria in which bacteria work as a biocontrol against the fungal pathogen both pre and post harvested conditions (Thokchom *et al.*, 2017; Bahadou *et al.*, 2018) (Tab.1). The mechanism followed by bacteria to suppress the fungal pathogens are mentioned below with detail.

Competition for Space and Nutrients: Food and space competition is a crucial antagonistic mechanism utilized by bacteria for managing various phytopathogens(Di Francesco *et al.*, 2016). Bacteria have the ability to colonize on scratched fruit to ingest the food (Carbon source) for their survival, restricting carbohydrate tendency for fungus, decreasing its germination rate, and accordingly reduced invasion capability on a host (Hernandez-Montiel *et al.*, 2018). Distinctive in vitro investigation has revealed that diverse carbon sources, predominately sucrose, glucose, and fructose, were limited to phytopathogenic fungi by various antagonistic bacteria(Adrees *et al.*, 2019). Limitation to phytopathogenic fungi becomes greater when carbon uptake increased by antagonist; hence, it is crucial to implement studies regarding usage of bacterial antagonists to conclude the lowest application criteria needed to limit the fungi on the host(Asari *et al.*, 2016). *Pseudomonas putida* is one of the bacteria that repressed the spore germination percentage of *P. digitatum* because of nutrient accessibility on the host(Yu and Lee, 2015). Further, other bacteria known to restrict the diverse infectious fungi utilizing carbon sources are Pseudomonas(Thokchom *et al.*, 2017), Bacillus(Chen *et al.*, 2016), and Pantoea species(Kim *et al.*, 2016).

Siderophore production: Microorganism development relies on an essential component that is iron(Terpilowska and Siwicki, 2019), the stable iron oxide multiplex forms when Fe2+ and Fe3+ oxidize with each other depending on the availability of water and oxygen. These complex molecule secluded with siderophore; bacteria is responsible for its production as they are peptide molecules having lateral chains along with functional groups which deliver high-affinity towards iron ions(Golonka *et al.*, 2019). Siderophore is distributed into four categories: 1) Catolatephenate 2) pyridoxines 3) Carboxylates and 4) hydroxamates(Carroll and Moore, 2018). Bacteria form siderophore, inhibit, and dislocate pathogenic organisms in host plants. Spore germination was limited by siderophore as well as mycelial growth of fungus(Cordova-Albores *et al.*, 2016). Antagonistic bacteria was recognized and reported that they produce varied forms of siderophores, some are used by diverse microorganisms, although remaining are particular to each species of bacteria. Their production was identified and proved to be beneficial for bacteria as biological control agent (BCA) by rejecting other pathogenic microorganisms on the plant(Drehe *et al.*, 2018; Zeng *et al.*, 2018). As far as competition was concerned to attain iron, greater inhibition of phytopathogen determine by the formation of siderophore with antagonistic bacteria(Andreolli *et al.*, 2019).

Table 1. Antagonistic capability of bacteria against fungal plant pathogens

Bacterial spp.	Fungal pathogens	Host/ Crops	References
B. velezensis	*F. graminearum*	Wheat	(Chen *et al.*, 2018)
Streptomyces viridodiasticus	*Fusarium oxysporum* f. sp. *Cubense*	Banana	(Getha and Vikineswary, 2002)
S. ambofaciens S2	*Colletotrichum gloeosporioides*	Chilli	(Heng *et al.*, 2015)
Bacillus subtilis	*Sclerotinia sclerotiorum*	*Lactuca sativa*	(Monteiro *et al.*, 2013)
Pseudomonas chlororaphis	*Sclerotinia sclerotiorum*	Soybean	(Selin *et al.*, 2009)
Bacillus amyloliquefaciens	*Penicillium expansum*	Apple	(Calvo *et al.*, 2017)
Bacillus megaterium	*Aspergillus flavus*	Peanut	(Carmona-Hernandez *et al.*, 2019)
Streptomyces yanglinensis	*Aspergillus flavus*	Peanut	(Shakeel *et al.*, 2018)
Bacillus megaterium	*Aspergillus flavus*	Peanut	(Chen *et al.*, 2019)
Bacillus pumilus	*Phaeomoniella chlamydospora*	Grapevine	(Haidar *et al.*, 2016)
Sphingopyxis sp. TBD 84, *Cupriavidus* sp. TBD 162	*Fusarium oxysporum*	Tomato	(wara *et al.*, 2016)
Bacillus subtilis s *B. amyloliquefaciens*	*Macrophomina phaseolina*	Bean	(wws *et al.*, 2016)
Bacillus spp.	*Penicillium purpurogenum*	Strawberries	(Alsohiby *et al.*, 2016)
Lactobacillus brevis LPBB 03	*Aspergillus westerdijkia*	*Coffee beans*	(de Melo Pereira *et al.*, 2016)
Bacillus subtilis	*Lasiodiplodia theobromae*	Rubberwood	(Sajitha and Dev, 2016)
Pseudomonas brassicacearum	*Verticillium dahliae*	Potato	(Novinscak *et al.*, 2016)
Bacillus subtilis	*Botrytis cinerea*	Grapes	(Mu *et al.*, 2017)
Bacillus amyloliquefaciens	*Fusarium graminearum*	Wheat and barley	(e *et al.*, 2017)
Bacillus pumilus MSUA3	*Rhizoctonia solani* *F. oxysporum*	*Fagopyrumesculentum* Moench	(Agarwal *et al.*, 2017)
B. cereus *B. mojavensis*	*M. grisea* *F. verticillioides* *F. proliferum*	Rice	(Agarwal *et al.*, 2017; Etesami and Alikhani, 2017)

Parasitism (Lithic Enzyme Production): Bacterial antagonist acquires feed from phytopathogen as parasitism occurs, engendering complete structure lysis. Bacterial antagonist feeds on the fungal cell wall composed of 20 % chitin, 51-60% glucan, as well as 21-30 % protein(Spadaro and Droby, 2016). Erect and insoluble chitin designed by N-Acetyl glucosamine (subunits) that interlinked with β-1,4, besides, provides support to the cell wall(Seidl, 2008). β-1,3-glucan is one of the essential components of the cell wall, in which several other components are covalently associated, providing mechanical stability as well as integrity. In most cases, proteins related to cell wall are glycoproteins as well as oligosaccharides. The protein associated with cell wall has a significant role in their synthesis, molecular absorption as well as contribute to protection. Diverse enzymes are needed to degrade the fungal protecting cell wall, specifically β-1,3-glucanase, chitinases, as well as proteases(Safdarpour and Khodakaramian, 2019). Bacteria emit one of the vital enzyme 'glucan' that have the ability to hydrolyze the glucans by following these two significant mechanisms: (a) Exo-1,3-glucanase can hydrolyze the concerned glucans by successive integration of glucose particles by the non-reducer residues, and (b) endo-1,3-glucanase stimulate the association with aleatory spots beside polysaccharide chain, although oligosaccharide, as well as glucose, are found in minor quantity(Spadaro and Droby, 2016). Chitinases are generally hydrolyzed by chitin, non-splitting N-Acetyl glucosamine found in 1,4 linkage by following these two mechanisms: (a) NAG residues successively segmented by exo-chitinase; and (b) aleatory sites concerned with polymer chain activated by the endo-chitinase(Stoykov *et al.*, 2015). As the site of action was concerned, proteases were divided into four essential groups: first one 'serine proteinases', second one 'cysteine proteinases,' third one 'aspartic proteinases', and fouth one 'metalloproteinases'(Barrett *et al.*, 2012). According to last year, diverse studies have been accomplished that is concerned with the production of yeast and bacteria from hydrolytic enzymes(Bahadou *et al.*, 2018). The majority of Bacillus, as well as Pseudomonas genera, contain effective antagonists concerned with controlling pathogenic organisms because uninterruptedly affect the chitinase(Yu *et al.*, 2008). (Shivakumar *et al.*, 2014)concluded his work that kinetic studies, purification, and characterization were performed on chitinase enzyme of concerned *B. subtilis*, here the moderately purified enzyme revealed antifungal activity not only for *R.solani*, but also against *Colletotrichum gloeosporioides*.

Formation of Biofilm and quorum sensing: As far as successful colonization on fruit surface was concerned, biocontrol through antagonistic properties associated bacteria was effective that have characteristics to assist their adherence, colonization, as well as multiplication. Due to these characteristics, biofilms were formed that contain micro-colonies among hydrated protein medium created by antagonistic bacteria and measured via quorum sensing with concerned regulators: farnesol, phenethyl alcohol, and tyrosol. The micro colonies concerned with the communication corridor not only release diverse chemical signals employing to supervise the associated environment but also fluctuating the genetic expression as well as attaining benefit over their opponents via quorum sensing(Chi *et al.*, 2015).The biofilms associated with biological control proved as a barrier for phytopathogen by standing between lesions tissues of the host. Although, less information is acknowledged regarding mechanism employed in biofilm formation. The chemical signals on the environment released by bacteria are not only concerned with the regulation of morphogenetic alternations, but also they are responsible for bacteria selection as BC(Beauregard *et al.*, 2013; Chen *et al.*, 2013). *Bacillus subtilis* is one of the bacteria that have not the only function in forming supporting community by utilizing a growing number of the population having isogenic ancestors, but also involved in macromolecule assembly, production as well as biofilm matrix formation(Vlamakis *et al.*, 2008; Ostrowski *et al.*, 2011). As far as the matrix was concerned abouta bacterium that comprises subsequent proteins TasA or TapA(Branda *et al.*, 2001; Romero *et al.*, 2011) as well as produced the polysaccharide having a large and diverse molecular weight(Branda *et al.*, 2001). The biofilm gathering takes place as long as coating protein over there for biofilm known as *BsIA*, earlier termed as *YuaB*(Kobayashi and Iwano, 2012; Kaufman *et al.*, 2017). Scientist work revealed that *Paenibacillus polymyxa* is beneficial bacteria colonize the majority of plant roots resulting in a structure that appears as biofilm, so this bacteria is involved in protecting the phytopathogens infectious diseases on plant roots(Haggag and Timmusk, 2008). Another bacteria, *Pseudomonas fluorescens* having strain CHA0, presented their capability in protecting plants by colonizing on carrot plant roots(Bianciotto *et al.*, 2001). *B. subtilis* have the capability to form biofilm style appearance on *Arabidopsis* plants and thus inhibit the *P. syringae* infection on the same plant(Bais *et al.*, 2004).

Antibiosis with antimicrobial metabolites: Antimicrobial metabolites consist of secondary metabolites, amongst heterogeneous groupshaving an organic compound of less molecular weight produced by concerned microorganisms, which proved to be lethal for the survival of other microbes (Thomashow, 2002). Antimicrobial metabolites, associated through broad-spectrum action, have been described that biological control takes place by using these genera of bacteria: *Pantoea*, *Agrobacterium*, *Serratia*, *Streptomyces*, *Pseudomonas*, *Bacillus*, *Stenotrophomonas*, and others. Genera bacillus, mainly found to be associated with lipoproteins that are iturin, surfactin, and fengycin(Ongena and Jacques, 2008),but *Pseudomonas,* comprises of antibiotic metabolite like DAPG, phenazine and pyrrolnitrin were discussed in studies(Raaijmakers and Mazzola, 2012). Antibiotics have a significant role in protecting the plant from other growing microbes afterward food and space competition, and thus produced by bacteria having low-molecular-weight, recognized as volatile organic compounds (VOCs) through antibiosis. Three main antibiotics are iturin, trichothecene, and pyrrolnitrin have been emitted by bacteria *B. subtilis*, *Myrothecium roridum*, and *P. cepacia* ,respectively, to control fungal diseases(Torres *et al.*, 2014). Antibiotics are proved to be effective in less concentration associated with chemical groups: alcohols, esters, aldehydes, terpenes, ketones, sulfur compounds, and lactones. Due to their volatile-ability in the environment, they can travel unrestricted distance in solid and liquid medium as well as in gas complexes, having a great advantageous effect as BCA.

Attention to these VOCs was less in the past than other associated antagonistic mechanisms. Although, nowadays, researchers pay attention to products related to volatile metabolism (Fialho *et al.*, 2011). Bio fumigation of fruit was possible *via* microorganisms that can emit VOCs in locked and protected chambers verified as an excellent alternative source to control some phytopathogens(Guevara-Avendaño *et al.*, 2019). Although, proved to be valuable that BCA release VOCs and their fungistatic activity was known, contribute to control the fungal pathogens. Yet, nearly a few phytopathogens able to introduce a wide-ranging VOC. Therefore, this way has to be evaluated in detail in the subsequent investigation studies (Spadaro and Droby, 2016). Scientists point out the genus *Bacillus* since effective BCA produces some secondary metabolites that have shown to be biologically energetic, determined with a biochemical summary. The two species are suggested as BCA as a result of this research are *Brevibacillus brevis* emit the fengycin and iturin A,and *Bacillus subtilis* emits gramicidin S (1–5) metabolites, which can prevent the growth progress of varied phytopathogens(Layton *et al.*, 2011). Scientists also proved that VOCs were produced by the *Arthrobacteragilis.* This was introduced for hindrance of *Botrytis cinerea* and *Phytophthoracinnamomi*, confirmed with gas chromatography and other analysis, in which dimethyl hexadecylamine was identified in the form of a compound, demonstrating the 12 times more hindrance as compared to fungicide (captan)(Velázquez-Becerra *et al.*, 2013).

Induction of resistance in host plant: Stimulation of resistance includes the BC bacterium capacity of inciting host defensive chemical and biochemical response, comprising the variation in the assembly of tissues and protein formation interlinked to pathogenesis; their expression occurs locally or either systemically (Fu *et al.*, 2010). Bacteria involvement in inducing resistance proved to be effective as BCA in their action and controlling diseases during storage(Jamalizadeh *et al.*, 2011; Hernandez-Montiel *et al.*, 2018). Defense in host activated and specified by releasing several enzymes along with metabolites, particularly (A) proteins interlinked with pathogenicity (PR proteins), comprises peroxidases, glucanases, catalase(provide tissue protection from oxidative injury),chitinases, protein reducers, superoxide dismutase, or lipid-movement proteins; (B) compound complexes associated with significant antimicrobial action, includes phytoalexins; and (C) Callose involvement in papillae formation and presence of lignin affirming strengthening to the cell wall. Some other arrangements are involved in triggering the immunity comprises (A) reactive oxygen species (ROS) production involved in the signaling process and have undeviating antimicrobial result; and (B) Stomata that leaf going toward closing. The majority of plants have an immune response that is facilitated and reliant on phytohormones, jasmonic acid, abscisic acid, salicylic acid, ethylene, and collaboration between them permitting the beginning of plant insusceptible response to protect against the particular pathogen (Hacquard *et al.*, 2017; Guo *et al.*, 2018).Even though induction of safe plant tissue resistance is interrelated with BCA treatment, evidence related to the substantial capacity that is brought to prevent plant disease was not recognized (Spadaro and Droby, 2016).

Commercial biocontrol products of bacteria: Biocontrol was relatively new as compared to the usage of pesticides. One of the bacteria, *Agrobacterium radiobacter*(K 84 strain), registered during 1979 in the United States for management of crown gall diseases. Fourteen bacteria were registered by the US until 2005. Mostly, they are sold for commercial purposes in the required amount (Fravel, 2005). The commercialization of bioproducts was yet in the preliminary phase, but it provides a safe product in the farmer market.

Biocontrol products depend on the multistep procedure for commercialization (Junaid *et al.*, 2013)comprising many activities are:

A) Phytopathogen isolation through the ecosystem
B) In vitro assessment of bio-agent in greenhouse
C) Analysis in the field for checking good isolate
D) Formulation with the help of mass production
E) Delivery and inspection of compatibility
F) Registration and declared the release in the market

Several bacterial antagonists were identified through laboratory experiments, after field analysis used as biofertilizer commercially in the field (Gotor-Vila *et al.*, 2017). Beneficial bacteria were used for significant product development by removing chemical toxins from the food supply (m *et al.*, 2019). The microorganism was isolated from sea, plant, and soil, used as BCA, which is a costly, complex, and cooperative process. In BCAs studies, much research was conducted; even so, commercial use is paradoxical and limited. The reason behind that, field conditions required high marketable consumption for effective control on a commercial basis. The circumstances depend mainly on the environment that is a variable factor and uncontrollable, including temperature, precipitation, humidity and, abiotic features that are overcome by fungicides and form a significant medium to manage fungal pathogens (Nunes, 2012). Additionally, before beginning the product development of BCAs, they should have much knowledge of numerous factors related to the management of fungal diseases, including involved phytopathogen, host kind on which outbreaks, diseases epidemiology, resistance associated with phytopathogen, as well as environmental circumstances need to know for using BCA. However, future problems arise unless successful antagonist selection takes place. For successful releasing of BCA in the market depends upon the production process that has pass-through diverse studies and developed a scale for acquiring enough quantity of BCA for its effective assessment in a packing plant, field and, glasshouse.

In many cases, product displays enough aspects not only related to their production on economic and technical basics but also their registration along with commercialization (Holert *et al.*, 2018). The primary purpose of the investigation associated with BCAs is to improve and make a desirable product used on a commercial basis. Although many efforts are utilized in BC research, some product was available commercially on the market (Droby *et al.*, 2016).These few products for BC are used to control the phytopathogens, although considered as first-generation BC products that have antagonistic bacteria. Some products include 'Aspire' *Candida oleophila*(Blachinsky *et al.*, 2007), 'Candifruit' Candida sake (Teixidó *et al.*, 2011), 'Yieldplus' *Cryptococcus albidus*(Kowalska *et al.*, 2012), and 'BioSave'*Pseudomonas syringae*(Janisiewicz and Korsten, 2002). They all were commercially available from a few years ago; although products were decreased in the market and suspension need appear. Moreover, biosave use to control diseases was still limited in the market of US (Janisiewicz and Peterson, 2004). 'Avogreen' *Bacillus subtilis* used against the spot of *Cercospora*sp in Africa on the fruit avocado, but unfortunately success not last,the reason behind that was the unreliable result (Demoz and Korsten, 2006).Nexy'*Candida oleophila'* prepared in Belgium and presented during 2005 for approval and received in 2013 by the European Union against phytopathogens of banana fruit (Sebastien and Jijakli, 2014). Bio-Ferm '*Aureobasidium pullulans*' must apply to protect the phytopathogen infection on fruits that are kept in storage (Lima *et al.*, 2015). Pantovital '*Pantoeaagglomerans'* was formulated against citrus fruit diseases, but their journey toward commercialization doesn't succeed (Usall *et al.*, 2016). Amylo-X *'Bacillus amyloliquefaciens'* produced by Biogard, in Italy, used against many diseases of vegetables. Shemer '*Metschnikowiafructicola'* formulated in Israel and effective in controlling postharvest diseases on many fruits such as grapes, strawberry, citrus and peach. Shemer production was under Bayer Crop Science, and the latter license was also provided to Koppert(Spadaro and Droby, 2016). Serenade '*Bacillus subtilis*' presented by Bayer, it was verified to be operative in the management of diseases in strawberry, tomato, and peach (Usall *et al.*, 2016). Though, these products are not alternatively effective as compared to synthetic products (Maida *et al.*, 2016).

Table 2. List of antibiotics produced by biocontrol bacteria

Antibiotic	Source	Targeted pathogen	Disease	Reference
Cyclic lipopeptide antibiotics (CLPs)	*B. subtilis*	*P. digitatum*	Decay on citrus fruit	(Waewthongrak *et al.*, 2015)
Fengycin A	*B.atrophaeus CAB-1*	*Sphaerotheca fuliginea*, *B. cinera*	Cucumber powdery mildew Tomato grey mold	(Zhang *et al.*, 2013)
Bacillomycin D	*B.velezensis* HN-2	*C. gloeosporioides*	Mango Anthracnose	(Jin *et al.*, 2020)
Iturin D and bacillomycin D	*B. subtilis*	*Xanthomonas oryzae* pv. *Oryzae Rhizoctonia solani, Fusarium verticelloides* and *Sclerotiumrolfsii*.	Bacterial leaf blightof rice	(Kumar *et al.*, 2020)
Mycostubilin	*Bacillus* BBG100	*Pythium aphanidermatum*	Damping off	(Junaid *et al.*, 2013)
Bacillomycin D	*B. subtilis*	*Rhizopus stolonifera*	Soft rot of tomato	(Lin *et al.*, 2019)
Zwitermycin A	*B. cereus*	*Pythium aphanidermatum*	Damping off	(Sarangi *et al.*, 2017)
Herbicolin	*Pantoea agglomerans* E325	*E.amylovora*	Apple's fire blight	(Pusey *et al.*, 2011)
Iturin A	*B.subtillus* QST713	*Candida Albicans*	Gray and green mold	(Ambrico and Trupo, 2017)

The antagonistic ability of bacteria against other plants pathogenic bacterial species: Phytopathogen has a damaging effect on the yield of agricultural produce due to the cuts and wounds produced through the harvesting. Bacteria, including Ralstonia, Xanthomonas, Erwinia, and Pseudomonas responsible for softening along with rotting of vegetables and fruits. Bactericide is a chemical, valid for the decay caused by bacteria on the fruits(Di Francesco *et al.*, 2016). Some of these chemical products are not approved and not available in the market because of their toxicological hazards. Furthermore, public fear related to pesticide usage was due to bactericide resistance in bacterial phytopathogen, and a greater cost was needed for new chemical development, so stimulate the search of alternative new approaches(Sharma *et al.*, 2009). Bacterial genera, including Bacillus, Pseudomonas, and Pantoea was valid BCAs, to manage the bacterial phytopathogens. Plant choose most of the bacteria, which are fitness for producing organic compounds by using exudates, generating the environment that has less diversity. In rhizosphere bacteria found abundantly and at greater rate affects the physiology of the plant, particularly effectiveness to colonize the root was considered. Although bacteria improve the growth of plants by improving limiting conditions and indirectly provide support to growth through secretion of antagonistic substances against phytopathogen and persuading the host resistance(Köhl *et al.*, 2019). Microorganism lives in soil colonize in the rhizosphere is an initial step in pathogenesis. Microbial inoculants are fundamentals utilized in the form of biofertilizers, phytostimulators, bioremediation, and biocontrol agents. For example, Pseudomonas spp is significant bacteria and utilized as a root colonizing model (Lugtenberg and Kamilova, 2009).

In the previous twenty years, the studies conducted related to it cleared that enzymes, volatiles, and antibiotics are some metabolites secreted by bacteria involved in managing various phytopathogens. In many studies, several antibiotics are proved to be broad-spectrum secreted by antagonistic bacteria. Their example includes pyrrolnitrin that have broad-spectrum action, Burkholderia and Pseudomonas are responsible for their production, observed previously by the scientist in 1960s (Nishida *et al.*, 1965), and this beneficial antibiotic was developed to control bacterial disease. *Bacillus amyloliquefaciens* are involved in suppressing the damaging phytopathogen by the action of competition, antibiosis, and stimulation of systemic resistance (Diallo et al., 2011). *B. amyloliquefaciens* and *B. subtilis* are responsible for the synthesis of polyketides (bacillaene, macrolactin, and difficidin) in a non-ribosomal manner that is significant and operational antibacterial complex (Chen et al., 2009).

Table 3. Examples of biocontrol bacteria against other bacteria

Antagonistic bacteria	Target bacteria	Host plant	References
Pseudomonas putida	*Erwinia carotovora*	Potato	(Xu and Gross, 1986)
Bacillus subtilis	*Pseudomonas syringae*	*Arabidopsis* roots	(Bais *et al.*, 2004)
Bacillus subtilis	*Xanthomonasspp*	Cotton	(Monteiro *et al.*, 2005)
Bacillus subtilis	*Xanthomonasspp*	Cabbage	(Jensen *et al.*, 2005)
Bacillus spp.	*Xanthomonas campestris*	Tomato	(Roberts *et al.*, 2008)
Bacillus spp.	*Xanthomona scampestrispv. Glycines*	Soybean	(Salerno and Sagardoy, 2003)
Streptomyces spp.	*Xanthomonas oryzae pv. Oryzae*	Rice	(Hastuti *et al.*, 2012)
Pseudomonas oleovorans *Agrobacterium tumefaciens*	*Ralstonia solanacearum*	Tomato	(Upreti and Thomas, 2015)
Bacillus amyloliquefaciens	*Acidovoraxavenae*	Cucurbits	(Jiang *et al.*, 2015)
Bacillus cereus	*Pseudomonas syringae*	Tomato	(Hong *et al.*, 2015)
Bacillus cereus *Streptomyces setonii*	*Xanthomonas* *Gardneri*	Tomato	(Ferraz *et al.*, 2015)
Pseudomonas fluorescens *Pseudomonas putida* *Enterobacter* spp.	*Ralstonia solanacearum*	Potato	(Kheirandish and Harighi, 2015)
Bacillus subtilis	*Erwinia amylovora*	Pear	(Arafat *et al.*, 2015)
Paenibacilluspolymyxa	*Xanthomonas spp.*	Cereal crops	(Rybakova *et al.*, 2015)
Endophytes bacteria	*Ralstonia solanacearum*	Tomato	(James and Mathew, 2015)
Lactic acid bacteria	*Yersinia enterocolitica*	Post harvested fruits	(Angmo *et al.*, 2016)
Pseudomonas aeruginosa	*Pathogenic bacteria spp.*	Banana	(Thomas and Sekhar, 2016)
Pseudomonas spp., *Serratia* and *Bacillus* spp.,	*Xanthomonas oryzae* pv. *Oryzae*	Rice	(Yasmin *et al.*, 2016)
Bacillus amyloliquefaciens *Lysinibacillus macrolides* *Bacillus subtilis*	*Burkholderiaglumae*	Rice	(Shrestha *et al.*, 2016)
Serratia spp.	*Xanthomonas oryzae* pv. *Oryzae*	Rice	(Khoa *et al.*, 2016)
Pseudomonas saponiphila	*Pathogenic bacteria spp.*	Medicinal plant	(Wu *et al.*, 2016)
fluorescent *Pseudomonas,* *Pantoeaagglomerans*	*Erwinia amylovora*	Pear and apple	(Sharifazizi *et al.*, 2017)
Pseudomonas aeruginosa	*Vibrio anguillarum*		(Zhang *et al.*, 2017)
Bacillus artrophaeus *Bacillus amyloliquefaciens*	*Ralstonia solanacearum*	Tobacco	(Tahir *et al.*, 2017)
Pseudomonas aeruginosa	*Xanthomonas oryzae* pv. *Oryzae*	Rice	(Yasmin *et al.*, 2017)
S. aureus, B. cereus and *P. aeruginosa*	*Ralstonia solanacearum*	Medicinal plant	(Semeniuc *et al.*, 2017)
Paenibacillus spp.	*Xanthomonas campestris* pv. *campestris*	Crucifer	(da Silva *et al.*, 2018)
Endophyte bacteria	*Pseudomonas syringae* pv. *actinidiae*	Kiwifruit	(Wicaksono *et al.*, 2018)
Pseudomonas fluorescens *Lysinibacillus* sp.,and *Bacillus subtilis*	*Ralstonia solanacearum*	Potato	(Djaya *et al.*, 2019)
Bacillus amyloliquefacien	*Ralstonia solanacearum*	Chilli	(HanQiao *et al.*, 2018)
Bacillus and streptomycin spp.	*Pseudomonas caricapapayae*	Papaya	(Hasan *et al.*, 2018)
Bacillus cereus Agrobacterium tumefaciens and Enterobacter sp.	*Ralstonia solanacearum*	Eggplant	(Achari and Ramesh, 2019)

Dipeptide bacilysin is also synthesized in a non-ribosomal manner and comprised of anticapsin along with alanine moieties, organized by polyketides, was proved to be effective against bacterial diseases (Bais *et al*., 2004; Chen *et al*., 2009). However, endophytes are active and productive BCAs fully dependant on their colonization in the surrounding of a plant. Colonization range in the rhizosphere by the endophytes depicts the bacterial pathogen contribution that acclimatizes to live selectively in particular ecological niches (Des Essarts *et al*., 2016).

The antagonistic ability of bacteria against plant parasitic nematodes: Nematode in the form of plant-parasitic entity is amongst the destructive pest of different crops as responsible for the heavy crop losses and cause more harm as compared to insect pests each year (Koenning *et al.*, 1999). Their management seems to be more challenging as compared to other pests because they increase their population in soil and frequently affect the underground portion of the crop (Stirling, 1991). However, chemicals to control nematode as nematicides are easily accomplished in the field and provide simultaneous results. Still, due to its hazardous effects on the environment and health, it is prohibited in many countries for resolving safety issues (Schneider *et al.*, 2003). The need for immediate consideration towards alternatives and innovative products that are environmentally friendly in order to inhibit the nematode population that is gradually becoming significant.

Table 4. Examples of biocontrol bacteria against plant-parasitic nematode.

Bacteria	Nematode	Host	References
Bacillus subtilis isolates Sb4-23 *Bacillus methylotrophicus*	*Meloidogyne incognita* *Meloidogyne incognita*	Tomato seed Tomato	(Adam *et al.*, 2014) (Zhou *et al.*, 2016)
B. subtilis	*Meloidogyne incognita*	Tomato	(Subhalaxmi *et al.*, 2017)
Pseudomonas Oryzihabitans	*Meloidogyne spp.*	Tomato	(Vagelas and Gowen, 2012)
Bacillus firmus	*Caenorhabditis elegans* and *M. incognita*	Different crops	(Geng *et al.*, 2016)
B. subtilis *B. laterosporus* *Bacillus* spp *Arthrobacter*spp *Lysobacter*spp	*Meloidogyne javenica* *Heteroderaglycines* *Panagrellusredivius* *Meloidogyne chitwoodi* *Pratylenchusneglectus*	Different crops Different crops Potato	(Xia *et al.*, 2011) (Tian *et al.*, 2007) (Castillo *et al.*, 2017)
Pseudomonas aeruginosa *Paenibacilluspolymyxa* *B. subtilis* *Pratylenchus penetrans*	*Meloidogyne incognita* *Meloidogyne hapla*	Different crops Tomato	(Soliman *et al.*, 2019) (Topalović *et al.*, 2019)
Bacillus, Serratia, Paenibacillus, Enterobacter and *Streptomyces* spp.	*Meloidogyne, Pratylenchus, Apratylenchus, Criconemella and Xiphinema spp.*	Coffee	(Hoang *et al.*, 2020)
Bacillus, Corynebacterium, Streptococcus, and *Staphylococcus* spp.	*Meloidogyne incognita*	Tomato	(Colagiero *et al.*, 2020)
Pasteuria spp.	*Helicotylenchusdigonicus, Pratylenchusthornei, P. neglectus, Geocenamusbrevidens, Tylenchhorhynchuscylindricus, Rotylenchuscypriensis, Meloidogyne javanica, and M.incognita*	Olive, peach, cherry, walnut, pear, vineyards, almond, sunflower, apple orchards and vegetable crop	(Öztürk *et al.*, 2020)

As we knew, the nematode population generally survives in the soil and is available to pathogenic bacteria and fungi to manage the nematode (Mankau, 1980; Jatala, 1986). Bacterial genera that are subjected to biological control include *Pseudomonas,Bacillus, and Pasteuria* that are found abundantly in the soil and have pronounced potential to control the nematode population. The modes utilized by the bacteria are numerous to eradicate the nematode: such as the ability to parasitize, production of antibiotics, toxins and enzymes that are intrusive in recognition of nematode by the host, competing and opposing for the accessible nutrients as well as persuading the host resistance, and encouraging proper plant development. Exploitive activities of bacteria luinematode population, such as predacious or free-living nematodes and parasitic nematodes(Mankau, 1980; Stirling, 1991; Siddiqui and Mahmood, 1999). The formation of complex linkage between bacteria and the nematodes, host, and condition of the environment to manage the nematode population in ordinary circumstances. Bacteria also have the capacity to mobilize and activates the fungi to kill the pathogenic nematodes that are problematic in agriculture (Wang *et al.*, 2010).*Pasteuria penetrans*areparasitic bacteria and destroy the *Meloidogyne* spp. that are responsible for the formation of root-knots in their host plant. *Pasteuria* forms spores that adhere to the cuticle of particularly second-phase juvenile, although their germinate begun as they arrived in host root and start nourishing. The capacity of cuticle penetration is through germ tubes result in the formation of vegetative microcolonies and proliferate on the body of an emergent female of a nematode. Although female nematode's reproductive system typically degenerate and responsible for the release of endospores in the soil (Mankau *et al.*, 1976; Sayre and Wergin, 1977). Spore adherence toa nematode cuticle is the initial phase of infection development (Davies *et al.*, 2001). Conversely, the reproductive structure of *Pasturia* doesn't recognize every nematode species because they have a limited host series such as *Pas. penetrans* inhibit the *Meloidogyne* spp., *Pas. nishizawae* inhibit the nematode of genera *Heterodera* and *Globoderaand Pas. thornei liable* to inhibit the P*ratylenchus*spp(Mendoza de Gives *et al.*, 1999; Atibalentja *et al.*, 2000).

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