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Review

Amelioration of Pathogen Induced Biotic Stress to Vegetable Crops by Plant Beneficial Bacteria: A Review

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Abstract

Among various crop damaging factors, biotic stresses primarily contribute to the limitation of the growth and development of plants, which leads to huge yield losses. Globally, about 25% crop yield is lost due to diseases and insect infestation. The production and consumption of vegetables is growing worldwide due to its nutritional value in human dietary systems. The vegetables are attacked by different soil borne pathogens which compromise yield and quality. To prevent such devastating effects, pesticides are applied in high throughput vegetable cultivation practices. However, the excessive and imprudent application of pesticides negatively affects the microbial diversity and soil biological activity. This in turn, detrimentally affects the yield and quality of vegetables. Eco-friendly sustainable agricultural practices that employ low cost microbial formulations can play pivotal roles in the management of biotic stresses. The use of plant beneficial bacteria to increase vegetable production may restrict pesticides application and also prevent the emergence of resistance of pathogens against toxic chemicals. Considering these, an attempt is made herein to highlight the impact of biotic stresses especially bacterial and fungal pathogens on some of the popularly grown vegetables. This review provides information about the active biomolecules associated with disease suppression and significance of plant beneficial bacteria in the amelioration of lethal vegetable diseases. The interplay between the soil beneficial microbes and vegetables will facilitate the development of bacteria-based antagonist strategies for inexpensive production of vegetables in stressful open field conditions.

Keywords: biotic stress, phytopathogens, vegetables, biocontrol, plant beneficial bacteria

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1 INTRODUCTION

Vegetables among many food crops are one of the most important constituents of the global dietary systems owing to their role in human health. So, the demand for nutritive vegetables with high quality is growing worldwide. The vegetable crops are extremely susceptible to biotic stresses such as insect-pests[1,2], bacterial[3,4] and fungal[5] phytopathogens and weeds[6], which have caused substantive yield losses in many countries. For example, a significant loss of 40% in potato due to pathogens is reported[7,8]. To safeguard the yield and quality of widely consumed vegetables such as tomato, potato, cabbage, ladyfinger etc. from biotic stresses, crop rotation[9,10], usage of disease resistant varieties[11] and other disease control measures are adopted. Moreover, various agrochemicals especially fungicides and insecticides[12] are applied in soil-vegetable systems to offset the negative impacts of biotic stresses. Sadly, many of these management strategies failed to harvest satisfactory results. Use of agrochemicals in vegetable production has been found destructive to nutrient composition and yield of vegetables, environment and via food chain, the human health. Due to this, agrochemicals application is considered unsuitable in vegetable production[13,14]. Considering all the harmful impact of pesticides, growers are advised to restrict the usage of agrochemicals for the maintenance of the yield and quality of vegetables. The question is how to make it feasible. Solutions, specifically the microbial formulation strategies, have been provided to the growers for the pesticide problems in vegetable production. In this regard, the use of plant beneficial bacteria (PBB): low-cost and environmentally sustainable options are advocated for enhancing vegetables quality and yield optimization[15,16]. Unfortunately, the scientific information on the amelioration of vegetable disease employing PBB in soil-plant systems are inadequate[17,18]. However, few pieces of literature on how PBB could be useful in circumventing the biotic stresses while concurrently amplifying the yield of vegetable crops are reported[19,20]. This review attempts to gather published information on the biotic stresses with a particular focus on the impact of phytopathogens on some widely cultivated vegetables. In addition, this review outlines the potential role of PBB in the management of diseases and their prospects in sustainable production of vegetables in different agrosystems. This review will therefore, be useful for growers to design and practice microbes-based strategies for inexpensive production of vegetables in different environmental conditions. Furthermore, the information given here will be helpful for researchers working in the area of PBB-vegetable interactions.

2 BIOTIC STRESS TO VEGETABLES AND HOW VEGETABLES RESPOND TO STRESS: AN OVERVIEW

Biotic stress in plants generally refers to the stresses caused by the living organisms, specifically, pathogens, insect pests, viruses and viroids, weeds, or intra/inter specific competition for limited available resources. The biotic stresses in general, are the major constraints of vegetable production worldwide (Table 1). Physiologically, the biotic stress agents limit the uptake of nutrients which negatively affects plant vigor and in extreme cases, the death of the host plants. However, the extent and severity of biotic stress differs with the weather conditions, soil-plant systems, cropping pattern, climatic seasons, cultivation practices, vegetable genotypes, and agroecological regions[29,30]. In general, hot and humid weather environment, nutrient-rich agrosystems and contemptible crop-management practices further predispose the vegetables to such biotic stresses.

Plants, however, have evolved defense systems (innate and systemic response) to combat different types of biotic stresses[31,32]. Chief among them is the evolution/identification of highly sophisticated crosstalk between different plant hormones, for instance, ethylene (ET), jasmonic acid (JA), auxin (IAA), abscisic acid (ABA), ethylene (ET), and salicylic acid (SA). These hormones are secreted in response to specific stimuli and enhance plants' endurance under stressed conditions[33,34]. Recent findings suggest that the protection against biotic stresses occur at critical stages of plants such as morphological, structural and physiological levels[35]. Evidence suggests that the interaction between pathogens and different plant signalling pathways determines the level of tolerance among infected plants[36]. All these, either alone or in synergism provides tolerance or resistance against biotic stresses and give plants the strength and rigidity[32,37]. For example, when plant is infected by any pathogen, the injured plants secrete reactive oxygen species (ROS) around the infection site called "oxidative bursts". This is considered as the primary disease resistant response against infections[38]. Besides ROS, in response to pathogen attack, plants increase cell lignifications which blocks the invasion of pathogens and thus reduces the host susceptibility[39]. Some of the other notable plant-based compounds secreted in response to infections and that provide protection against biotic stresses include β-aminobutyric acid (BABA)[40,41] or benzothiadiazole (BTH)[42], SA[43,44], JA[15, 45] and ABA[46]. As an example, the relationship between the endogenously secreted SA and the resistance exhibited against biotrophic and hemibiotrophic pathogens in plants have been positively correlated. The exogenous SA application induced the local and systemic acquired resistance in tomato against *F. oxysporum*[47].

3 HOW IS BIOTIC STRESS MEASURED?

Soil borne plant pathogens among biotic stresses account for huge economic, quality, and yield losses to vegetable crops worldwide[48], which necessitates timely detection and evaluation of the damage caused by such soil borne pathogens. The biotic-induced stresses, therefore, are monitored right from the early growth stage

Table 1. Examples of Some Biotic Stresses Adversely Affecting the Vegetable Production

Biotic Stress	Host Plant	Diseases	Causal Organism	Crop Response	Ref
Bacteria	Tomato	Bacterial canker	*Clavibacter michiganensis*	Systemically colonizes tomato xylem leading to unilateral leaflet wilt, marginal leaf necrosis, stem and petiole cankers, and plant death.	[21]
Viruses		Tomato root rot, Tomato yellow leaf curl virus (TYLCV)	*Pythium aphanidermatum Begomovirus*	Death of plants, Yield losses	[22,23]
Fungi		Early blight	*Alternaria solani*	Early blight can affect almost all parts of the tomato plants, including the leaves, stems, and fruits. The plants may not die, but they will be weakened and will set fewer tomatoes than normal.	[24]
Nematodes		Root-knot nematode disease	*Meloidogyne incognita*	*Loss of fruit yield*	[25]
Weeds	Okra	-	Cynodon dactylon, Eleusine indica, *Amaranthus spinosus* and Commelina benghalensis	*Yield loss*	[6]
Insect- Pests	Eggplants	-	Shoot and fruit borer	*Damages foliage, flower buds and fruits*	[26]
		-	Jassids	*Affect leaves and fruit yields*	[27]
		-	Leaf eating beetles	Feed on leaves and seriously damage plants	[28]

until harvest to identify and properly diagnose diseases on time. This will help to find a suitable management strategy to limit the damage caused by the pathogens. In this regard, researchers focus onto assess- (i) the effects of pathogens on plants (ii) pathogen growth during interactions and (iii) how plants own active biomolecules following infection overcome the biotic stresses (self-defence). Conventionally, the disease assessment of crop plants is conducted by monitoring symptoms through human naked eyes and brain to measure their incidence. Also, the detection or pathogen identification methods depend on isolation, microscopic examination and growth of recovered pathogens[49]. The traditional approaches are, however, destructive, manual expertise demanding, labour intensive, and time consuming. Therefore, researchers apply physiological-based markers approach to find a better vegetable disease detection method[50]. Some of the most commonly applied methods include (i) Diaminobenzidine (DAB) staining and luminol-based assays and nitroblue tetrazolium (NBT) staining methods: detecting reactive oxygen species (ROS) for example, hydrogen peroxide (H_2O_2) and superoxide (O_2^-), respectively, (ii) Aniline blue staining method: measuring callose deposition, (iii) Membrane damage: detecting electrolyte leakage, and (iv) Trypan blue staining method: evaluating cell death. Of these, the DAB, an organic compound, when reacts with H_2O_2 and peroxidase is oxidized to an insoluble brown alcohol precipitate whereas luminol is oxidized by Horseradish Peroxidase (HRPO) in the presence of H_2O_2 and releases chemiluminescence[51,52]. The chemiluminescence is measured by luminometer or is photographed (imaged) employing a photon detecting imaging system. The NBT reacts with O_2^- and forms an insoluble formazan (dark blue deposit) that can be visualized. The DAB or NBT staining product is, however, proportional to the amount of H_2O_2/O_2^- in the tissue. Callose, a polysaccharide, generated in response to wounding and pathogen elicitors is deposited at the interface between the plasma membrane and plant cell wall[53, 54]. Callose formation can be detected and quantified by staining with aniline blue. Mechanistically, the callose reacts with aniline blue and fluoresces under UV light. The death of plants after infection is attributed to the hypersensitive response[55,56] or the collapse of the plant immune system. Trypan blue staining is the classical technique that can detect and quantify infection-induced cell death[57,58]. Healthy plant cells with unbroken membranes preserve electrolytes within the cell boundaries. But the stability and integrity of the membrane are disrupted under the attack from infectious organisms, which, therefore, results in electrolyte leakage[59,60]. The evaluation of electrolyte leakage from leaf discs that floats on water determines the severity of cell membrane instability and damage.

The biotic stress can also be detected by expression analyses of defense-marker genes by qRT-PCR, RNA sequencing, proteomics and microarrays. These techniques provide information about metabolic alteration caused by pathogens[61-63]. In addition, the synthesis and accumulation of stressed-induced biomolecules such as SA[64], JA[65], ABA[66] or ET[67] have been measured in infected plants[68-70]. Recently, chlorophyll fluorescence imaging (Chl-FI), a very pertinent and a highly delicate technique, has been used for the detection of plant stress and monitoring crop performance[71]. The Chl-FI, a diagnostic tool, is used to determine the photosynthesis activity at different stages of plant growth (cellular, foliage, and whole-plant) that allow researchers to perform phenotyping of plants[72]. The Chl-FI gives knowledge about the timing and position of the pathogen development and contributes immensely to understanding the regulation of photosynthesis from foliage to crop scale. Among the extensively researched diseases detected by Chl-FI, the disease caused by fungi and oomycetes have been reported. As an example, reduction in chlorophyll content of cucumber leaves infected with viral (Cucumber mosaic virus and Cucumber green mottle mosaic virus) and powdery mildew (*Sphaerotheca fuliginea*) fungal pathogen has been detected[73]. These techniques in general, provide sufficient evidence to explain variations in plant transcriptional and physiological responses due to infection caused by the soil borne pathogens. Lately, several automatic and semi-automatic techniques such as Back-Propagation Neural Network (BPNN), Support Vector Machine (SVM), K-Nearest Neighbors (KNN), Radial Basis Function Neural Network (RBFNN), Color Co-occurrence Method (CCM) and Spatial Gray-Level Dependence Matrices (SGDM) have been developed for the detection of plant pathogens[74,75]. These techniques help to identify pathogens in healthy or diseased leaves. However, various challenges accompany these techniques during processing. For example, the automation of the detection system during complex imaging outside under intense lightning and environmental conditions is difficult.

4 WHY ARE PLANT BENEFICIAL BACTERIA PREFERRED FOR VEGETABLE DISEASES MANAGEMENT?

Indeed, bacterial and fungal phytopathogens among biotic stresses are the most deadly menace to the nutritional value, biomass, and yield of vegetable crops worldwide[76]. So, it is imperative to realize the threat and devise protection strategies to maintain both the yield and quality of vegetables, for which the vegetable growers espouse different methods to suppress the disease causing bioagents. Such methods include field sanitization, use of disease resistant cultivars, crop rotation, and pesticides application[17,77]. Agrochemicals, especially the use of pesticides among many diseases management options in general, are effective in reducing the crop damage in different agrosystems[78,79]. The emergence of resistance among pathogens toward pesticides, the residual toxicity to neighbouring non-target organisms and environmental pollution are, however, the biggest global challenges. To date, there have been no available environmentally sustainable solutions to prevent biotic stresses. Therefore, the scientists in recent times have directed their efforts onto discover inexpensive, eco-friendly, and viable alternative that can be effective in the suppression of vegetable diseases. Such microbial formulations may achieve to optimize the production of safe and good quality vegetables under open field conditions[80,81]. The plant beneficial bacteria endowed, especially with the disease eradication ability, often termed "microbiological control agents or "microbial antagonists", inhibit soil borne phytopathogens by secreting various antimicrobial metabolites. Additionally, they promote the growth and development of vegetables by supplying essential plant nutrients and phytohormones (Table 2). Essentially, the antimicrobial metabolites of microbial or any biological origin, are easily biodegradable compared to the frequently used agrochemicals[100]. Considering all, an attempt is made herein to explore the role of microbial formulations in disease suppression vis-a-vis growth and yield optimization of some of the most popularly cultivated and widely consumed vegetables.

5 DISEASE MANAGEMENT BY PLANT BENEFICIAL BACTERIA: A GENERAL PERSPECTIVE

Plant beneficial bacteria are bacteria that infect, colonize surfaces and augment the overall development of plants by one or simultaneous growth modulating mechanisms[101,102]. Management of biotic stresses including those of plant pathogens using PBB has indeed been one of the greatest interests to researchers[103,104]. The PBB containing disease suppression abilities include bacteria belonging to different functional groups such as N_2 fixers[105], P-solubilizers[106], K[107], and Zn-solubilizers[108,109] etc. The wide-ranging soil borne PBB protects the vegetables from pathogen attack directly by secreting pathogen-antagonizing substances[110]. The antimicrobial metabolites include the broad-spectrum antibiotics[111-113], cell wall degrading enzymes[114], iron-chelating compound, siderophores[115,116], cyanogenic compounds, HCN[117,118] or bacteriocins[119,120] and ACC deaminase[121]. They also limit the pathogen populations through competition for space and nutrients or indirectly by inducing the resistance mechanisms[122,123], all of which contribute to enhancingthe yield and quality of vegetables. Of these, siderophores, lytic enzymes, antibiotics and bacteriocins that disintegrate cellular architecture and ACC deaminase that lowers the stress hormone, ethylene, have been widely studied mechanisms of antagonistic PBB. The PBB have shown effective antagonism in treating different pathogens including bacteria[124], fungi[125] and viral diseases[126]. In PBB, few bacteria secrete antibiotics, pyrrolnitrin, pyoluteorin, 2, 4-DAPG, etc. to inhibit the growth of phytopathogens[127]. The stimulation of induced systemic resistance (ISR) is yet another significant disease suppressive mechanism adopted by PBB. However, the PBB may employ simultaneous mechanisms of antagonism to provide better results (Figure 1). As an example, P. fluorescens CHA0 synthesized two antifungal compounds such as 2,4-diacetylphloroglucinol (DAPG)[128,129] and pyoluteorin (PLT)[130] which together suppressed various soil borne plant diseases[131]. Below are some of the important compounds released by PBB to inhibit the pathogens and help promote growth and yield of vegetables.

Table 2. Diseases of Some Common Vegetables and Their Management by Plant Beneficial Bacteria

Disease	Infected Plants	Bioagents	Microbial Antagonists	Inhibitory Biomolecules	Ref
Fusarium wilt	Tomato	*F. oxysporum* f sp. *lycopersici*	*Bacillus aryabhattai strain* SRB02	Phytohormones: Salicylic acid and amino acids	[15]
Fusarium wilt	Tomato	*F. oxysporum* f sp. *lycopersici*	*Streptomyces griseus*	Glucanase, chitinase, peroxidase	[82]
Bacterial wilt	Tomato	*R. solanacearum*	*Bacillus, Brevibacillus Pseudomonas, Trichoderma*	Peroxidase, phenylalanine ammonia lyase, polyphenol oxidase	[83]
Bacterial wilt	Eggplant	*R. solanacearum*	P. polymyxa	Lipopeptides	[84,85]
Bacterial wilt	Eggplant	*R. solanacearum*	P. fluorescens	Rhizosphere colonization	
Powdery mildew	Cucumber	*Podosphaera xanthii* (Castagne)	*T. harzianum, T. viride*, B. subtilis, P. polymyxa, S. *marcescens*	Peroxidase, polyphenol oxidase, phenols content (TPC)	[86]
Damping-off	Cucumber and Tomato	*Pythium aphanidermatum*	*Talaromyces variabilis*	Glucanase, cellulase and siderophores	[87]
Phytophthora crown rot	Cucumber	*Phytophthora capsica*	*P. stutzeri, B. subtilis, B. amyloliquifaciens, S. maltophilia*	Competitive root tip colonization	[88]
Phytophthora crown rot	Cucumber	*P. capsica*	*P. stutzeri, B. subtilis,* Stenotrophomonas maltophilia, *B. amyloliquefaciens*	Catalase	[88]
Damping off	Cucumber	*Pythium ultimum*	*P. fluorescens, Pseudomonas* sp., *B. subtilis*	Antibiotics and metabolites	[89]
Downy mildew	Cucumber	*Pseudoperenospora cubensis*	Consortium of *Achromobacter* sp., *Streptomyces* sp., *B. licheniformis*	Induced systemic resistance	[90]
Root and collar rot	Okra	*Macrophomina phaseolina*	*T. viride*	ND	[91]
Root rot	Okra	*R. solani*	*P. fluorescens*	Siderophores, HCN, IAA	[92]
Chilli Fruit Rot	Chilli	*P. capsici*	*T. asperellum, T. harzianum, B. subtilis*	Volatiles and non- volatile metabolites	[93]
Bacterial spot	Pepper	*Xanthomonas campestris* pv. *Vesicatoria*	Lactic acid bacteria	Siderophores	[94]
Early blight	Potato	*A. solani* and *A. Grandis*	Mycoparasitic fungus *Clonostachys: C. chloroleuca, C. pseudochroleuca, C. rhizophaga*	Bioactive substances and cell wall- degrading enzymes	[95]
Late blight	Potato	*P. infestans*	*Streptomyces*	Amylases, cellulases	[96]
Early blight	Potato	*Alternaria solani*	*T. harzianum with P. fluorescens*	ND	[97]
Late blight	Potato, Pepper	*P. infestans; P. capsica*	*Chaetomium globosum; Burkholderia cepacian*	Endo and exoglucanases; antimicrobials	[98,99]

ND=Not Detected

5.1 Defence Molecules Produced by Plant Beneficial Bacteria

5.1.1 Iron Chelating Compounds

Siderophores are low molecular weight (≈2.0 KDa) iron chelating peptide molecules which are secreted under low-iron limited conditions by rhizosphere PBB [132,133]. Plant beneficial bacteria including N_2 fixers, for example, rhizobia and *Azotobacter*[134], P-solubilizers[116], K and Zn solubilizers[92] excrete functionally different types of siderophores (hydroxamates, catecholates, phenolates, and carboxylates). The released siderophores form a complex with soil iron and limit its availability to phytopathogens[135]. Moreover, the siderophore regulates the population size by restricting the Fe supply to phytopathogens and therefore, protect plants from further infection[136,137]. As an example, the siderophores positive PBB, *P. aeruginosa* (strain FB2) and *B. subtilis* (strain RMB5) demonstrate significant antagonistic activity against different fungal plant pathogens, *F. oxysporum*, *F. moniliforme*, *R. solani*, *Colletotrichum gloeosporioides*, *C. falcatum*, *A. niger*, and *A. flavus*[115]. Pyoverdines produced mainly by pseudomonads such as *P. protegens*, *P. aeruginosa* and *P. fluorescens* have shown adequate antagonistic activity against many pathogenic bacteria and fungi such as *Pythium* and *Fusarium* species. The tomato plants were then protected from pathogen-based damage and achieved healthy growth[138]. Similarly, the siderophore pseudobactin secreted by *P. putida* suppresses the growth and infection of *F. oxysporum* and *R. solani* by reducing the Fe availability[127]. Species of *Azotobacter* also secretes different types of siderophores, azotochelin, protochelin, aminochelin, and azotobactin that shield the food crops from phytopathogens such as *Alternaria*, *Fusariun* and *Aspergillus*. Given the direct impact on disease progression, the siderophores-mediated suppression of soil borne pathogen provides a promising avenue for PBB engineering and pathogen control.

5.1.2 Pathogen Modulating Enzyme

Plant beneficial bacteria also produce the growth modulating enzyme, 1-aminocyclopropane-1-carboxylate (ACC) deaminase that induces tolerance against biotic stresses[139,140]. The ACC deaminase lowers the concentration of ethylene (ET) produced under severe biotic stresses[141]. Ethylene (C_2H_4 or $H_2C{=}CH_2$), a stress phytohormone, induce chlorosis, senescence, and abscission in plants which aggravates the fatal impact of different pathogens[142,143]. When produced by PBB, the ACC deaminase splits the ACC (a precursor of ethylene) into α-ketobutyrate and ammonia that reduces the precursor levels by inducing the ACC oxidase activity and ACC synthase in stressed conditions[144, 145]. Accordingly, the ET concentration declines in the surrounding environment and thus plants are relieved from ET pressure. Plants therefore exhibit better growth and yields[146,147]. The ACC deaminase produced by PBB *Paenibacillus lentimorbus* have induced tolerance in tomato against *Scelerotium rolfsii*, a causal organism of southern blight disease. The bacterized tomato plants displayed modulated ET pathway and antioxidants activities. The systemic tolerance was substantiated by pathogen related gene expression analysis[148].

5.1.3 Unregulated Waste Products: Cyanogenic Compounds

Plant beneficial bacteria, in particular, fluorescent pseudomonads, studied extensively owing to their abilities to produce toxic antimicrobial metabolites including cyanogenic compounds are implicated in plant disease management[149,150]. Many authors have reported HCN (a volatile poisonous secondary metabolite) producing PBB and their use as the antagonist in disease suppression and growth and yield enhancement of vegetables[151]. Mechanistically, HCN cracks and distorts the fungal hyphae leading to alteration in cellular structure and function due to vacuolation and protoplast leakage[152]. Cyanide, a toxic substance, acts by forming stable complexes with some of the essential elements such as Cu^{2+}, Fe^{2+}, and Mn^{2+} which consequently disrupts the functional aspect of protein. HCN effectively blocks the transport of electron and interrupts the supply of energy to the cell, and the death of biotic forms including pathogenic microbes occur under HCN positive environment. In a greenhouse study, Hyder and co-workers[153] observed that the HCN positive *P. putida, P. libanensis, P. aeruginosa, B. subtilis, B. megaterium* and *B. cereus* significantly suppressed the infections caused by a notorious fungus *Phytophthora capsici* by 52.3–63% and concurrently enhanced the growth characters of chilli pepper. In addition, the HCN positive *P. japonica* (strain NBRC 103040), *B. megaterium* (strain CtST3.5), *Pseudomonas sp.* (strain Gamma-81), *P. tolaasii* (strain ATCC 33618), *P. chlororaphis* (strain Lzh-T5) and *P. mosselii* (strain CV25) inhibited the growth of pathogenic *A. tumefaciens* and affected the survivability of *Meloidogyne incognita* juveniles[154]. Additionally, the gall formation on tomato plants by *A. tumefaciens* was prevented by *P. japonica* and *Pseudomonas sp.* Other PBB such as *B. megaterium, P. chlororaphis*, *P. tolaasii*, and *P. mosselii*, however, decline the number and biomass of galls produced on *A. tumefaciens* inoculated tomato plants grown either in the presence or absence of *M. incognita*. In general, all HCN producer PBB declined the *M. incognita* population and nematode gall numbers when used against *M. incognita*. Conclusively, the HCN-positive PBB caused a significant increase in overall performance of tomato plants colonized by *A. tumefaciens* and/or *M. incognita*.

5.1.4 Antibiosis and Antimicrobial Peptides

Production of antimicrobials such as lipopeptides, polyketides, and antifungal metabolites with broad-spectrum action is yet another vital defense strategy adopted by PBB to control the attack by phytopathogens[25, 155,156]. 2,4-diacetylphloroglucinol (DAPG), phenazine-1-carboxylic acid, oomycin, zwittermycin A, pyrrolnitrin, fengycin, iturin, phycocyanin and kanosamine[154,157, 158] etc. are some of the common antibiotics that inhibit the growth and infective ability of phytopathogens. The notable PBB being capable of producing such antimicrobials are *B. subtilis, B. amyloliquefaciens, B. velezensi, P. putida*, *P. fuorescens, P. brassicacearum, and P. polymyxa*[103, 159]. Functionally, the antimicrobials adversely affect the cell wall[160], damage the membrane integrity, and destruct protein synthesis by blocking the formation of initiation complexes on the small subunit of the microbial ribosomes[161], which inhibits the growth and development of phytopathogens. DAPG, a polyketide antimicrobial compound released by pseudomonads is used to control many soil-borne plant pathogens[162,163]. The DAPG produced by cell free culture filtrates of *P. fluorescens* (VSMKU3054) expressively prevents the in vitro growth of *R. solanacearum*, a causative agent of bacterial wilt disease of tomato, and other fungal pathogens, *R. solani, S. rolfsii, M. phaseolina* and *F. oxysporum*. Following inoculation, DAPG positive *P. fluorescens* (VSMKU3054) significantly

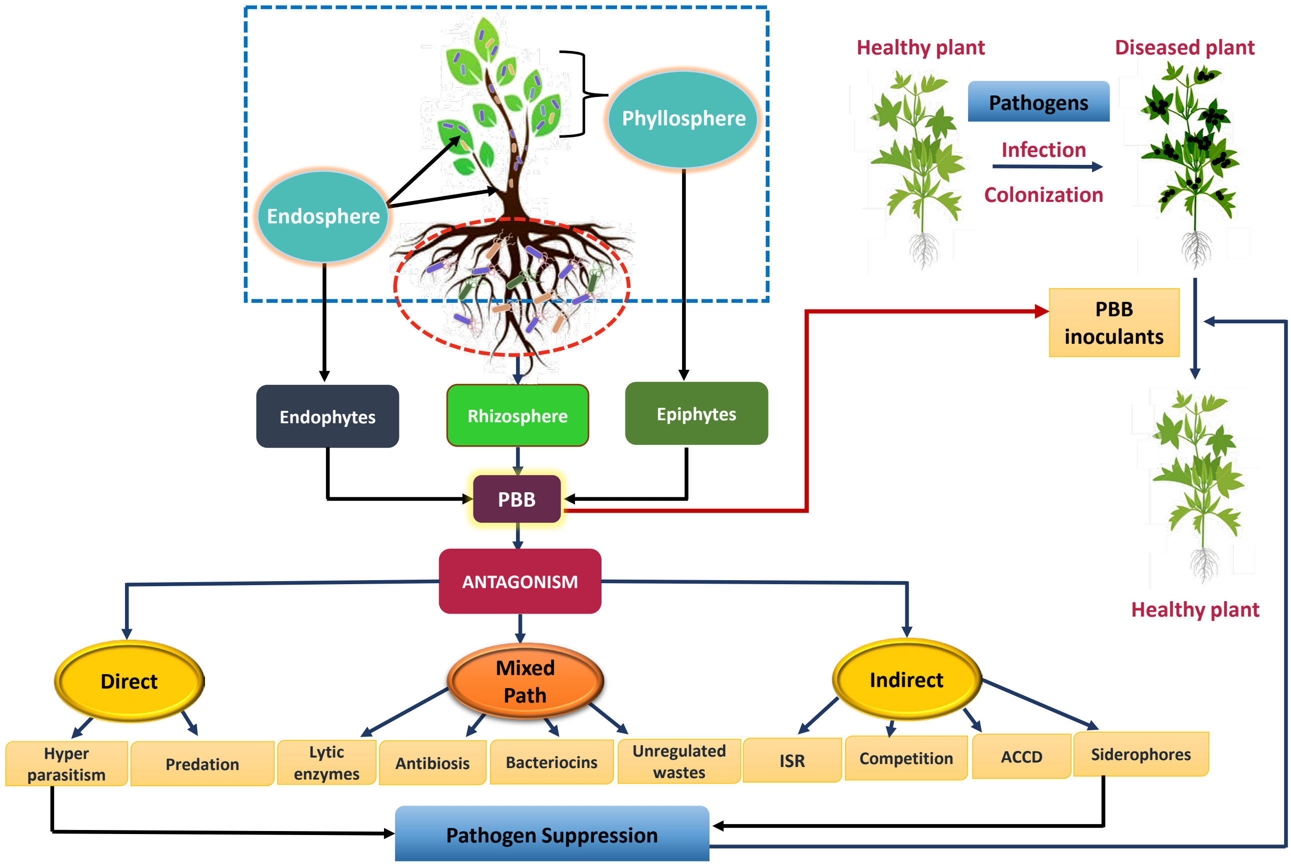

Figure 1. A mechanistic model explaining the bio-management of phytopathogens adopted by plant beneficial bacteria.

control the wilt disease of tomato[164]. Other PBB, like, *Burkholderia* sp. HQB-1 produces phenazine that possesses redox activity and has been reported to suppress wilt causing F. oxysporum[165]. In addition to *Pseudomonas sp.*, several Gram negative and Gram positive PBB strains are also known to produce antibiotics, polymyxin, circulin and colistin, that can limit the growth of many bacterial and fungal plant pathogens[161,166].

Antibacterial peptides synthesized ribosomally by PBB termed "bacteriocins" are proteins with an antimicrobial activity that are used by producing strains to reduce competition from related bacterial strains[120]. Once excreted into the environment, the bacteriocins destruct the bacterial cells which are closely related to the producer strains[167,168]. In crop production systems, the bacteriocins have been found effective in suppressing the growth of phytopathogens[127]. However, unlike conventional antibiotics, bacteriocins are narrow-spectrum proteinaceous toxins that can be bacteriostatic or bactericidal even for the synthesizing bacteria. Megacins, marcescins, cloacins and pyocins are some of the notable bacteriocins excreted by *B. megaterium, S. marcescens, E. cloacae* and *P. pyogenes*, respectively[169]. Bacteriocins produced by species of *Bacillus* have received great attention due to their wide spectrum activity against multiple pathogens[170]. As an example, the bacteriocins including known compounds such as fengycin, surfactin, bacillibactin, subtilin, etc. produced by *Bacillus* strains show inhibitory activity against bacterial and fungal phytopathogens, *E. carotovora, P. syringae, R. solani, B. cinerea, V. dahlia* and *P. infestans*[119].

5.1.5 Cell Wall Degrading Enzymes

Several lytic enzymes are released by PBB that hydrolyse fungal/bacterial polymeric compounds, cellulose, hemicellulose, chitin, and proteins[171]. The hydrolytic enzymes, for instance, chitinase[172], glucanase[173], ß-1, 3-glucanase[174], cellulases[175], proteases[176], phenylalanine ammonia lyase, peroxidase, polyphenol oxidase, catalase[177], lipases[178] etc. secreted by PBB degrade the cell wall of pathogens and ultimately cause their death. Since the fungal cell walls are mainly composed of chitin and beta-glucans, the PBB through lytic enzymes inhibit the growth of pathogenic fungi. Symbiotic N_2 fixing (SNF) rhizobium, *S. fredii* and free-living *P. fluorescens* produces chitinase and beta-glucanases, which have been reportedto inhibit the growth of *F. udum*. Accordingly, the PBB could manage the fusarium wilt disease caused by the fungus[179]. Antagonistic bacteria *S. marcescens* hamper the mycelial growth of *S. rolfsii* through chitinase[180] while *Lysobacter enzymogenes* suppress the growth of *Bipolaris* and *Pythium sp*. by glucanase[181]. The secretion of defense enzymes such as SOD, guaiacol peroxidise, catalase and ascorbate peroxidase by *Paenibacillus* lentimorbus in wake of inoculation ameliorate the biotic stress caused by *S. rolfsii* in tomato plants[148]. Also, *E. asburiae* BQ9 exhibits resistance against tomato yellow leaf curl virus. The expression of defense-related genes and antioxidant enzymes, including phenylalanine ammonia lyase, peroxidase, catalase, and superoxide dismutase contributes to the disease resistance[126].

5.1.6 Induced Systemic Resistance (ISR) and Competition

Apart from directly inactivating the phytopathogens, the PBB may also activate plant defence systems and induce resistance against different pathogens. The signalling cascade and wide-spread mechanism called "induced systemic resistance (ISR)"[182] evolved within plants are induced by different biotic agents including rhizobacteria[183]. When a powerful pathogen attacks the host plant, the ISR is activated[123,184] (Table 3). Notable PBB that induce ISR in potato, tomato, and Chinese cabbage against potential pathogens such as *Bemisia tabaci, Fusarium, M. phaseolina, R. solani, R. solanacearum, Colletotrichum orbiculare, B. cinerea*, and *Pectobacterium carotovorum* belongs to *Pseudomonas*, *Alcaligenes, Paenibacillus*, and Chryseobacterium[196,182]. The PBB such as *B. amyloliquefaciens, Lactobacillus paracasei, P. fuorescens,* and *P. putida* have been found to protect plants including tomato by inducing ISR against phytopathogens[197,198]. The ISR is though, not specific against any individual pathogen, plays a critical role in the management of plant diseases. The ISR is developed by PBB colonization of plant roots and is mediated by plant hormones for instance, JA, ET or phenolic compounds etc.[199,200] produced by infected plants.

Competition for space and nutrients between PBB and pathogens is considered an important strategy in plant protection[67,201]. The PBB usually compete with the pathogens both for physical space and growth supporting nutrients with limited amounts, both of which can alter the growth and infection ability of the pathogens[202,203]. Among PBB, pseudomonads in general are the better colonizers[204] of the plant root surface and through this ability can restrict the spread and growth of pathogens. Furthermore, in colonizing and aggregating onto seeds or soils, PBB strive for the limited available nutrients. Through active nutrient uptake mechanisms, PBB deter the growth of pathogenic fungi and bacteria by preventing the accessibility of nutrients to competing pathogens. For example, the soil suppressiveness to Fusarium wilt of tomato is attributed to competition for carbon and iron between the rhizospheres pathogenic *F. oxysporum* and F047 of *F. oxysporum*, a non-pathogenic endophytic strain and the wild population of fluorescent pseudomonads, respectively[205,206]. Conclusively, the PBB consisting of biocontrol potentials serve as an inexpensive and environmentally friendly approach for maintaining the yield and quality of vegetables while eliminating/reducing the use of agrochemicals in vegetable cultivation practices.

6 MANAGEMENT OF VEGETABLE PATHOGENS BY PLANT BENEFICIAL BACTERIA: FEW EXAMPLES

Microbes-based strategies broadly known as "Microbial control" is receiving increasing attention as an environmentally comprehensive substitute to pesticides in vegetable production practices worldwide. The role of PBB in the management of phytopathogens causing severe losses to some of the most common vegetables are described.

6.1 Bacterial and Fungal Wilt of Tomato and Brinjal

6.1.1 Bacterial Wilt of Tomato

Tomato (*Solanum lycopersicum* L.), commercially the second most important edible vegetable crop after potato, owing to its high nutritive value (a rich source of vitamin A and C) is cultivated and consumed worldwide[207]. The yield and quality of tomato, however, suffers heavily from attack by nearly 200 species of plant pathogens including bacteria, fungi such as *Fusarium, Pythium, Rhizoctonia*, and *Verticillium* and viruses etc.[208,209] Wilt, among vegetal diseases, is the most common and devastating one against tomato caused by the microbial pathogens[210] in the tropical and subtropical areas of the world[211]. Among bacterial pathogens, *R. solanacearum* is the second most damaging bacterial pathogen that causes vascular wilt in tomato plants with swift and lethal wilting symptoms[212,213]. The yield loss of tomato due to this pathogen varies between 2 to 90% in different cultivation areas[214,215]. Different strategies such as, agrochemicals, antimicrobial plant extracts, soil disinfection, antibiotics, crop rotation and resistant cultivars etc. are adopted to reduce the losses caused to tomato by bacterial pathogens[216,217]. Notwithstanding the effectiveness of in restricting the growth, development and infection potential of phytopathogens, their harmful effects on microbial diversity, soil biological activity[218,219] and tomato yields[220] raise global concerns. In order to prevent the lethal effect of chemicals, biological control measures in the management of bacterial wilt disease are desirable[221]. Several antagonistic PBB for example, *P. fluorescens, P. putida, Bacillus* sp. etc. applied in soil-plant systems suppress the tomato wilt disease[83,222,223]. The tomato plants inoculated with *B. velezensis* (B63) and *P. fluorescens* (P142) significantly reduce the population densities of *R. solanacearum* (B3B) and hence, the wilt systems. Analysis by Confocal Laser Scanning Microscopy (CLSM) revealed an aggressive colonization of bacterial antagonists in roots, root hairs, epidermal cells and within xylem vessels that primed the plant defence against fungal pathogens. Similarly, the disease intensity was minimum (17.95%) while the biocontrol efficacy was maximum (68.19%) when tomato plants were bio-primed with *B. amyloliquefaciens* DSBA-11. The *B. amyloliquefaciens* strain DSBA-12 and *B. subtilis* strain DTBS-5 on the other hand had poor biocontrol ability which resulted in slightly higher disease intensity due to *R. solanacearum* infection.

Table 3. Examples of induced systemic resistance against diseases in vegetable crops

Vegetables	Elicitor PBR	PBR Strains	Resistant Against Pathogens	Ref
Tomato	*B. cereus*	EPL1.1.3	*Ralstonia syzigiisub*	[185]
	P. fluorescens	PF15	Fusarium wilt	[186]
	E. asburiae	BQ9	Yellow leaf curl virus	[126]
	P. putida	BTP1	*B. cinerea*	[187]
	P. putida	WCS 358	Broad spectrum	[188]
Chilli	*Bacillus sp.*	BSp.3/aM	*Colletotrichum capsica*	[189]
	B. vallismortis	EXTN-1	*Phytophthora capsica*	[190]
Black pepper	*P. fluorescens*	Pf1	*P. capsica*	[191]
Cucumber	*B. megaterium*	L8	*Pythium aphanidermatum*	[192]
Potato	*B. vallismortis*	EXTN-1	Potato Virus Y and X	[193]
	P. fluorescens	89B61	*P. infestans*	[194]
French bean	*P. putida*	WCS 358	Broad spectrum	[188]
Radish	*P. fluorescens*	WCS-374	*F. oxysporum f. sp. raphanin*	[195]

Bacillus strains in general, declined the *R. solanacearum* populations in infected plants and consequently optimized the vegetative growth, yields and quality of tomato[223]. The innate immunity triggered by environmentally friendly PBB to plants was owing to the secretion of peroxidase, phenylalanine ammonia lyase and polypehenol oxidase[83].

6.1.2 Fusarium Wilt of Tomato

Vascular wilt caused by the soilborne fungus *F. oxysporum* f. sp. lycopersici (FOL) is one of the most destructive fungal diseases of tomato in many vegetable growing countries. As a soil inhabitant, the fungus spreads to different agronomic areas through infested soil transport, good quality water (irrigation water), infected plants and seeds[224]. The pathogenic fungus enters through the root via wounds or natural openings. After massive aggregation, they cause stern vascular damage by disrupting water transport leading to wilting and subsequently plant death[225]. More than 80% of crop loss that has been reported is attributed to infections[226]. Traditionally, growers apply fungicides to control this disease but the emergence of resistance among pathogens against chemicals becomes a major concern worldwide[227]. Considering this, the use of many PBB such as species of *Pseudomonas* and *Bacillus* entailing antifungal activity have been recommended for examining the spread of fungal wilt disease[228,229]. Inoculation of *B. aryabhattai* SRB02 for example significantly improves the growth while tumbling the disease in both tolerant and susceptible tomato cultivars[15]. The susceptible and tolerant tomato cultivars bacterized with *B. aryabhattai* (strain SRB02) have significantly higher amounts of amino acids following infection by *F. oxysporum*. The plant defence hormone analysis revealed maximum concentration of SA with gradual reduction in JA in diseased plants. These observations fairly proved the antagonistic potentials of strain SRB02 which triggered the release of endogenous phytohormones and amino acid[15,230]. Several other researchers have also concluded that the antibiotics for instance zwittermicin, bacillomycin, fengycin, bacilysin and difficidin produced by *B. amyloliquefaciens* strains can be useful in the management of fusarium wilt that consequently could improve the growth and yield of tomato[231,232].

6.1.3 Bacterial Wilt of Eggplant

Bacterial wilt of eggplant (*Solanum melongena*) is one of the most destructive diseases of brinjal caused by *R. solanacearum*. This disease has threatened brinjal production throughout the temperate and tropical regions of the world[233,234]. Owing to the long survivability and variable forms of the pathogen in soil and the ability to re-infect the healthy plants, chemical means failed to manage this pathogen[235]. In greenhouse experiment, the application of *P. polymyxa* (IMA5) markedly optimized the growth, above/underground seedling/root length and biomass of *R. solanacearum* infected eggplants while exhibiting greatest biocontrol efficiency. The MALDI-TOF MS analysis revealed the production of antimicrobial lipopeptide by bacterial antagonist and therefore, the antagonistic activity was ascribed to the production of polymyxin and tridecaptin[84]. Also, the *P. fluorescens*, a widely studied antagonist when applied as bacterial formulations enhanced the growth and yield features such as leaf area, number and biomass of fruits, height and yield of *R. solanacearum* infested brinjal plants[85]. The bacterial formulations applied to seed, root and soil further reduce the occurrence and sternness of the bacterial wilt disease. The substantial aggregation and colonization of the antagonist onto the seed surface from where it moves to the expanded roots is considered the best place for microbial colonization[236]. This PBB strategy for disease suppression is considered promising in brinjal cultivation practices for reasons explained earlier.

6.1.4 Fusarium Wilt of Eggplant

Fusarium wilt of eggplant caused by *F. oxysporum* f. sp. *melongenae* is a serious vegetable disease. The pathogenic fungus invades the vascular bundles, blocks the xylem tissues, and disrupts the water transport, leading to severe wilting and consequently the death of the plants[237]. Sadly, the *Fusarium* spores resist abiotic stresses and persist in the soil indefinitely. The control of this fungal pathogen and the deadly disease secondary to its impact is, therefore, utterly challenging. The use of PBB has, however, given some ray of hope as an alternative strategy to other modes of wilt management. Recently, two Gram positive PBB, *B. amyloliquefaciens* (KY568716) and *B. velezensis* (KY568715) showing broad-spectrum antifungal activity against *F. oxysporum, A. alternata, C. capsici, M. phaseolina, S. hydrophilum, R. solani* and *P. digitatum*, when applied on diseased eggplants, effectively reduced the lethal *Fusarium* wilt disease owing to lytic enzymes. Accordingly, the antagonists significantly promoted the biological features such as length, biomass and chlorophyll content of eggplants after stress was ameliorated[238]. In other investigation, *P. aeruginosa* (P07-1), *P. putida* (P11-4), *P. aeruginosa* (85A-2), *B. amyloliquefaciens* (76A-1) and *B. cereus* (B10a) substantially inhibited the mycelial growth leading eventually to a massive reduction (85%) in the incidence of the disease. The *P. aeruginosa* (P07-1) and *P. putida* (P11-4) among all bacterial antagonists, colonize aggressively within eggplants, prevent the entry of the fungal mycelium inside the host tissues, and consequently alleviate the disease effect. The reduction in brinjal wilt disease is attributed to the ISR and secretion of several enzymes, peroxidase, polyphenol oxidase, catalase and cell wall degrading enzymes[239].

6.2 Root Rot Disease of Okra

Okra (*Abelmoschus esculentus* L. Moench) is regarded as an integral component of balanced food systems owing to its amino-acid composition which is rich in lysine and tryptophan, dietary fibers, and other essential nutrients[240,241]. Like other edible vegetables, cultivated okra is susceptible to many pathogens including fungi of genera *Rhizoctonia* (root rot), *Fursarium* (wilt), *Pythium*, *Phytophthora*, *Macrophomina* (damping off), *Colletotrichum* (anthracnose), *Cercospora* (leaf spot), *Erysiphe* (powdery mildew) and *Botrytis* (pod rot), bacteria such as *Xanthomonas esculenti* (leaf spot) and viruses (yellow vein mosaic) and different insect pests[242-244]. Root rot of okra among many *R. solani* driven diseases is one of the most distressing diseases which has endangered the cultivation of okra worldwide. The application of PBB either alone or in combination with other bioagents have, however, been found successful in mitigating the destructive impact of root rotting fungi. Furthermore, the PBB application stimulates the synthesis of polyphenols and improve the antioxidant levels in okra plants[245]. *Pseudomonas* (*P. flourescens* PF-7 and PF-8) as an antagonist suppressed the *R. solani* growth significantly leading to a considerable increase in the vigour index of okra plants[92]. The excretion of secondary metabolites including pigments, siderophores, and cyanogen, etc. in addition to the release of IAA, SA and P solubilization by *P. fluorescens* causes an overall improvement in the yield and quality of okra. The biocontrol potentials and ability to secrete different growth modifying substances makes *P. fluorescens* a most ideal microbiological agent for upgrading the production of okra in different agrosystems.

6.3 Early and Late Blight of Potato

Potato (*Solanum tuberosum* L.) is the most important edible food crop which is cultivated widely in the temperate, sub-tropical, and tropical regions. Early blight caused by *A. solani* is one of the most common foliar diseases of potato around the world and causes yield losses of up to 80%[246]. After infection, the disease symptoms appear first onto the lower senescing leaves that subsequently turn chlorotic and abscise prematurely. Eventually, the brown spot enlarges gradually and leads to complete destruction of plant foliage. Also, the stem canker or collar rot, sunken spots, lesions on upper stems and petioles or dark leathery fruit spots, etc. are other visible symptoms that appear in wake of infection[247]. Moreover, the early blight may also cause dry rotting of tubers which spoils the yield and quality of tubers. However, the incidence and severity of disease depends on different factors such as cropping season, cultivation regions, cultivar genotypes and the health and stage of potato plants. Though, chemical fungicides are generally used to control potato early blight, the residual toxicity to non-target organisms and environmental hazards can be not underestimated. Therefore, the bacterial antagonists have been attempted to optimize the yield and quality of potato[248]. For instance, a formulation consisting of *P. fluorescens* and T. harzianum, when applied in combination with the fungicide mancozeb, inhibited the growth of *A. solani* and greatly reduced the severity and incidence of the disease. The reduction in disease then produces a substantial improvement in the growth and yield of potato[97].

Late blight is another most devastating disease of potato and is the re-emerging problem worldwide. The yield losses due to this deadly disease caused by the oomycete *Phytophthora infestans*[249] varies from countries to countries depending upon the adopted plant protection measures and growing cultivars[250,251]. For example, the yield loss in potato due to late blight has been reported as 100% under epidemic condition in Pakistan while in India the reduction in potato production due to this disease averages 15% across the country[252]. On the other hand, the total cost of late blight in Europe arising out of yield loss and the cost associated with its control has been estimated over one billion euros per year[253]. In traditional cultivation practices, potato growers adopt different management strategies for late blight disease. They use chemicals, host resistant cultivars, biological control measures and cultural control methods[254], among which the bio-based measures involving the use of bacterial antagonists especially the genera *Pseudomonas* and *Bacillus* for potato late blight have been proved effective and economical[255,256]. In a greenhouse experiment, *P. chlororaphis* (strain R47) efficiently reduced the incidence of *P. infestans*, and demonstrated the highest level of *P. infestans* inhibition which was followed by *P. fluorescens* (R76) and *P. marginalis* (S35). The inhibitory action of *Pseudomonas* strains was mediated through the antifungal compounds[257,258]. As a result, the growth of *P. infestans* were suppressed significantly that leads to a significant enhancement in potato production[259]. The application of single bacterial antagonist against *P. infestans* sometimes, however, is counterproductive because the pathogen can attack its host by multiple routes. To be specific, this pathogen can enter through direct sporangia germination or via the release of motile zoospores; both situations involve host cell penetration and mycelial development[249]. Therefore, the approaches based on multiple rather than single antagonist strain each targeting different route of infection are desirable. This strategy shows great potential to further improve the amelioration efficiency of co-cultures. To date, very few studies have been conducted to address this issue and test the effect of composite PBB antagonists for potato diseases control. De Vrieze and co-workers achieved significantly improved protection of potato against *P. infestans-induced* blight disease when using combination of five *Pseudomonas* strains than when applying each *Pseudomonas* strain separately[260]. This finding indeed paves the way for better understanding of antagonists' microbiome management that subsequently could be integrated into global potato production strategies.

6.4 Bacterial Soft Rot of Cabbage

Cabbage (*Brassica oleracea* L.), one of the most widely cultivated crucifers worldwide suffers heavily from bacterial soft rot disease[261]. The disease caused by *Pectobacterium carotovorum* subsp. *carotovorum* (Pcc)[262,263] is a major constraint in Chinese cabbage production[264,265]. Chemical methods though generally effective are considered unsuitable due to environmental pollution and the emergence of resistance among target pathogens[266]. Bacterial antagonists is one of the most effective and economical microbiological approaches for soft rot disease[264]. Among bacterial agents, *Bacillus, Pseudomonas, Lactobacillus, Lactococcus*, and *Paenibacillus* have been used for soft rot management[267,268]. Studies by Cui and co-workers revealed that the extent of soft rot in Chinese cabbage and transmission of *P. carotovorum* to the stem progeny in greenhouse conditions and its persistence in the rhizosphere was significantly declined due to the antibacterial activities of *B. amyloliquefaciens* KC-1[269].

6.5 Damping-off and Root Rot of Cucumber

Long English cucumber (*Cucumis sativus* L.; Cucurbitaceae) is grown as a vegetable crop in greenhouses in many regions of the world. Damping-off and root rot caused by soil borne fungal pathogen *Pythium sp*. is a serious and widespread disease[270,271]. Generally, the intensity of damping-off and root rot pathogens are maximum during the cool and wet environment. Pathogenically, this fungus affects almost all growth stages and organs (e.g., radicle, hypocotyl, cotyledons, seed coat, endosperm, and embryo) of plants[272,273]. The infectious magnitude of damping-off and root rot pathogens can be suppressed by certain fungicides, such as captan, thiram, iprodione, fenaminosulf, fosetyl-Al, and metalaxyl[274,275]. The microbiological control measures are, however, desired to clean up the damping-off and root rot diseases due to least/no hazards to the environment[87,276]. A few species of PBB especially the genera, *Pseudomonas* and *Bacillus*, have been found useful in alleviating the effect of damping-off and root rot pathogen *P. ultimum*[277,278]. In a study, Khabbaz and Abbasi reported that the three antagonistic PBB, *P. fluorescens* (9A-14), *Pseudomonas sp*. (8D-45) and *B. subtilis* (8B-1) when used alone or in combination enhanced the overall growth of cucumber by suppressing the unpleasant impact of *P. ultimum-induced* damping-off and root rot diseases[89]. The pre- and post-planting application of PBB caused a substantial reduction in the intensity of the cucumber diseases by 27%–50% leading thereby to a considerable increase in plant growth. The enhancement in cucumber yield and quality was attributed to the production of antibiotics and other anti-fungal metabolites by PBB[86, 102]. In conclusion, the sole or composite formulations of PBB could be developed as a safe and inexpensive biofungicides on commercial scale to optimize cucumber production globally under real field conditions. This will substantially reduce the dependence on fungicides being applied in traditional production systems to offset the damping-off and root rot disease in cucumber.

7 CONCLUSIONS AND FUTURE PROSPECTS

Vegetables are one of the most important constituents of human food systems. Most of the vegetable crops are susceptible to many biotic stresses, among which soil borne bacterial and fungal pathogens markedly reduce the yield and quality of widely grown and pleasantly consumed vegetables. The loss in vegetable production can be reduced by employing conventional approaches such as the use of resistant cultivars, crop rotation, field sanitization, and biocides. The exorbitant cost, the emergence of resistance among pathogens, and environmental pollution caused by pesticide applications, however, remain major global issues to be addressed. The success that has been achieved so far at the bench scale clearly suggests that the microbial formulations could safely and inexpensively be exploited as an antagonist to alleviate the biotic stresses. Furthermore, they can act as biological enhancers for the nutrition and yield optimization of vegetables under stressed open field conditions. Despite the incredible developments made in this area to date, scientists/researchers need to identify the soil microbiota with profound disease suppression abilities from the unexplored soil ecosystems. Such PBB with multiple plant growth-enhancing traits demonstrate great potential in enhancing vegetable production under biotic stressed open field conditions. The molecular engineering of antagonists and transferring the desired genes coding for disease suppression/growth promotion into PBB deficient in such features are desirable. The use of advanced microscopic and some molecular techniques like cryo-SEM and HR-TEM, RFLP analysis, FISH, automated DNA sequencing methods, etc. may be valuable in deciphering the physiological details of PBB and devising the strategies for uplifting vegetable production in open field conditions.

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Conflicts of Interest
The authors declare that there is no conflict of interests.

Author Contribution
Khan MS conceptualized, designed and edited this manuscript; Rizvi A surveyed, collected and organized the latest scientific information and edited the original draft; Ahmed B revised the scientific literatures for important intellectual content; Umar S critically revised and proofread the manuscript; all authors approved the final version.

Abbreviation List
ABA, Abscisic acid
ACC deaminase, 1-Aminocyclopropane-1-carboxylate deaminase
BABA, β-aminobutyric acid
BPNN, Back-propagation neural network
BTH, Benzothiadiazole
CCM, Color co-occurrence method
Chl-FI, Chlorophyll fluorescence imaging
DAB, Diaminobenzidine
DAPG, 2,4-Diacetylphloroglucinol
ET, Ethylene
FISH, Fluorescence *in situ* hybridization
H_2O_2, Hydrogen peroxide
HCN, Hydrogen cyanide
HRPO, Horseradish peroxidase
HR-TEM, High-resolution transmission electron microscopy
IAA, Indole acetic acid
ISR, Induced systemic resistance
JA, Jasmonic acid
KNN, K-Nearest neighbours
NBT, Nitroblue tetrazolium
$O2^-$, Superoxide
PBB, Plant beneficial bacteria
PLT, Pyoluteorin
RBFNN, Radial basis function neural network
RFLP, Restriction fragment length polymorphism
ROS, Reactive oxygen species
SA, Salicylic acid
SEM, Scanning electron microscopy
SGDM, Spatial gray-level dependence matrices
SNF, Symbiotic nitrogen fixation
SVM, Support vector machine
TYLCV, Tomato yellow leaf curl virus

References
[1] Maish SC. Lepidopterous pests, biology and its effect on vegetable crops. *J Entomol Zool Stud,* 2019; 7: 593-597.
[2] Phophi MM, Mafongoya PL. Constraints to vegetable production resulting from pest and diseases induced by climate change and globalization: A Review. *J Agric Sci*, 2017; 9: 11-25. DOI: 10.5539/jas.v9n10p11.
[3] BalaliGI, Yar DD, Afua Dela VG et al. Microbial contamination, an increasing threat to the consumption of fresh fruits and vegetables in today's world. *Intern J Microbiol*, 2020; 22: 1-13. DOI: 10.1155/2020/3029295.
[4] Su L, Zhang L, Nie D et al. Bacterial tomato pathogen *Ralstonia solanacearum* invasion modulates rhizosphere compounds and facilitates the cascade effect of fungal pathogen *Fusarium solani*. *Microorganisms*, 2020; 8: 806. DOI: 10.3390/microorganisms8060806.
[5] Prakash N, Erayya S, Srinivasaraghavan A et al. Effect of fungal pathogen on physiological function of vegetables. Ansar M, Ghatak A ed. The Vegetable Pathosystem: Ecology, Disease Mechanism, and Management. Apple Academic Press: New York, USA, 2019; 163-200.
[6] Santos RNV, Pires TP, Mesquita MLR et al. Weed interference in okra crop in the organic system during the dry season. *Planta Daninha*, 2020; 38: e020217201. DOI: 10.1590/S0100-83582020380100014.
[7] Ashraf M, Ahmad MSA, Öztürk M et al. Crop improvement through different means: Challenges and prospects. Crop Production for Agricultural Improvement. Springer Science & Business Media: Dordrecht, The Kingdom of the Netherlands, 2012; 1-15. DOI: 10.1007/978-94-007-4116-4_1.
[8] Schwarz D, Rouphael Y, Colla G et al. Grafting as a tool to improve tolerance of vegetables to abiotic stresses: Thermal stress, water stress and organic pollutants. *Sci Hortic-Amsterdam,* 2010; 127: 162-171. DOI: 10.1016/j.scienta.2010.09.016.
[9] Tariq M, Ali H, Hussain N et al. Fundamentals of crop rotation in agronomic management. Hasanuzzaman ed. Agronomic crops. Springer: Singapore, 2019; 545-559. DOI: 10.1007/978-

981-32-9151-5_24.
[10] IkedaK, Banno S, Furusawa A et al. Crop rotation with broccoli suppresses Verticillium wilt of eggplant. *J Gen Plant Pathol*, 2015; 81: 77-82. DOI: 10.1007/s10327-014-0559-6.
[11] Witek K, Jupe F, Witek AI et al. Accelerated cloning of a potato late blight-resistance gene using RenSeq and SMRT sequencing. *Nature Biotechnol*, 2016; 34: 656-660. DOI: 10.1038/nbt.3540.
[12] Lin S, Tang T, Cang T et al. The distributions of three fungicides in vegetables and their potential health risks in Zhejiang, China: A 3-year study (2015-2017). *Env Poll*, 2020; 267: 115481. DOI: 10.1016/j.envpol.2020.115481.
[13] Mishra P, Sharma A, Sharma D. A study on harmful effects of pesticide residue in vegetables. *Intern J Recent Res Rev*, 2014; 7: 45-48.
[14] Gafar MO, Elhag AZ, Abdelgader MA. Impact of pesticides malathion and sevin on growth of snake cucumber (Cucumis melo L. var. Flexuosus) and soil. *Univ J Agric Res,* 2013; 1: 81-84. DOI: 10.13189/ujar.2013.010307.
[15] Shahzad R, Tayade R, Shahid M et al. Evaluation potential of PGPR to protect tomato against *Fusarium* wilt and promote plant growth. *Peer J*, 2021; 9: e11194. DOI: 10.7717/peerj.11194.
[16] Miljaković D, Marinković J, Balešević-Tubić S. The Significance of *Bacillus* spp. in disease suppression and growth promotion of field and vegetable crops. *Microorganisms*, 2020; 8: 1037. DOI: 10.3390/microorganisms8071037.
[17] Zaidi A, Ahmad E, Khan MS et al. Role of plant growth promoting rhizobacteria in sustainable production of vegetables: Current perspective. *Sci Hortic-Amsterdam,* 2015, 193: 231-239. DOI: 10.1016/j.scienta.2015.07.020.
[18] Loganathan M, Garg R, Venkataravanappa V et al. Plant growth promoting rhizobacteria (PGPR) induces resistance against *Fusarium* wilt and improves lycopene content and texture in tomato. *Afr J Microbiol Res*, 2014; 8: 1105-1111. DOI: 10. 5897/AJMR2013.5653.
[19] Mekonnen H, Kibret M. The roles of plant growth promoting rhizobacteria in sustainable vegetable production in Ethiopia. *Chem Biol Technol Ag*, 2021; 8: 1-11. DOI: 10.1186/s40538-021-00213-y.
[20] McGovern RJ. Management of tomato diseases caused by *Fusarium oxysporum*. *Crop Prot*, 2015; 73: 78-92. DOI: 10.1016/j.cropro.2015.02.021.
[21] Peritore-Galve FC, Tancos MA, Smart CD. Bacterial canker of tomato: revisiting a global and economically damaging seedborne pathogen. *Plant Dis,* 2021; 105: 1581-1595. DOI: 10.1094/PDIS-08-20-1732-FE.
[22] Hassanisaadi M, Shahidi Bonjar GH, Hosseinipour A et al. Biological control of *Pythium aphanidermatum*, the causal agent of tomato root rot by two *Streptomyces* root symbionts. *Agron*, 2021; 11: 846. DOI: 10.3390/agronomy11050846.
[23] Prasad A, Sharma N, Hari-Gowthem G et al. Tomato yellow leaf curl virus: impact, challenges, and management. *Trends Plant Sci,* 2020; 25: 897-911. DOI: 10.1016/j.tplants.2020.03.015.
[24] Sanoubar R, Barbanti L. Fungal diseases on tomato plant under greenhouse condition. *Eur J Biol Res,* 2017; 7: 299-308. DOI: 10.5281/zenodo.1011161.
[25] Zhou L, Jiang HX, Sun S et al. Biotechnological potential of a rhizosphere Pseudomonas aeruginosa strain producing phenazine-1-carboxylic acid and phenazine-1-carboxamide. *World J Microb Biot*, 2016; 32: 50. DOI: 10.1007/s11274-015-1987-y.
[26] Prodhan MZH, Hasan MT, Chowdhury MMI et al. Bt eggplant (*Solanum melongena* L.) in Bangladesh: Fruit production and control of eggplant fruit and shoot borer (*Leucinodes orbonalis* Guenee), effects on non-target arthropods and economic returns. *PLoS One*, 2018; 13: e0205713. DOI: 10.1371/journal.pone.0205713.
[27] Dahatonde JA, Pandya HV, Raut SB et al. Seasonal abundance of jassid and whitefly on brinjal (*Solanum melongena* L.) in relation to major abiotic factors. *Intern J Plant Protect*, 2014; 7: 257-259.
[28] Ponnuvel M, Reegan AD, Rahman MA et al. Effect of hadda beetle, Epilachna vigintioctopunctata Fab. (Coleoptera: Coccinellidae) infestation on eggplant leaf (*Solanum melongena* L.) and bio-control potential of essential oil formulations. *Pak J Biol Sci,* 2013; 16: 991-997. DOI: 10.3923/pjbs.2013.991.997.
[29] Nicoletto C, Maucieri C, Zanin G et al. Vegetables quality and biotic stress. Ansari RA, Mahmood I ed. Plant Health Under Biotic Stress: Volume 1: Organic Strategies. Springer Singapore: Singapore, 2019; 107-128. DOI: 10.1007/978-981-13-6043-5_6.
[30] Ramegowda V, Senthil-Kumar M. The interactive effects of simultaneous biotic and abiotic stresses on plants: mechanistic understanding from drought and pathogen combination. *J Plant Physiol,* 2015; 176: 47-54. DOI: 10.1016/j.jplph.2014.11.008.
[31] Iqbal Z, Iqbal MS, Hashem A et al. Plant defense responses to biotic stress and its interplay with fluctuating dark/light conditions. *Front Plant Sci*, 2021; 12: 297. DOI:10.3389/fpls.2021.631810.
[32] Lamers J, Van Der Meer T, Testerink C. How plants sense and respond to stressful environments. *Plant Physiol,* 2020; 182: 1624-1635. DOI: 10.1104/pp.19.01464.
[33] Wasternack C, Song S. Jasmonates: biosynthesis, metabolism, and signaling by proteins activating and repressing transcription. *J Exp Bot,* 2017; 68: 1303-1321. DOI: 10.1093/jxb/erw443.
[34] Vlot AC, Dempsey DA, Klessig DF. Salicylic Acid, a mul-tifaceted hormone to combat disease. *Annu Rev Phyto-pathol,* 2009; 47: 177-206. DOI: 10.1146/annrev.phyto.050908.135202.
[35] Saijo Y, Loo EP. Plant immunity in signal integration between biotic and abiotic stress responses. *New Phytol*, 2020; 225: 87-104. DOI: 10.1111/nph.15989.
[36] Nejat N, Mantri N. Plant immune system: crosstalk between responses to biotic and abiotic stresses the missing link in understanding plant defence. *Curr Issues Mol Biol*, 2017; 23: 1-6. DOI: 10.21775/cimb.023.001.
[37] Peck S, Mittler R. Plant signaling in biotic and abiotic stress. *J*

Exp Bot, 2020; 71: 1649-1651. DOI: 10.1093/jxb/eraa051.

[38] Zhang Z, Chen Y, Li B et al. Reactive oxygen species: A generalist in regulating development and pathogenicity of phytopathogenic fungi. *Comp Struct Biotec*, 2020; 18: 3344-3349. DOI: 10.1016/j.csbj.2020.10.024.

[39] Purwantisari S, Priyatmojo A, Sancayaningsih RP et al. Lignification on potatoes by application of *Trichoderma viride. IOP Conference Series: Earth Env Sci*, 2020; 518: 012075. DOI: 10.1088/1755-1315/518/1/012075.

[40] Wilkinson SW, Pastor V, Paplauskas S et al. Long-lasting β-aminobutyric acid-induced resistance protects tomato fruit against *Botrytis cinerea*. *Plant Pathol,* 2018; 67: 30-41. DOI: 10.1111/ppa.12725.

[41] Wang J, Cao S, Wang L et al. Effect of β-aminobutyric acid on disease resistance against *Rhizopus* rot in harvested peaches. *Front Microbiol,* 2018; 9: 1505. DOI: 10.3389/fmicb.2018.01505.

[42] López-Gresa MP, Payá C, Rodrigo I et al. Effect of benzothiadiazole on the metabolome of tomato plants infected by citrus exocortis viroid. *Viruses*, 2019; 11: 437. DOI: 10.3390/v11050437.

[43] Koo YM, Heo AY, Choi HW. Salicylic acid as a safe plant protector and growth regulator. *Plant Pathol J,* 2020; 36: 1-10. DOI: 10.5423/PPJ.RW.12.2019.0295.

[44] Bhasker P, Gupta PK, Sharma HP. Role of salicylic acid on growth, yield, quality and disease pest reaction of onion (*Allium cepa l.*) cv. Agrifound Light Red. *SAARC J Agric*, 2020; 18: 39-49. DOI: 10.3329/sja.v18i1.48380.

[45] Alcalá EIL, Hernández JML, Iliná A et al. Application of jasmonic acid as an inducer of plant resistance to pathogens. *Revista mexicana de ciencias agrícolas*, 2017; 8: 673-683. DOI: 10.29312/remexca.v8i3.40.

[46] Agehara S, Leskovar DI. Abscisic acid: a new management tool to improve quality and marketability of vegetable transplants. Proceedings of the 2015 Annual Meeting of the International Plant Propagators' Society. ISHS: PA, USA, 2016; 291-292. DOI: 10.17660/ActaHortic.2016.1140.64.

[47] Jendoubi W, Harbaoui K, Hamada W. Salicylic acid-induced resistance against *Fusarium oxysporumf.*s. pradicis lycopercisi in hydroponic grown tomato plants. *J New Sci Agric Biotechnol*, 2017; 21: 985-995.

[48] Bebber DP, Gurr SJ. Crop-destroying fungal and oomycete pathogens challenge food security. *Fungal Genet Biol*, 2015; 74: 62-64. DOI: 10.1016/j.fgb.2014.10.012.

[49] Barbedo JGA, Godoy CV. Automatic classification of soybean diseases based on digital images of leaf symptoms. SBI AGRO, 2015.

[50] Bach-Pages M, Preston GM. Methods to quantify biotic-induced stress in plants. Medina C, López-Baena FJ ed. Host-Pathogen Interactions. Humana Press: New York, USA, 2018; 241-255. DOI: 10.1007/978-1-4939-7604-1_19.

[51] Bisceglia NG, Gravino M, Savatin DV. Luminol-based assay for detection of immunity elicitor-induced hydrogen peroxide production in *Arabidopsis thaliana* leaves. *Bio-protocol,* 2015; 5: e1685. DOI: 10.21769/BioProtoc.1685.

[52] Smith JM, Heese A. Rapid bioassay to measure early reactive oxygen species production in *Arabidopsis* leave tissue in response to living *Pseudomonas syringae*. *Plant Methods*, 2014; 10: 1-9. DOI: 10.1186/1746-4811-10-6.

[53] Voigt CA. Callose-mediated resistance to pathogenic intruders in plant defense related papillae. *Front Plant Sci*, 2014; 5: 1-6. DOI: 10.3389/fpls.2014.00168.

[54] Luna E, Pastor V, Robert J et al. Callose deposition: a multifaceted plant defense response. *Mol Plant Microbe in*, 2011; 24: 183-193. DOI: 10.1094/MPMI-07-10-0149.

[55] Hiruma K, Fukunaga S, Bednarek P et al. Glutathione and tryptophan metabolism are required for *Arabidopsis* immunity during the hypersensitive response to hemibiotrophs. *Proc Natl Acad Sci*, 2013; 110: 9589-9594. DOI: 10.1073/pnas.1305745110.

[56] Greenberg JT, Yao N. The role and regulation of programmed cell death in plant-pathogen interactions. *Cell Microbiol,* 2004; 6: 201-211. DOI: 10.1111/j.1462-5822.2004.00361.x.

[57] Dıaztielas C, Gran˜a E, Sotelo T et al. The natural compound trans-chalcone induces programmed cell death in *Arabidopsis thaliana* roots. *Plant Cell Environ,* 2012; 35: 1500-1517. DOI: 10.1111/j.1365-3040.2012.02506.x.

[58] Alvarez ME, Pennell RI, Meijer PJ et al. Reactive oxygen intermediates mediate a systemic signal network in the establishment of plant immunity. *Cell*, 1998; 92: 773-784. DOI: 10.1016/s0092-8674(00)81405-1.

[59] Verlag F, Campos PS, Quartin V et al. Electrolyte leakage and lipid degradation account for cold sensitivity in leaves of *coffea* sp. plants. *J Plant Physiol,* 2003; 160: 283-292. DOI: 10.1078/0176-1617-00833.

[60] Bajji M, Kinet JM, Lutts S. The use of the electrolyte leakage method for assessing cell membrane stability as a water stress tolerance test in durum wheat. *Plant Growth Regul,* 2002; 36: 61-70. DOI: 10.1023/A:1014732714549.

[61] Yang Y, Wang M, Yin Y et al. RNA-seq analysis reveals the role of red light in resistance against *Pseudomonas syringae* pv. *tomato* DC3000 in tomato plants. *BMC Genomics,* 2015; 16: 1-16. DOI: 10.1186/s12864-015-1228-7.

[62] Pombo MA, Zheng Y, Fernandez-Pozo N et al. Transcriptomic analysis reveals tomato genes whose expression is induced specifically during effector-triggered immunity and identifies the Epk1 protein kinase which is required for the host response to three bacterial effector proteins. *Genome Biol*, 2014; 15: 1-16. DOI: 10.1186/s13059-014-0492-1.

[63] Howard BE, Hu Q, Babaoglu AC et al. High-throughput RNA sequencing of Pseudomonas-infected *Arabidopsis* reveals hidden transcriptome complexity and novel splice variants. *PLoS One*, 2013; 8: e74183. DOI: 10.1371/journal.pone.0074183.

[64] Hernández-Aparicio F, Lisón P, Rodrigo I et al. Signaling in the tomato immunity against *Fusarium oxysporum*. *Molecules*, 2021; 26: 1818. DOI: 10.3390/molecules26071818.

[65] Escobar-Bravo R, Alba JM, Pons C et al. A jasmonate-inducible defense trait transferred from wild into cultivated tomato establishes increased whitefly resistance and reduced viral disease incidence. *Front Plant Sci,* 2016; 7: 1-16. DOI: 10.3389/fpls.2016.01732.

[66] Hu S, Bidochka MJ. Abscisic acid implicated in differential plant responses of *Phaseolus vulgaris* during endophytic colonization by *Metarhizium* and pathogenic colonization by *Fusarium*. *Sci Rep*, 2021; 11: 1-12. DOI: 10.1038/s41598-021-90232-4.

[67] Di FA, Ugolini L, D'Aquino S et al. Biocontrol of *Monilini-alaxa* by *Aureobasidium pullulans* strains: insights on competition for nutrients and space. *Int J Food Microbiol*, 2017; 248: 32-38. DOI: 10.1016/j.ijfoodmicro.2017.02.007.

[68] O'Leary BMO, Neale HC, Geilfus C et al. Early changes in apoplast composition associated with defence and disease in interactions between *Phaseolus vulgaris* and the halo blight pathogen *Pseudomonas syringae* pv. Phaseolicola. *Plant Cell Environ,* 2016; 39: 2172-2184. DOI: 10.1111/pce.12770.

[69] Ward JL, Forcat S, Beckmann M et al. The metabolic transition during disease following infection of *Arabidopsis thaliana* by *Pseudomonas syringae* pv. Tomato. *Plant J*, 2010; 63: 443-457. DOI: 10.1111/j.1365-313X.2010.04254.x.

[70] Forcat S, Bennett MH, Mansfield JW et al. A rapid and robust method for simultaneously measuring changes in the phytohormones ABA, JA and SA in plants following biotic and abiotic stress. *Plant Methods*, 2008; 4: 1-8. DOI: 10.1186/1746-4811-4-16.

[71] Pérez-Bueno ML, Pineda M, Barón M. Phenotyping plant responses to biotic stress by chlorophyll fluorescence imaging. *Front Plant Sci*, 2019; 10; 1-15. DOI: 10.3389/fpls.2019.01135.

[72] Zabala MDT, Littlejohn G, Jayaraman S et al. Chloroplasts play a central role in plant defence and are targeted by pathogen effectors. *Nat Plants,* 2015; 1: 1-10. DOI: 10.1038/nplants.2015.74.

[73] Berdugo CA, Zito R, Paulus S et al. Fusion of sensor data for the detection and differentiation of plant diseases in cucumber. *Plant Pathol*, 2014; 63: 1344-1356. DOI: 10.1111/ppa.12219.

[74] Sandhu GK, Kaur R ed. Plant disease detection techniques: a review: 2019 International Conference on Automation, Computational and Technology Management (ICACTM), London, UK, 24-26 April 2019. New York, NY: IEEE; 2019. DOI: 10.1109/ICACTM.2019.8776827.

[75] Chanda M, Biswas M ed. Plant disease identification and classification using back-propagation neural network with particle swarm optimization: 2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI), Tirunelveli, India, 23-25 April 2019. New York, NY: IEEE; 2019. DOI: 10.1109/ICACTM.2019.8776827.

[76] Tournas VH. Spoilage of vegetable crops by bacteria and fungi and related health hazards. *Crit Rev Microbiol*, 2005; 31: 33-44. DOI: 10.1080/10408410590886024.

[77] Donley N. The USA lags behind other agricultural nations in banning harmful pesticides. *Environ Health*, 2019, 18: 1-12. DOI: 10.1186/s12940-019-0488-0.

[78] Schreinemachers P, Tipraqsa P. Agricultural pesticides and land use intensification in high, middle and low income countries. *Food Policy,* 2012; 37: 616-626. DOI: 10.1016/j.foodpol.2012.06.003.

[79] Whipps JM, Gerhardson B. Biological pesticides for control of seed- and soil-borne plant pathogens. Elsas JDV, Jansson JK, Trevors JT ed. Modern soil microbiology, 2nd ed. CRC Press: Florida, USA, 2006; 479-501.

[80] De Corato U. Soil microbiota manipulation and its role in suppressing soil-borne plant pathogens in organic farming systems under the light of microbiome-assisted strategies. *Chem Biol Technol Ag*, 2020; 7: 1-26. DOI: 10.1186/s40538-020-00183-7.

[81] Ghosh R, Barman S, Mukherjee R et al. Role of phosphate solubilizing *Burkholderia* spp. for successful colonization and growth promotion of *Lycopodium cernuum* L. (Lycopodiaceae) in lateritic belt of Birbhum district of West Bengal, India. *Microbiol Res*, 2016; 183: 80-91. DOI: 10.1016/j.micres.2015.11.011.

[82] Anitha A, Arunkumar D, Saraswathi RK. Induction of defense proteins in tomato treated with *Streptomyces griseus* against *Fusarium oxysporum* f. sp. *Lycopersici*. *Biosc Biotech Res Comm,* 2020; 13: 2240-2248. DOI: 10.21786/bbrc/13.4/92.

[83] Konappa N, Krishnamurthy S, Arakere UC et al. Efficacy of indigenous plant growth-promoting rhizobacteria and Trichoderma strains in eliciting resistance against bacterial wilt in a tomato. *Egyp J Biol Pest Co*, 2020; 30: 1-13. DOI: 10.1186/s41938-020-00303-3.

[84] Alamer ISA, Li B, Tomah AA et al. Isolation, identification and characterization of rhizobacteria strains for biological control of bacterial wilt (*Ralstonia solanacearum*) of eggplant in China. *Agric*, 2020; 10: 37. DOI: 10.3390/agriculture10020037.

[85] Chakravarty G, Kalita MC. Biocontrol potential of *Pseudomonas fluorescens* against bacterial wilt of brinjal and its possible plant growth promoting effects. *Ann Biol Res,* 2012; 3: 5083-5094.

[86] Sarhan EAD, Abd-Elsyed MHF, Ebrahiem AMY. Biological control of cucumber powdery mildew (*Podosphaera xanthii*) (Castagne) under greenhouse conditions. *Egyp J Biol Pest Control*, 2020; 30: 1-7. DOI: 10.1186/s41938-020-00267-4.

[87] Halo BA, Al-Yahyai RA, Maharachchikumbura SSN et al. *Talaromyces variabilis* interferes with *Pythium aphanidermatum* growth and suppresses *Pythium*-induced damping-off of cucumbers and tomatoes. *Sci Rep-UK*, 2019; 9: 11255. DOI: 10.1038/s41598-019-47736-x.

[88] Islam S, Akanda AM, Prova A et al. Isolation and identification of plant growth promoting rhizobacteria from cucumber rhizosphere and their effect on plant growth promotion and disease suppression. *Front Microbiol,* 2016; 6: 1-12. DOI: 10.3389/fmicb.2015.01360.

[89] Khabbaz SE, Abbasi PA. Isolation, characterization, and formulation of antagonistic bacteria for the management of seedlings damping-off and root rot disease of cucumber. *Can J Microbiol*, 2014; 60: 25-33. DOI:10.1139/cjm-2013-0675.

[90] Sen K, Sengupta C, Saha J. PGPR consortium in alleviating downy mildew of cucumber. *Int J Plant Anim Env Sci,* 2014; 4: 150-159.

[91] Brahmbhatt AB, Aravind T. Management of root and collar rot *(Macro-phomina Phaseolina* (Tassi) Goid.) of OKRA (*Abelmoschus esculentus* (L.) Moench) through bioagents,

oil cakes and fungicides. *J Pharmacogn Phytochem,* 2018; 7: 631-635.

[92] Adhikari A, Dutta S, Nandi S et al. Antagonistic potentiality of native rhizobacterial isolates against root rot disease of okra, incited by Rhizoctonia solani. *Afr J Agr Res*, 2013; 8: 405-412. DOI: 10.5897/AJAR13.003.

[93] Anjum MZ, Adnan M, Ali SM et al. Antifungal potential of biocontrol agents against Phytophthora capsici causing chili fruit rot. *Agr Res Tech: Open Access J*, 2019; 22: 156-159. DOI: 10.19080/ARTOAJ.2019.22.556209.

[94] Shrestha A, Kim BS, Park DH. Biological control of bacterial spot disease and plant growth-promoting effects of lactic acid bacteria on pepper. *Biocontrol Sci Techn*, 2014; 24: 763-779. DOI: 10.1080/09583157.2014.894495.

[95] Da Silva HAO, Teixeira WD, Borges ÁV et al. Biocontrol of potato early blight and suppression of *Alternaria grandis* sporulation by *Clonostachys* spp. *Plant Pathol,* 2021; 70: 1677-1685. DOI: 10.1111/ppa.13402.

[96] Brmejo AC, Castro JC, Hilacondo WC et al. Rhizospheric actinomycetes from organic crops of native potato (*Solanum tuberosum*): isolation, phenotypic characterization, molecular identification, and impact on biocontrol of *Phytophthora infestans* (Mont.) de Bary. *Scientia Agropecuaria*, 2020; 11: 223-231. DOI: 10.17268/sci.agropecu.2020.02.09.

[97] Mane MM, Lal A, Zghair QN et al. Efficacy of certain bio agents and fungicides against early blight of potato (*Solanum tuberosum* L.). *Int J Plant Protect,* 2014; 7: 433-436. DOI: 10.15740/HAS/IJPP/7.2/433-436.

[98] Shanthiyaa V, Saravanakumar D, Rajendran L et al. Use of *Chaetomium globosum* for biocontrol of potato late blight disease. *Crop Prot,* 2013; 52: 33-38. DOI: 10.1016/j.cropro.2013.05.006.

[99] Sopheareth M, Chan S, Naing KW et al. Biocontrol of late blight (*Phytophthora capsici*) disease and growth promotion of pepper by *Burkholderia cepacia* MPC-7. *Plant Pathology J,* 2013; 29: 67-76. DOI: 10.5423/PPJ.OA.07.2012.0114.

[100] Lugtenberg B, Kamilova F. Plant-growth-promoting rhizobacteria. *Ann Rev Microbiol*, 2009; 63: 541-556. DOI: 10.1146/annurev.micro.62.081307.162918.

[101] Backer R, Rokem JS, Ilangumaran G et al. Plant growth-promoting rhizobacteria: context, mechanisms of action, and roadmap to commercialization of biostimulants for sustainable agriculture. *Front Plant Sci,* 2018; 9: 1768. DOI: 10.3389/fpls.2018.01473.

[102] Sarhan EAD, Shehata HS. Potential plant growth-promoting activity of *Pseudomonas* spp. and *Bacillus* spp. as biocontrol agents against damping-off in alfalfa. *Plant Pathology J*, 2014; 13: 8-17. DOI: 10.3923/ppj.2014.8.17.

[103] Cao Y, Pi H, Chandrangsu P et al. Antagonism of two plant-growth promoting *Bacillus velezensis* isolates against *Ralstonia solanacearum* and *Fusarium oxysporum*. *Sci Rep*, 2018; 8: 1-14. DOI: 10.1038/s41598-018-22782-z.

[104] Tariq M, Noman M, Ahmed T et al. Antagonistic features displayed by plant growth promoting rhizobacteria (PGPR): a review. *J Plant Sci Phytopathol*, 2017; 1: 38-43. DOI: 10.29328/journal.jpsp.1001004.

[105] Sistani NR, Kaul HP, Desalegn G et al. *Rhizobium* impacts on seed productivity, quality, and protection of *Pisum sativum* upon disease stress caused by *Didymella pinodes*: phenotypic, proteomic, and metabolomic traits. *Front Plant Sci,* 2017; 8: 1961. DOI: 10.3389/fpls.2017.01961.

[106] Mitra D, Anđelković S, Panneerselvam P et al. Phosphate-solubilizing microbes and biocontrol agent for plant nutrition and protection: current perspective. *Commun Soil Sci Plan,* 2020; 51: 645-657. DOI: 10.1080/00103624.2020.1729379.

[107] Aallam Y, Maliki BE, Dhiba D et al. Multiple potential plant growth promotion activities of endemic *Streptomyces* spp. From moroccan sugar beet fields with their inhibitory activities against *Fusarium* spp. *Microorganisms*, 2021; 9: 1429. DOI: 10.3390/microorganisms9071429.

[108] Bhatt K, Maheshwari DK. Zinc solubilizing bacteria (*Bacillus megaterium*) with multifarious plant growth promoting activities alleviates growth in *Capsicum annuum* L. *3 Biotech*, 2020; 10: 1-10. DOI: 10.1007/s13205-019-2033-9.

[109] Paredes-Villanueva J, Del Rosario JL, Urcia-Pulido M et al. Plant growth promoter collection of *Gluconacetobacter diazotrophicus* from the northern coast of Peru. *Scientia Agropecuaria,* 2020; 11: 15-21. DOI: 10.17268/sci.agropecu.2020.01.02.

[110] Jiao X, Takishita Y, Zhou G et al. Plant associated rhizobacteria for biocontrol and plant growth enhancement. *Front Plant Sci,* 2021; 12: 420. DOI: 10.3389/fpls.2021.634796.

[111] Zhang QX, Kong XW, Li SY et al. Antibiotics of *Pseudomonas protegens* FD6 are essential for biocontrol activity. *Australas Plant Path,* 2020; 49: 307-317. DOI: 10.1007/s13313-020-00696-7.

[112] Vinodkumar S, Nakkeeran S, Renukadevi P et al. Biocontrol potentials of antimicrobial peptide producing *Bacillus* species: multifaceted antagonists for the management of stem rot of carnation caused by *Sclerotinia sclerotiorum*. *Front Microbiol,* 2017; 8: 446. DOI: 10.3389/fmicb.2017.00446.

[113] Meyer SLF, Everts KL, Gardener BM et al. Assessment of DAPG-producing *Pseudomonas fluorescens* for management of *Meloidogyne incognita* and *Fusarium oxysporum* on Watermelon. *J Nematol,* 2016; 48: 43-53. DOI: 10.21307/jofnem-2017-008.

[114] Hamane S, Zerrouk MH, Lyemlahi AE et al. Screening and characterization of phosphate-solubilizing rhizobia isolated from *Hedysarum pallidum* in the northeast of Morocco. Kumar M, Kumar V, Prasad R ed. Phyto-Microbiome in Stress Regulation. Springer: Singapore, 2020; 113-124. DOI: 10.1007/978-981-15-2576-6_7.

[115] Ali S, Hameed S, Shahid M et al. Functional characterization of potential PGPR exhibiting broad-spectrum antifungal activity. *Microbiol Res,* 2020; 232: 126389. DOI: 10.1016/j.micres.2019.126389.

[116] Mendoza-Arroyo GE, Chan-Bacab MJ, Aguila-Ramírez RN et al. Inorganic phosphate solubilization by a novel isolated bacterial strain *Enterobacter* sp. ITCB-09 and its application potential as biofertilizer. *Agriculture*, 2020; 10: 383. DOI: 10.3390/agriculture10090383.

[117] Boubekri K, Soumare A, Mardad I et al. The screening of

potassium- and phosphate-solubilizing actinobacteria and the assessment of their ability to promote wheat growth parameters. *Microorganisms*, 2021; 9: 470. DOI: 10.3390/microorganisms9030470.

[118] Kang BR, Anderson AJ, Kim YC. Hydrogen cyanide produced by *Pseudomonas chlororaphis* O6 exhibits nematicidal activity against *Meloidogyne hapla*. *Plant Pathol J*, 2018; 34: 35-43. DOI: 10.5423/PPJ.OA.06.2017.0115.

[119] Zhou L, Song C, Li Z et al. Antimicrobial activity screening of rhizosphere soil bacteria from tomato and genome-based analysis of their antimicrobial biosynthetic potential. *BMC Genomics*, 2021; 22: 1-14. DOI: 10.1186/s12864-020-07346-8.

[120] Nazari M, Smith DL. A PGPR-produced bacteriocin for sustainable agriculture: a review of thuricin 17 characteristics and applications. *Front Plant Sci*, 2020; 11: 916. DOI: 10.3389/fpls.2020.00916.

[121] Mukhtar T, Smith D, Sultan T et al. Mitigation of heat stress in *Solanum lycopersicum* L. by ACC-deaminase and exopolysaccharide producing *Bacillus cereus*: effects on biochemical profiling. *Sustainability-Basel*, 2020; 12: 2159. DOI: 10.3390/su12062159.

[122] Köhl J, Kolnaar R, Ravensberg WJ. Mode of action of microbial biological control agents against plant diseases: relevance beyond efficacy. *Front Plant Sci,* 2019; 10: 845. DOI: 10.3389/fpls.2019.00845.

[123] Pieterse CMJ, Zamioudis C, Berendsen RL et al. Induced systemic resistance by beneficial microbes. *Ann Rev Phytopathol,* 2014; 52: 347-375. DOI: 10.1146/annurev-phyto-082712-102340.

[124] Liu K, Garrett C, Fadamiro H et al. Antagonism of black rot in cabbage by mixtures of plant growth-promoting rhizobacteria (PGPR). *Bio Control*, 2016; 61: 605-613. DOI: 10.1007/s10526-016-9742-3.

[125] Kumari S, Khanna V. Effect of antagonistic rhizobacteria inoculated with *Mesorhizobium ciceri* on control of fusarium wilt in chickpea (*Cicer arietinum* L.). *Afr J Microbiol Res,* 2014; 8: 1255-1265. DOI: 10.5897/AJMR2013.6481.

[126] Li H, Ding X, Wang C et al. Control of tomato yellow leaf curl virus disease by *Enterobacter asburiae* BQ9 as a result of priming plant resistance in tomatoes. *Turk J Biol*, 2016; 40: 150-159. DOI: 10.3906/biy-1502-12.

[127] BeneduziA, Ambrosini A, Passaglia LM. Plant growth-promoting rhizobacteria (PGPR): their potential as antagonists and biocontrol agents. *Genet Mol Biol,* 2012; 35: 1044-1051. DOI: 10.1590/s1415-47572012000600020.

[128] Keel C, Schnider U, Maurhofer M et al. Suppression of root diseases by *Pseudomonas* fluorescens CHA0: importance of the bacterial secondary metabolite2,4-diacetylphloroglucinol. *Mol Plant Microbe Interact,* 1992; 5: 4-13. DOI: 10.1094/MPMI-5-004.

[129] Keel C, Wirthner PH, Oberhänsli TH et al. Pseudomonads as antagonists of plant pathogens in the rhizosphere: role of the antibiotic 2,4-diacetylphloroglucinol in the suppression of black root rot of tobacco. *Symbiosis*, 1990; 9: 327-341.

[130] Maurhofer M, Keel C, Haas D et al. Pyoluteorin production by *Pseudomonas fluorescens* strain CHA0 is involved in the suppression of *Pythium* damping-off of cress but not of cucumber. *Eur J Plant Pathol*, 1994; 100: 221-232. DOI: 10.1007/BF01876237.

[131] Haas D, Keel C. Regulation of antibiotic production in root colonizing Pseudomonas sp. and relevance for biological control of plant disease. *Annu Rev Phytopathol*, 2003; 41: 117-153. DOI: 10.1146/annurev.phyto.41.052002.095656.

[132] Ghazy N, El-Nahrawy S. Siderophore production by *Bacillus subtilis* MF497446 and *Pseudomonas koreensis* MG209738 and their efficacy in controlling *Cephalosporium maydis* in maize plant. *Arch Microbiol*, 2021; 203: 1195-1209. DOI: 10.1007/s00203-020-02113-5.

[133] Srinivasan T, Kumar AG, Ganesh PS. PGPR Siderophore and its role in antimicrobial activity in plants-A Review. *J Agric, For Meteorol Res*, 2019; 2: 73-76.

[134] Verma T, Pal P. Isolation and screening of rhizobacteria for various plant growth promoting attributes. *J Pharmacogn Phytochem*, 2020; 9: 1514-1517. DOI: 10.22271/phyto.2020.v9.i1z.10678.

[135] Shaikh SS, Sayyed RZ. Reddy MS. Plant growth-promoting rhizobacteria: An eco-friendly approach for sustainable agroecosystem. Hakeem KR, Akhtar MS, Abdullah SNA ed. Plant, Soil and Microbes: Volume 1: Implications in Crop Science. Springer: NY, USA, 2016; 181-201. DOI: 10.1007/978-3-319-27455-3_10.

[136] Gu S, Wei Z, Shao Z et al. Competition for iron drives phytopathogen control by natural rhizosphere microbiomes. *Nature Microbiol,* 2020; 5: 1002-1010. DOI: 10.1038/s41564-020-0719-8.

[137] Olanrewaju OS, Glick BR, Babalola OO. Mechanisms of action of plant growth promoting bacteria. *World J Microb Biot*, 2017; 33: 1-16. DOI: 10.1007/s11274-017-2364-9.

[138] Ruiz JA, Bernar EM, Jung K. Production of siderophores increases resistance to fusaric acid in *Pseudomonas protegens* Pf-5. *PLOS ONE*, 2015; 10: e0117040. DOI: 10.1371/journal.pone.0117040.

[139] Zhao G, Wei Y, Chen J et al. Screening, identification and growth-promotion products of multifunctional bacteria in a Chinese Fir Plantation. *Forests*, 2021; 12: 120. DOI: 10.3390/f12020120.

[140] Kalam S, Basu A, Podile AR. Functional and molecular characterization of plant growth promoting *Bacillus* isolates from tomato rhizosphere. *Heliyon*, 2020; 6: e04734. DOI: 10.1016/j.heliyon.2020.e04734.

[141] Gupta S, Pandey S. ACC deaminase producing bacteria with multifarious plant growth promoting traits alleviates salinity stress in French bean (*Phaseolus vulgaris*) plants. *Front Microbiol*, 2019; 10: 1506. DOI: 10.3389/fmicb.2019.01506.

[142] Etesami H, Glick BR. Halotolerant plant growth-promoting bacteria: Prospects for alleviating salinity stress in plants. *Environ Exp Bot*, 2020; 178: 104124. DOI: 10.1016/j.envexpbot.2020.104124.

[143] Dubois M, Van den Broeck L, Inzé D. The pivotal role of ethylene in plant growth. *Trends Plant Sci*, 2018; 23: 311-323. DOI: 10.1016/j.tplants.2018.01.003.

[144] Glick BR. Bacteria with ACC deaminase can promote plant growth and help to feed the world. *Microbiol Res*, 2014; 169: 30-39. DOI: 10.1016/j.micres.2013.09.009.

[145] Gontia-Mishra I, Sasidharan S, Tiwari S. Recent developments in use of 1-aminocyclopropane-1-carboxylate (ACC) deaminase for conferring tolerance to biotic and abiotic stress. *Biotechnol Lett*, 2014; 36: 889-898. DOI: 10.1007/s10529-014-1458-9.

[146] Orozco-Mosqueda MDC, Glick BR, Santoyo G. ACC deaminase in plant growth-promoting bacteria (PGPB): an efficient mechanism to counter salt stress in crops. *Microbiol Res*, 2020; 235: 126439. DOI: 10.1016/j.micres.2020.126439.

[147] Khan MS, Zaidi A, Ahmad E. Mechanism of phosphate solubilization and physiological functions of phosphate-solubilizing microorganisms. Khan MS, Zaidi A, Musarrat J ed. Phosphate solubilizing microorganisms, 2014; 31-62. DOI: 10.1007/978-3-319-08216-5_2.

[148] Dixit R, Agrawal L, Gupta S et al. Southern blight disease of tomato control by 1-aminocyclopropane-1-carboxylate (ACC) deaminase producing *Paenibacillus lentimorbus* B-30488. *Plant Signal Behav*, 2016; 11: e1113363. DOI: 10.1080/15592324.2015.1113363.

[149] Sureshbabu K, Amaresan N, Kumar K. Amazing multiple function properties of plant growth promoting rhizobacteria in the rhizosphere soil. *Int J Curr Microbiol App Sci,* 2016; 5: 661-683. DOI: 10.20546/ijcmas.2016.502.074.

[150] Zohara F, Akanda MAM, Paul NC et al. Inhibitory effects of *Pseudomonas* spp. on plant pathogen *Phytophthora capsici* in vitro and in planta. *Biocatal Agr Biotechnol,* 2016; 5: 69-77. DOI: 10.1016/j.bcab.2015.12.009.

[151] Ahmed B, Zaidi A, Khan MS et al. Perspectives of plant growth promoting rhizobacteria in growth enhancement and sustainable production of tomato. Zaidi A, Khan MS ed. Microbial strategies for vegetable production. Springer: Cham, Switzerland, 2017; 125-149. DOI: 10.1007/978-3-319-54401-4_6.

[152] Radhakrishnan R, Hashem A, Abd-Allah EF. *Bacillus*: A biological tool for crop improvement through bio-molecular changes in adverse environments. *Front Physiol*, 2017; 8: 667. DOI: 10.3389/fphys.2017.00667.

[153] Hyder S, Gondal AS, Rizvi ZF et al. Characterization of native plant growth promoting rhizobacteria and their anti-oomycete potential against *Phytophthora capsici* affecting chilli pepper (*Capsicum annum* L.). *Sci Rep*, 2020; 10: 13859. DOI: 10.1038/s41598-020-69410-3.

[154] Abd El-Rahman AF, Shaheen HA, Abd El-Aziz RM et al. Influence of hydrogen cyanide-producing rhizobacteria in controlling the crown gall and root-knot nematode, Meloidogyne incognita. *Egyp J Biol Pest Co*, 2019; 29: 1-11. DOI: 10.1186/s41938-019-0143-7.

[155] Hamid S, Lone R, Mohamed HI. Production of antibiotics from PGPR and their role in biocontrol of plant diseases. Mohamed HI, El-Beltagi HES, Abd-Elsalam KA ed. Plant Growth-Promoting Microbes for Sustainable Biotic and Abiotic Stress Management. Springer Nature: Cham, Switzerland, 2021; 441-461. DOI: 10.1007/978-981-13-6986-5_1.

[156] Ulloa-Ogaz AL, Muñoz-Castellanos LN, Nevárez-Moorillón GV. Biocontrol of phytopathogens: Antibiotic production as mechanism of control. Méndez-Vilas A ed. The battle against microbial pathogens: Basic science, technological advances and educational programs. Formatex Research Center S.L.: Badajoz, Spain, 2015; 305-309.

[157] Biessy A, Filion M. Phloroglucinol derivatives in plant-beneficial *Pseudomonas* spp.: Biosynthesis, Regulation, and Functions. *Metabolites*, 2021; 11: 182. DOI: 10.3390/metabo11030182.

[158] Wang X, Mavrodi DV, Ke L et al. Biocontrol and plant growth-promoting activity of rhizobacteria from Chinese fields with contaminated soils. *Microbiol Biotechnol*, 2015; 8: 404-418. DOI: 10.1111/1751-7915.12158.

[159] Sun D, Zhuo T, Hu X et al. Identification of a *Pseudomonas putida* as biocontrol agent for tomato bacterial wilt disease. *Biol Cont*, 2017; 114: 45-50. DOI: 10.1016/j.biocontrol.2017.07.015.

[160] Dilantha WG, Nakkeeran S, Zhang Y. Biosynthesis of antibiotics by PGPR and its relation in biocontrol of plant diseases. Siddiqui ZA ed. PGPR: Biocontrol and Biofertilization. Springer Science & Business Media: Dordrecht, The Netherlands, 2006; 67-109. DOI: 10.1007/1-4020-4152-7_3.

[161] Maksimov IV, Abizgil'dina RR, Pusenkova LI. Plant growth promoting rhizobacteria as alternative to chemical crop protectors from pathogens (Review). *Appl Biochem Microbiol*, 2011; 47: 333-345. DOI: 10.1134/S0003683811040090.

[162] Gong L, Tan H, Chen F et al. Novel synthesized 2, 4-DAPG analogues: antifungal activity, mechanism and toxicology. *Sci Rep*, 2016; 6: 1-9. DOI: 10.1038/srep32266.

[163] Zhou T, Chen D, Li C et al. Isolation and characterization of *Pseudomonas brassicacearum* J12 as an antagonist against *Ralstonia solanacearum* and identification of its antimicrobial components. *Microbiol Res*, 2012; 167: 388-394. DOI: 10.1016/j.micres.2012.01.003.

[164] Suresh P, Varathraju G, Shanmugaiah V et al. Partial purification and characterization of 2, 4-diacetylphloroglucinol producing *Pseudomonas fluorescens* VSMKU3054 against bacterial wilt disease of tomato. *Saudi J Biol Sci*, 2021; 8: 2155-2167. DOI: 10.1016/j.sjbs.2021.02.073.

[165] Xu Z, Wang M, Du J et al. Isolation *Burkholderia* sp. HQB-1, a promising biocontrol bacteria to protect banana against *Fusarium* wilt through phenazine-1-carboxylic acid secretion. *Front Microbiol,* 2020; 11: 605152. DOI: 10.3389/fmicb.2020.605152.

[166] Ayoub Moubareck C. Polymyxins and bacterial membranes: a review of antibacterial activity and mechanisms of resistance. *Membranes*, 2020; 10: 181. DOI: 10.3390/membranes10080181.

[167] Jung WJ, Mabood F, Souleimanov A et al. Stability and antibacterial activity of bacteriocins produced by *Bacillus thuringiensis* and *Bacillus thuringiensis* ssp. kurstaki. *J Microbiol Biotechnol*, 2008; 18: 1836-1840. DOI: 10.4014/jmb.0800.120.

[168] Riley MA, Wertz JE. Bacteriocins: evolution, ecology, and application. *Ann Rev Microbiol*, 2002; 56: 117-137. DOI:

10.1146/annurev.micro.56.012302.161024.

[169] Cascales E, Buchanan SK, Duché D et al. Colicin biology. *Microbiol Mol Biol*, 2007; 71: 158-229. DOI: 10.1128/MMBR.00036-06.

[170] Abriouel H, Franz CM, Ben Omar N et al. Diversity and applications of *Bacillus* bacteriocins. *FEMS Microbiol Rev*, 2011; 35: 201-232. DOI: 10.1111/j.1574-6976.2010.00244.x.

[171] Gupta G, Parihar SS, Ahirwar NK et al. Plant growth promoting rhizobacteria (PGPR): Current and future prospects for development of sustainable agriculture. *J Microb Biochem Technol*, 2015; 7: 096-102. DOI: 10.4172/1948-5948.1000188.

[172] Shrivastava P, Kumar R, Yandigeri MS. *In vitro* biocontrol activity of halotolerant *Streptomyces aureofaciens* K20: A potent antagonist against *Macrophomina phaseolina* (Tassi) Goid. *Saudi J Biol Sci*, 2017; 24: 192-199. DOI: 10.1016/j.sjbs.2015.12.004.

[173] Figueroa-Lopez AM, Cordero-Ramirez JD, Martinez-Alvarez JC et al. Rhizospheric bacteria of maize with potential for biocontrol of *Fusarium verticillioides. Springer Plus,* 2016; 5: 330. DOI: 10.1186/s40064-016-1780-x.

[174] El-Gamal NG, Shehata AN, Hamed ER. Improvement of lytic enzymes producing *Pseudomonas fluorescens* and *Bacillus subtilis* isolates for enhancing their biocontrol potential against root rot disease in tomato plants. *Res J Pharm Biol Chem Sci*, 2016; 7: 1394-1400.

[175] Ashwini N, Srividya S. Potentiality of *Bacillus subtilis* as biocontrol agent for management of anthracnose disease of chilli caused by *Colletotrichum gloeosporioides* OGC_1. *3 Biotech*, 2014; 4: 127-136. DOI: 10.1007/s13205-013-0134-4.

[176] Rais A, Jabeen Z, Shair F et al. *Bacillus* spp., a bio-control agent enhances the activity of antioxidant defense enzymes in rice against *Pyricularia oryzae*. *PLoS One*, 2017; 12: e0187412. DOI: 10.1371/journal.pone.0187412.

[177] Janahiraman V, Anandham R, Kwon SW et al. Control of wilt and rot pathogens of tomato by antagonistic pink pigmented facultative methylotrophic *Delftialacustris* and *Bacillus* spp. *Front Plant Sci*, 2016; 7: 1626. DOI: 10.3389/fpls.2016.01626.

[178] Mota MS, Gomes CB, Souza Júnior IT et al. Bacterial selection for biological control of plant disease: criterion determination and validation. *Braz J Microbiol,* 2017; 48: 62-70. DOI: 10.1016/j.bjm.2016.09.003.

[179] Kumar H, Bajpai VK, Dubey RC. Wilt disease management and enhancement of growth and yield of *Cajanus cajan* (L) var. Manak by bacterial combinations amended with chemical fertilizer. *Crop Protect*, 2010; 29: 591-598. DOI: 10.1016/j.cropro.2010.01.002.

[180] Ordentlich A, Elad Y, Chet I. The role of chitinase of Serratia marcescens in biocontrol of Sclerotium rolfsii. *Phytopathol,* 1988; 78: 84-88.

[181] Palumbo JD, Yuen GY, Jochum CC et al. Mutagenesis of beta-1,3-glucanase genes in Lysobacter enzymogenes strain C_3 results in reduced biological control activity toward bipolaris leaf spot of tall fescue and *Pythium* damping-off of sugar beet. *Phytopathol*, 2005; 95: 701-707. DOI: 10.1094/PHYTO-95-0701.

[182] Murthy KN, Uzma F, Chitrashree CS. RETRACTED: Induction of systemic resistance in tomato against *Ralstonia solanacearum* by *Pseudomonas fluorescens*. *Am J Plant Sci,* 2014; 5: 1799-1811. DOI: 10.4236/ajps.2014.512193.

[183] Mandal P. An overview of PGPR/PGPF mediated induced systemic resistance (ISR) in plant defense. *Rev Res*, 2019; 8: 1-8.

[184] Pal S, Bal S. Induced Systemic Resistance and its importance in eco-friendly disease management in vegetable crops. *Agr & Food: e- Newsl*, 2020; 2: 22870.

[185] Yanti Y. Involvement of jasmonic acid in the induced systemic resistance of tomato against *Ralstonia syzigiisub* sp. indonesiensis by indigenous endophyte bacteria. *IOP Conf Ser: Earth Environ Sci*, 2019; 347: 012024. DOI: 10.1088/1755-1315/347/1/012024.

[186] Lamia B, Messaoud B, Ahmed C et al. Activity of plant growth promoting rhizobacteria (PGPRs) in the biocontrol of tomato *Fusarium* wilt. *Plant Prot Sci*, 2017; 53: 78-84. DOI: 10.17221/178/2015-PPS.

[187] Mariutto M, Duby F, Adam A et al. The elicitation of a systemic resistance by *Pseudomonas putida* BTP1 in tomato involves the stimulation of two lipoxygenase isoforms. *BMC Plant Biol,* 2011; 11: 1-15. DOI: 10.1186/1471-2229-11-29.

[188] Meziane H, Van Der Slui I, Van Loon LC et al. Determinants of *P. putida* WCS 358 involved in induced systemic resistance in plants. *Mol Plant Pathol,* 2005; 6: 177-185. DOI: 10.1111/j.1364-3703.2005.00276.x.

[189] JayapalaN, Mallikarjunaiah NH, Puttaswamy H et al. Rhizobacteria *Bacillus spp*. induce resistance against anthracnose disease in chili (*Capsicum annuum* L.) through activating host defense response. *Egyp J Biological Pest Control*, 2019; 29: 1-9. DOI: 10.1186/s41938-019-0148-2.

[190] Park K, Park YS, Ahamed J et al. Elicitation of induced systemic resistance of chili pepper by iturin A analogs derived from *Bacillus vallismortis* EXTN-1. *Can J Plant* Sci, 2016; 96: 564-570. DOI: 10.1139/cjps-2015-0199.

[191] Shobha MS. Effect of endophytic and plant growth promoting rhizobacteria against foot rot disease of *Piper nigrum* L. *Int J Env Agr Biotechnol,* 2018; 3: 268282. DOI: 10.22161/ijeab/3.6.7.

[192] Liang JG, Tao RX, Hao ZN et al. Induction of resistance in cucumber against seedling damping-off by plant growth-promoting rhizobacteria (PGPR) *Bacillus megaterium* strain L8. *Afr J Biotechnol,* 2011; 10: 6920-6927.

[193] Park KS, Paul D, Ryu KR et al. *Bacillus vallismortis* strain EXTN-1 mediated systemic resistance against potato virus Y and X in the field. *The Plant Pathol J,* 2006; 22: 360-263. DOI: 10.5423/PPJ.2006.22.4.360.

[194] Yan Z, Reddy MS, Ryu CM et al. Induced systemic protection against tomato late blight elicited by plant growth-promoting rhizobacteria. *Phytopathol*, 2002; 92: 1329-1333. DOI: 10.1094/PHYTO.2002.92.12.1329.

[195] Leeman M, Den Ouden FM, Van Pelt JA et al. Iron availability affects induction of systemic resistance to *Fusarium* wilt of radish by *Pseudomonas fluorescens*. *Phytopathol*, 1996; 86: 149-155.

[196] Abdallah RAB, Mokni-Tlili S, Nefzi A et al. Biocontrol

of *fusarium* wilt and growth promotion of tomato plants using endophytic bacteria isolated from *Nicotiana glauca* organs. *Biol Control*, 2016; 97: 80-88. DOI: 10.1016/j.biocontrol.2016.03.005.

[197] Wu G, Liu Y, Xu Y et al. Exploring elicitors of the benefcial rhizobacterium *Bacillus amyloliquefaciens* SQR9 to induce plant systemic resistance and their interactions with plant signaling pathways. *Mol Plant Microbe Interact*, 2018; 31: 560-567. DOI: 10.1094/MPMI-11-17-0273-R.

[198] Boukerma L, Benchabane M, Charif A et al. Activity of plant growth promoting rhizobacteria (PGPRs) in the biocontrol of tomato *fusarium* wilt. *Plant Prot Sci*, 2017; 53: 78-84. DOI: 10.17221/178/2015-PPS.

[199] Arévalo-Marín DF, Briceño-Robles DM, Mosquera T et al. Jasmonic acid priming of potato uses hypersensitive response-dependent defense and delays necrotrophic phase change against *phytophthora infestans*. *Physiol Mol Plant Pathol*, 2021; 10: 101680. DOI: 10.1016/j.pmpp.2021.101680.

[200] Meena M, Swapnil P, Divyanshu K et al. PGPR-mediated induction of systemic resistance and physiochemical alterations in plants against the pathogens: Current perspectives. *J Basic Microbiol,* 2020; 60: 828-861. DOI: 10.1002/jobm.202000370.

[201] Spadaro D, Droby S. Development of biocontrol products for postharvest diseases of fruit: the importance of elucidating the mechanisms of action of yeast antagonists. *Trends Food Sci Technol,* 2016; 47: 39-49. DOI: 10.1016/j.tifs.2015.11.003.

[202] Segarra G, Casanova E, Avilés M et al. *Trichoderma asperellumstrain* T34 controls *Fusarium* wilt disease in tomato plants in soilless culture through competition for iron. *Microb Ecol*, 2010; 59: 141-149. DOI: 10.1007/s00248-009-9545-5.

[203] Höfte M, Bakker P. Competition for iron and induced systemic resistance by siderophores of plant growth promoting rhizobacteria. *Microb Siderophores*, 2007: 121-133; DOI: 10.1007/978-3-540-71160-5_6.

[204] Zhao LF, Xu YJ, Ma ZQ et al. Colonization and plant growth promoting characterization of endophytic *Pseudomonas chlororaphisstrain* Zong1 isolated from Sophora alopecuroides root nodules. *Braz J Microbiol*, 2013; 44: 623-631. DOI: 10.1590/S1517-83822013000200043.

[205] Haas D, De´fago G. Biological control of soil-borne pathogens by fluorescent pseudomonads. *Nat Rev Microbiol,* 2005; 3: 307-319. DOI: 10.1038/nrmicro1129.

[206] Lemanceau P, Alabouvette C. Suppression of *Fusarium* wilts by fluorescent pseudomonads: mechanisms and applications. *Biocontrol Sci Technol,* 1993; 3: 219-234. DOI: 10.1080/09583159309355278.

[207] Hanson PM, Yang RY. Epidural analgesia inhibits the renin and aldosterone response to surgery, World Vegetable Center. *Ekin J,* 2016; 2: 1-10. DOI: 10.1111/j.1399-6576.1979.tb01450.x.

[208] Kolomiets JV, Grygoryuk IP, Butsenko LM. Bacterial diseases of tomato plants in terms of open and covered growing of Ukraine. *Ann Agric Sci*, 2017; 15: 213-216. DOI: 10.1016/j.aasci.2017.05.010.

[209] Stout MJ, Kurabchew H, Leite GLD. Host-plant resistance in tomato. Wakil W, Brust GE, Perring TM ed. Sustainable Management of Arthropod Pests of Tomato. Academic Press: Massachusetts, USA, 2017; 217-236. DOI: 10.1016/B978-0-12-802441-6.00009-7.

[210] Tahat MM, Sijam k. *Ralstonia solanacearum*: The Bacterial Wilt Causal Agent. *Asian J Plant Sci*, 2010; 9: 385-393. DOI: 10.3923/ajps.2010.385.393.

[211] Wei Y, Caceres-Moreno C, Jimenez-Gongora T et al. The *Ralstonia solanacearum* csp22 peptide, but not flagellin-derived peptides, is perceived by plants from the Solanaceae family. *Plant Biotechnol J*, 2018; 16: 1349-1362. DOI: 10.1111/pbi.12874.

[212] Galeano Vanegas NF, Marulanda Moreno SM, Padilla Hurtado BE et al. Antagonism of plant growth promoting rhizobacteria against the causal agent of the vascular wilting of tomato. *Revista Colombiana de Biotecnol*, 2020; 22: 35-43. DOI: 10.15446/rev.colomb.biote.v22n2.79449.

[213] Mansfield J, Genin S, Magori S et al. Top 10 plant pathogenic bacteria in molecular plant pathology. *Mol Plant Pathol,* 2012; 13: 614-629. DOI: 10.1111/j.1364-3703.2012.00804.x.

[214] Elphinstone JG. The current bacterial wilt situation: a global overview. Allen C, Prior P, Hayward AC ed. Bacterial wilt disease and the *Ralstonia solanacearum* species complex. American Phytopathological Society: Minnesota, USA, 2005; 9-28.

[215] Mishra A, Mishra SK, Karmakar SK et al. Assessment of yield loss due to wilting and some popular tomato cultivars. *Env Ecol,* 1995; 28: 287-290.

[216] Yuliar, Yanetri AN, Toyota K. Recent trends in control methods for bacterial wilt diseases caused by *Ralstonia solanacearum. Microbes Environ,* 2015; 30: 1-11. DOI: 10.1264/jsme2.ME14144.

[217] Munhoz LD, Fonteque JP, Santos IM et al. Control of bacterial stem rot on tomato by extracellular bioactive compounds produced by *Pseudomonas* aeruginosa LV strain. *Cogent Food & Agric*, 2017; 3: 1282592. DOI: 10.1080/23311932.2017.1282592.

[218] Satapute P, Milan VK, Shivakantkumar SA et al. Influence of triazole pesticides on tillage soil microbial populations and metabolic changes. *Sci Total Envi,* 2019; 651: 2334-2344. DOI: 10.1016/j.scitotenv.2018.10.099.

[219] Baćmaga M, Wyszkowska J, Kucharski J. The effect of the Falcon 460 EC fungicide on soil microbial communities, enzyme activities and plant growth. *Ecotoxicol*, 2016; 25: 1575-1587. DOI: 10.1007/s10646-016-1713-z.

[220] Glover-Amengor M, Tetteh FM. Effect of pesticide application rate on yield of vegetables and soil microbial communities. *West Afr J ApplEcol,* 2008; 12. DOI: 10.4314/wajae.v12i1.45749.

[221] Singh D, Yadav DK, Shweta S et al. Genetic diversity of iturin producing strains of *Bacillus* species antagonistic to *Ralstonia solanacerarum* causing bacterial wilt disease in tomato. *Afr J Microbiol Res*, 2013; 7: 5459-5470. DOI: 10.5897/AJMR12.2125.

[222] Maji S, Chakrabartty PK. Biocontrol of bacterial wilt of tomato caused by *Ralstonia solanacearum* by isolates of plant

growth promoting rhizobacteria. *Aus J Crop Sci,* 2014; 8: 208-214.

[223] Singh D, Yadav DK, Chaudhary G et al. Potential of *Bacillus amyloliquefaciens* for biocontrol of bacterial wilt of tomato incited by *Ralstonia solanacearum*. *J Plant Pathol Microbiol*, 2016; 7: 1-6. DOI: 10.4172/2157-7471.1000327.

[224] Jones JB, Zitter TA, Momol MT et al. Compendium of tomato diseases, 2nd ed. The American Phytopathological Society: Minnesota, USA, 2014. DOI: 10.1094/9780890544341.

[225] Burgess LW, Phan HT, Knight TE et al. Diagnostic manual for plant diseases in Vietnam. Australian Centre for International Agricultural Research, ACIAR, 2008.

[226] Worku M, Sahe S. Review on disease management practice of tomato wilt caused by *Fusarium oxysporum* in case of Ethiopia. *J Plant PatholMicrobiol*, 2018; 9: 9-12. DOI: 10.4172/2157-7471.1000460.

[227] Zouari I, Jlaiel L, Tounsi S et al. Biocontrol activity of the endophytic *Bacillus amyloliquefaciens* strain CEIZ-11 against *Pythium aphanidermatum* and purification of its bioactive compounds. *Biol Control*, 2016; 100: 54-62. DOI: 10.1016/j.biocontrol.2016.05.012.

[228] Ajilogba CF, Babalola OO, Ahmad F. Antagonistic effects of *Bacillus* Species in biocontrol of tomato *Fusarium* wilt. *Ethno Med*, 2013; 7: 205-216. DOI: 10.1080/09735070.2013.11886462.

[229] Jacobsen BJ, Zidack NK, Larson BJ. The role of *Bacillus*-based biological control agents in integrated pest management systems: Plant diseases. *Phytopathol*, 2004; 94: 1272-1275. DOI: 10.1094/PHYTO.2004.94.11.1272.

[230] Dihazi A, Jaiti FW, Taktak et al. Use of two bacteria for biological control of bayoud disease caused by *Fusarium oxysporum* in date palm (*Phoenix dactylifera* L) seedlings. *Plant Physiol Biochem,* 2012; 55: 7-15. DOI: 10.1016/j.plaphy.2012.03.003.

[231] Athukorala SNP, Fernando WGD, Rashid KY. Identification of antifungal antibiotics of *Bacillus* species isolated from different microhabitats using polymerase chain reaction and MALDI-TOF mass spectrometry. *Can J Microbiol*, 2009; 55: 1021-1032. DOI: 10.1139/w09-067.

[232] Chen X, Scholz R, Borriss M et al. Difficidin and bacilysin produced by plant-associated *Bacillus* amyloliquefaciensd are efficient in controlling fire blight disease. *J Biotech,* 2009; 140: 38-44. DOI: 10.1016/j.jbiotec.2008.10.015.

[233] Singh D, Chaudhary G, Yadav DK. Genetic diversity of Indian isolates of *Ralstonia solanacearum* causing bacterial wilt of eggplant (*Solanum melongena*). *Ind J Agric Sci,* 2017; 87: 1466-1475.

[234] Sakthivel K, Gautam RK, Kumar K et al. Diversity of *Ralstonia solanacearum* strains on the Andaman Islands in India. *Plant Dis*, 2016; 100: 732-738. DOI: 10.1094/PDIS-03-15-0258-RE.

[235] Champoiseau Patrice G, Jones Jeffrey B, Caitilyn A. *Ralstonia solanacearum* Race 3 Biovar 2 causes tropical losses and temperate anxieties. *Plant Manag Network*, 2009; 10: 35. DOI: 10.1094/PHP-2009-0313-01-RV.

[236] Achari GA, Ramesh R. Colonization of eggplant by endophytic bacteria antagonistic to *Ralstonia solanacearum*, the bacterial wilt pathogen. *Proc Nat Acad Sci, India Section B: Biol Sci,* 2021; 89: 585-593. DOI: 10.1007/s40011-018-0972-2.

[237] Altınok HH. First report of *Fusarium* wilt of eggplant caused by *Fusarium oxysporum* f. sp. melongenae in Turkey. *Plant Pathol,* 2005; 54: 577. DOI: 10.1111/j.1365-3059.2005.01235.x.

[238] Chakraborty N, Chakraborty N, Acharyya P et al. Isolation, characterization and identification of novel broad spectrum bacterial antagonist (s) to control *Fusarium* wilt of eggplant. *Physiol Mol Plant Pathol*, 2021; 24: 101711. DOI: 10.1016/j.pmpp.2021.101711.

[239] Altinok HH, DikilitasM, Yildiz HN. Potential of *Pseudomonas* and *Bacillus* isolates as biocontrol agents against *fusarium* wilt of eggplant. *Biotechnol Biotechnol Eq,* 2013; 27: 3952-3958. DOI: 10.5504/BBEQ.2013.0047.

[240] USDA National Nutrient Database 2016 USDA National Nutrient Database, 2016.

[241] Hughes J. Just famine foods? What contribution can underutilized plant make to food security? *Acta Hortic*, 2009; 806: 39-47. DOI: 10.17660/ActaHortic.2009.806.2.

[242] Yadav RK, Ghasolia RP, Yadav RK. Studies of physiological parameters on the growth of sclerotio formation of *Rhizoctonia solani* with okra (*Abelmoschus esculentus* L. Moench). *Int J Curr Microbiol App Sci,* 2020; 9: 524-531. DOI: 10.20546/ijcmas.2020.905.059.

[243] Mishra GP, Singh B, Seth T et al. Biotechnological advancements and begomovirus management in okra (*Abelmoschus esculentus* L.): Status and perspectives. *Front Plant Sci*, 2017; 8: 360. DOI: 10.3389/fpls.2017.00360. eCollection 2017.

[244] Siddappa B, Amaresh YS, Naik MK et al. Estimation of yield loss due to powdery mildew in okra. *J Mycol Plant Pathol,* 2013; 43: 190-192.

[245] Shafique HA, Sultana V, Ara J et al. Role of antagonistic microorganisms and organic amendment in stimulating the defense system of okra against root rotting fungi. *Polish J Microbiol,* 2015; 64: 157-162.

[246] Vloutoglou I, Kalogerakis SN. Effects of inoculum concentration, wetness duration and plant age on development of early blight (*Alternaria solani*) and on shedding of leaves in tomato plants. *Plant Pathol,* 2000; 49: 339-345. DOI: 10.1046/j.1365-3059.2000.00462.x.

[247] Raziq F, Ishtiaq S. Integrated control of *Alternaria solaniwith Trichoderma* sp. and fungicides under in vitro conditions. *Sarhad J Agric*, 2010; 26: 613-619.

[248] Caulier S, Gillis A, Colau G et al. Versatile antagonistic activities of soil-borne *Bacillus* spp. and *Pseudomonas* spp. against *Phytophthora infestans* and other potato pathogens. *Front Microbiol,* 2018; 9: 143. DOI:10.3389/fmicb.2018.00143.

[249] Fry W. *Phytophthora infestans*: the plant (and R gene) destroyer. *Mol Plant Pathol*, 2008; 9: 385-402. DOI: 10.1111/j.1364-3703.2007.00465.x.

[250] Lal M, Yadav S, Sharma S et al. Integrated management of

late blight of potato. *J Appl Nat Sci,* 2017; 9: 1821-1824. DOI: 10.31018/jans.v9i3.1445.

[251] Tsedaley B. Late blight of potato (*Phytophthora infestans*) biology, economic importance and its management approaches. *J Biol Agric Healthcare,* 2014; 4: 215-225.

[252] Collins WW. The Global Initiative on Late Blight-alliance for the future. Khurana SMP ed. Potato, global research & development, Proceedings of the Global Conference on Potato, New Delhi, India, 6-11 December 1999: Volume 1. Indian Potato Association: Shimla, India, 2000; 513-524.

[253] Haverkort AJ, Boonekamp PM, Hutten R et al. Societal costs of late blight in potato and prospects of durable resistance through cisgenic modification. *Potato Res,* 2008; 51: 47-57. DOI: 10.1007/s11540-008-9089-y.

[254] Cooke LR, Schepers HTAM, Hermanse A et al. Epidemiology and integrated control of potato late blight in Europe. *Potato Res*, 2011; 54: 183-222. DOI: 10.1007/s11540-011-9187-0.

[255] De Vrieze M, Pandey P, Bucheli TD et al. Volatile organic compounds from native potato-associated *Pseudomonas* as potential anti-oomycete agents. *Front Microbiol*, 2015; 6: 1295. DOI: 10.3389/fmicb.2015.01295.

[256] Velivelli SLS, De Vos P, Kromann P et al. Biological control agents: from field to market, problems and challenges. *Trends Biotechnol,* 2014; 32: 493-496. DOI: 10.1016/j.tibtech.2014.07.002.

[257] Morrison CK, Arseneault T, Novinscak A et al. Phenazine-1-carboxylic acid production by *Pseudomonas fluorescens* LBUM636 alters *Phytophthora infestans*' growth and late blight development. *Phytopathol*, 2016; 107: 273-279. DOI: 10.1094/PHYTO-06-16-0247-R.

[258] Hunziker L, Bonisch D, Groenhagen U et al. Pseudomonas strains naturally associated with potato plants produce volatiles with high potential for inhibition of Phytophthora infestans. *Appl Environ Microbiol,* 2015, 81: 821-830. DOI: 10.1128/AEM.02999-14.

[259] Guyer A, DeVrieze M, Bönisch D et al. The Anti-Phytophthora effect of selected potato associated *Pseudomonas* strains: from the laboratory to the field. *Front Microbiol,* 2015; 6: 1309. DOI: 10.3389/fmicb.2015.01309.

[260] De VriezeM, Germanier F, Vuille N et al. Combining different potato-associated *Pseudomonas* strains for improved biocontrol of *Phytophthora infestans*. *Front Microbiol,* 2018; 9: 2573. DOI: 10.3389/fmicb.2018.02573.

[261] Perombelon MCM, Kelman A. Ecology of the soft rot Erwinias. *Ann Rev Phytopathol*, 1980; 18: 361-387. DOI: 10.1146/annurev.py.18.090180.002045.

[262] Popović T, Jelušić A, Marković S et al. Characterization of *Pectobacterium carotovorum* subsp. carotovorum isolates from a recent outbreak on cabbage in Bosnia and Herzegovina. *Pesticidi i fitomedicina*, 2019; 34: 211-222. DOI: 10.2298/PIF1904211P.

[263] Nazerian E, Sijam K, Mior Ahmad ZA et al. First report of cabbage soft rot caused by *Pectobacterium carotovorum* subsp. carotovorum in Malaysia. *Plant Dis*, 2011; 95: 491. DOI: 10.1094/PDIS-09-10-0683.

[264] Gerayeli N, Baghaee-Ravari S, Tarighi S. Evaluation of the antagonistic potential of *Bacillus* strains against *Pectobacteriumcarotovorum* subsp. carotovorum and their role in the induction of resistance to potato soft rot infection. *Eur J Plant Pathol,* 2018; 150: 1049-1063. DOI: 10.1007/s10658-017-1344-0.

[265] Garge SS, Nerurkar AS. Evaluation of quorum quenching *Bacillus* spp. for their biocontrol traits against *Pectobacterium carotovorum* subsp. carotovorum causing soft rot. *Biocataly Agric Biotechnol*, 2017; 9: 48-57. DOI: 10.1016/j.bcab.2016.11.004.

[266] Gill HK, Garg H. Pesticide: environmental impacts and management strategies. *Pesticides-toxic aspects*, 2014; 8: 187. DOI: 10.5772.57399.

[267] Li J, Hu M, Xue Y et al. Screening, identification and efficacy evaluation of antagonistic bacteria for biocontrol of soft rot disease caused by Dickeyazeae. *Microorganisms*, 2020; 8: 697. DOI: 10.3390/microorganisms8050697.

[268] Shrestha A, Kim EC, Lim CK et al. Biological control of soft rot on Chinese cabbage using beneficial bacterial agents in greenhouse and field. *The Korean J Pestic Sci*, 2009; 13: 325-331.

[269] Cui W, He P, Munir S et al. Biocontrol of soft rot of Chinese cabbage using an endophytic bacterial strain. *Front Microbiol*, 2019; 10: 1471. DOI: 10.3389/fmicb.2019.01471.

[270] Lamichhane J, Dürr C, Schwanck A et al. Integrated management of damping-off diseases. A Review. *Agron Sustain Dev*, 2017; 37: 10. DOI: 10.1007/s13593-017-0417-y.

[271] Parveen T, Sharma K. *Pythium* diseases, control and management strategies: A review. *IntJ Plant Anim Env Sci,* 2015; 5: 244-257.

[272] Hatami N, Aminaee MM, Zohdi H et al. Damping-off disease in greenhouse cucumber in Iran. *Arch Phytopathol Plant Protec*, 2013; 46: 796-802. DOI: 10.1080/03235408.2012.752145.

[273] Moulin F, Lemanceau P, Alabouvette C. Pathogenicity of *Pythium* species on cucumber in peat-sand, rockwool and hydroponics. *Eur J Plant Pathol,* 1994; 100: 3-17. DOI: 10.1007/BF01871963.

[274] Vatchev T, Maneva S. Chemical control of root rot complex and stem rot of greenhouse cucumber in strawbale culture. *Crop Prot,* 2012; 42: 16-23. DOI: 10.1016/j.cropro2012.08.001.

[275] Leisso RS, Miller PR, Burrows ME. The influence of biological and fungicidal seed treatments on chickpea (*Cicer arietinum*) damping off. *Can J Plant Pathol*, 2009; 31: 38-46. DOI: 10.1080/07060660909507570.

[276] Mahmoud AF, Abdalla OA. Biological control of fungi associated with damping-off and root rot disease of cucumber (*Cucumis sativus* L.). *Arch Phytopathol Plant Prot*, 2021; 54: 870-885. DOI: 10.1080/03235408.2020.1860412.

[277] Georgakopoulos DG, Fiddaman P, Leifert C et al. Biological control of cucumber and sugar beet damping-off caused by *Pythium* ultimum with bacterial and fungal antagonists. *J Appl Microbiol,* 2002; 92: 1078-1086. DOI: 10.1046/j.1365-2672.2002.01658.x.

[278] Yang HS, Sohn HB, Chung YR. Biological control of *pythium* damping-off of cucumber by *Bacillus stearothermophilus* YC4194. *Korean Soc Plant Pathol*, 2002; 8: 49-52. DOI: 10.5423/RPD2002.8.4.234.