

Review Article

Biocontrol agents against post harvest decay in fruits and vegetables: A review

Abstract

Post harvest losses are the major threats in the supply chain between harvest and consumption which contribute 44% of the total loss of fruits and vegetables. Among the various causes, post harvest diseases are major **post harvest** decay of fruits and vegetables accounting for 20-25% losses. The causative fungus belonging to both biotrophic and necrotrophic nature belongs to the genera of *Aspergillus*, *Penicillium*, *Botrytis*, etc. Management of post harvest diseases by conventional chemicals is not preferred due to residual effects and toxicity. Considering the global demand and consumer awareness about the health effects of pesticides, biocontrol agents are getting attention in recent times for post harvest disease management. Biocontrol **agents** like *Trichoderma*, *Bacillus* and *Pseudomonas* have been explored for successful management of post harvest diseases of citrus, strawberry, tomato, etc. The possible mode actions of the BCAs are competition for nutrients and space, production of antimicrobial compounds, hydrolytic enzymes, and induced resistance. The added advantage of BCAs is that they can be integrated with other physical, natural compounds and additives for coatings due to their synergistic and mutualistic effect. The product development for biocontrol origin must be encouraged to utilize the benefits they provide. Several constraints in process of product development may arise which can be overcome by more research, education, training at the farm level, and multi-omics studies to unravel the potentials of the BCAs.

Key words: Biocontrol agent, biotrophic, necrotrophic, BCA, synergistic

INTRODUCTION

Fruits and vegetables are considered as major source of nutritional security providing vital minerals and nutrients as well as economically viable crops for the growers. Various biotic factors challenge the crops during pre and post harvest, of which, fungal and bacterial pathogens are causes severe losses by causing many diseases resulting in significant economic losses. According to the Food and Agriculture Organization, about 45% loss occurs

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in harvested fruits, vegetables, roots, and tubers and out of this about 20– 25% loss is caused by pathogens during postharvest handling even in developed countries [1,2,3]. Post harvest loss is the loss of a commodity after it is harvested and such losses cause considerable damage both quantity and quality of fruits. It can be due to various reasons such as environmental factors (temperature, humidity during harvest and transportation); physical injuries during crop harvesting and transportation and, microbial actions [4,5]. Post harvest loss is not only the numerical count of lost fruit and the quality or taste. Qualitative food loss can degrade the food's nutrients, texture, shape, or taste. Commercially, these products will fetch a lower price. However, quantitative food losses are the reductions in edible produce mass accessible for personal food across supplier management segments. In simple terms, quantitative food loss is unconsumed food. Pests eating or spoiling the food can cause this quantitative food loss[6]. In developing countries, postharvest losses are often more severe due to pest and pathogen infestation (bacteria, fungi, and insects), unfavourable environmental conditions (rain, humidity, frost, and heat), water loss, saccharification, sprouting, and also inadequate storage and transportation facilities. Traditionally, chemical fungicides and/or food preservatives are used to control postharvest decays[7]. However, exposure to the chemicals is often hazardous to humans, animals, and the environment[8]. Since fresh fruits and many vegetables are consumed raw, fungicide contamination in such commodities pose serious health risk to the consumers. Due to the toxicological risk of residual chemicals in food products, their application in the postharvest period has been limited to a few registered chemicals and is completely prohibited in some European countries[9] restricting export possibilities of many crops. Instead there is growing demand for organic produce or quality food with no chemical residues. The increasing relevance of food and environmental problems, as well as growing demand for energy conservation through natural “green” technologies and organic products, would make it highly desirable to have an approach to the reduction of postharvest food losses that is novel, efficient, environment friendly, and bio-safe[10]. **In recent time** microbes are being explored as potential; alternative to post harvest fungicides. Biological products with beneficial strains, such as plant growth-promoting bacteria (PGPB), endophytes, and many yeasts are being explored as new strategy against postharvest disease [11,12]. Rise in literature demonstrating role of microbes like Bacillus spp, Pseudomonas, Yeasts amply demonstrates need to introduce these microbes for value chain management including post harvest diseases[7]. The microbe based products establish various physiological changes in host plant metabolism,

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leading to systemic resistance and prolonged shelf-life without causing adverse effects on plants, humans, or the environment.

POST HARVEST PATHOGENS

Phytopathogenic fungi and bacteria cause postharvest diseases of economically important fruits and vegetables. Different species of bacteria belonging to the major genera viz. *Pseudomonas*, *Xanthomonas*, *Erwinia*, *Xylella*, *Ralstonia* and fungal genera include *Penicillium*, *Aspergillus*, *Botrytis*, *Fusarium*, *Alternaria*, *Colletotrichum*, etc. The most important pathosystem of postharvest fruits and vegetables includes green mold (*Penicillium digitatum*), blue mold (*Penicillium italicum*), graymold (*Botrytis cinerea*), and white mold (*Sclerotinia* spp.) [13]

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Table 1: Postharvest diseases of economically important fruits and vegetables

Nature of disease	Disease name	Crop	References
Fungi	<i>Botrytis cinerea</i>	Tomatoes, citrus fruit, grapes, strawberries	[14]
	<i>Penicillium expansum</i>	Apples, citrus fruit	[15]
	<i>Penicillium italicum</i>	Citrus fruit	[15]
	<i>Plasmopara viticola</i>	Grapes	[16]
	<i>Rhizopus stolonifera</i>	Strawberries	[16]
	<i>Alternaria alternata</i>	Tomatoes, grapes	[16]
	<i>Fusarium</i> spp.	Melons	[16]
	<i>Trichothecium roseum</i>	Cucurbits (Melons)	[16]
	<i>Colletotrichum gloeosporioides</i>	Loquats	[16]
Bacteria	<i>Clavibacter michiganensis</i>	Tomatoes	[17]
	<i>Xanthomonas axonopodis</i>	Tomatoes, peppers	[18]
	<i>Salmonella enteric</i>	Tomatoes, melons	[19]
	<i>Escherichia coli</i>	Tomatoes, strawberries	[19]

Virus	Ringspot virus	Papayas	[20]
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Post harvest physiological changes like transpiration, respiration, ethylene production and senescence affect the post harvest disease development and deterioration of the fruits. All the changes encourage the biotrophic pathogen to act as necrotrophs and elicit symptoms and also attract opportunistic pathogens which help in disease development and affect the post-harvest quality.

Impacts of post harvest diseases on fruits and vegetables

- i) Reduce the quality in harvest fruits and vegetables.
- ii) Reduce the shelf life of the products due to rotting.
- iii) As a result of decay fruits appear to be ugly in appearance and the market value decreases.
- iv) Due to low market value it increases the cost of production and challenges food security globally.
- v) It also has impacts on human health due to the production of harmful mycotoxins.

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Management Strategies

Diseases in harvested fruits are managed through different methods like physical treatments by use of heat treatment, irradiation, precooling, modified and controlled atmospheric storage and innovative packaging [21,22,23]. Various chemical treatments are used such as sanitizing agents like chlorinated water, sodium hypochloride, etc for surface cleaning of fruits and vegetables [24]. Use of inorganic and organic compounds which belongs to GRAS (Generally regarded as safe) category are and also considered safe for human [25]. Several natural antifungal compounds from plants and animals origin are used to control post harvest diseases which have low phytotoxicity and environmental toxicity [26, 27]. Biocontrol by microbial antagonists (bacteria, yeasts, fungi) is under investigation as an alternative to the application of synthetic fungicides for disease control in the field and postharvest applications [2, 29].

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Microbes in Post Harvest Disease Management

Fruits and vegetables produce which contains unauthorized pesticides are being rejected by the international market due to pesticides residues exceeding permissible limits, and with inadequate labelling and packaging. Hence, biological control through bioagents have a great potential, among the important microbes *Trichoderma viride*, *T. harzianum*, *Pseudomonas flourescens* and *Bacillus subtilis* are most efficient bioagents which act as a producer of biologically active metabolites like antibiotics, bacteriocin and inducers of systemic resistance in plants. Biofilm formed by antagonistic yeast stick to pathogen and parasitize on the hyphae of the pathogen [30, 31].

A potential microbial antagonist should have certain desirable characteristics to make it an ideal bioagent[32, 33]. The antagonist should be: (a) genetically stable; (b) effective at low concentrations; (c) not fastidious in its nutritional requirements; (d) capable of surviving under adverse environmental conditions; (e) effective against a wide range of the pathogens and different harvested commodities; (f) resistant to pesticides; (g) a non-producer of metabolites harmful to human; (h) non-pathogenic to the host; (i) preparable in a form that can be effectively stored and dispensed; and (j) compatible with other chemical and physical treatments. In addition, a microbial antagonist should have an adaptive advantage over a specific pathogen[34].

There are two basic approaches for using microbial antagonists for controlling the postharvest diseases of fruits and vegetables: 1) the Use of microorganisms which already exist on the product itself, which can be promoted and managed or 2) those that can be artificially introduced against postharvest pathogens.

1) Natural microbial antagonist

Natural occurring antagonists are those, which are present naturally on the surface of fruits and vegetables, and after isolation, antagonists are used for the control of postharvest diseases. [35] found that when concentrated washings from the surface of citrus fruit were plated out on an agar medium, only bacteria and yeast appeared while after dilution of these washings, several rot fungi appeared on the agar, suggesting that yeast and bacteria may be suppressing fungal growth. Thus, it indicates that when fruits and vegetables are washed, they are more susceptible to decay than those, which are not washed at all.

2) Artificially introduced microbial antagonist

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Although the first reported use of a microbial antagonist was the control of Botrytis rot of strawberry (*Fragaria x ananassa*Duch.) with *Trichodermaspp.*[36], the first classical work was the control of brown rot of stone fruits by *Bacillus subtilis*[37]. The biocontrol potential of several other microbial antagonists has also been demonstrated in several fruits such as banana [38], mango (*Mangifera indica* L.) [39,40], litchi (*Litchi chinensis* Sonn.) [41], papaya (*Carica papaya* L.) [42], avocado [43], kiwi fruit (*Actinidia deliciosa* Ber.) [44], jujube [45] and vegetables like tomatoes [46]cabbage (*Brassica oleracea* var. *capitata* L.) [47], chillies (*Capsicum fruitsecence* L.) [48] and potato [49]. Some artificially introduced microbial antagonists are listed below:-

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Table 2: List of microbial antagonist

Antagonists	Disease(Pathogen)	Fruits/vegetables	References
<i>Aureobasidium pullulans</i>	Monilinia rot (<i>Monilinia laxa</i>)	Banana	[50]
	Penicillium rots (<i>Penicillium spp.</i>)	Citrus	[51]
	Botrytis rot (<i>Botrytis cinerea</i>)	Grapes	[52]
	Soft rot (<i>Monilinia laxa</i>)	Grapes	[32]
<i>Bacillus subtilis</i>	Brown rot (<i>Lasiodiplodia theobromae</i>)	Apricot	[37]
	Stem end rot (<i>Botrydiploidiatheobromae</i> Pat.)	Avocado	[43]
	Green mold (<i>Penicillium digitatum</i>)	Citrus	[53]
	Gray mold (<i>Botrytis cinerea</i>)	Strawberry	[54]
	Alternaria rot (<i>Alternaria alternata</i>)	Muskmelon	[55]
<i>Candida sake</i> (CPA-1)	Penicillium rot (<i>Penicillium expansum</i>)	Apple	[56, 57]
	Blue mold (<i>Penicillium expansum</i>)	Pear	[5]

<i>Enterobacter cloacae</i>	Rhizopus rot (<i>Rhizopus stolonifer</i>)	Peach	[58]
<i>Metschnikowia pulcherrima</i>	Blue mold (<i>Penicillium expansum</i>) and Gray mold (<i>Botrytis cinerea</i>)	Apple	[59]
<i>Pseudomonas aeruginosa</i> (Schroter) Migula	Bacterial soft rot (<i>Erwinia carotovorasub sp. Carotovora</i>)	Cabbage	[47]
<i>Trichoderma harzianum</i>	Anthrachnose (<i>Colletotrichum musae</i>)	Banana	[60]
	Gray mold (<i>Botrytis cinerea</i>)	Kiwi	[44]
	Anthrachnose (<i>Colletotrichum gloeosporioides</i>)	Rambutan	[61]
<i>Trichoderma viride</i>	Green mold (<i>Penicillium digitatum</i>)	Citrus	[62]
	Gray mold (<i>Botrytis cinerea</i>)	Strawberry	[63]
	Stem-end rot (<i>Botryodiplodiatheobromae</i>)	Mango	[36]

Mode of Action

1) Competition for space and nutrients

Antagonistic microorganisms trigger inhibition of rapid wound site colonization, which is a crucial step in controlling postharvest decay. The efficiency of the antagonist mainly depends on their ability to outperform pathogens based on their capacity for rapid growth and survival under unfavorable conditions, and is strongly dependent on their initial concentration when applied on the wound site[64].The most effective concentration in controlling postharvest fruit/vegetable diseases is generally considered to be 10^7 - 10^8 CFU/mL[65].As similar ecological niches exist in both endophytic and phytopathogenic microorganisms, endophytes are considered a prime candidate for the biocontrol of phytopathogens[66]. Due to the stable pH, proper humidity, sufficient nutrient flow, and

lack of competition in the endosphere, endophytes have a significant advantage over epiphytic organisms available in the rhizosphere and phyllosphere [67,68].

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Competition for nutrients is another significant contribution to the biocontrol of pathogens. *In-vitro* studies shows that bacterial inoculants take up nutrients faster than pathogenic fungus; this can lead to the inhibition of the germination of pathogen spores at the wound site. A fundamental strategy for nutrient competition is the attachment of microbial antagonists to the hyphae of a pathogen since the antagonists feed on nutrients faster than the target pathogen, thus hampering spore germination and pathogen growth[58]. Nevertheless, in certain cases such as *Aureobasidium pullulans* against *Botrytis cinerea*, *Rhizopus stolonifer*, *Penicillium expansum*, and *Aspergillus niger*, which infect table grapes and *P. expansum* and *B. cinerea* on apple fruit, direct physical interaction is not required for the antagonistic activity[69]. In such circumstances antagonism does not occur via the direct attachment of antagonistic microorganisms to pathogen hyphae. Rather, it is highly likely that other alternative mechanisms, such as the production of a wide range of biologically active molecules, such as antibiotics, biosurfactants, siderophores, hydrogen cyanide, and hydrolases increase their advantage against pathogens as they compete for a suitable niche for colonization[70, 71].

2) Production of Antimicrobial Compounds

Antibiotics are a heterogeneous group of low molecular weight organic compounds produced by bacteria, which suppress or diminish the growth and development of phytopathogenic microorganisms[72]. Antibiotics can cause disruption in a microorganism's cell wall structure or membrane function, disrupt protein synthesis, and inhibit respiratory enzyme function[73]. Thus, most *Bacillus* antibiotics are active against both gram-positive and gram-negative bacteria, as well as phytopathogenic fungi such as *Aspergillus flavus*, *Alternaria solani*, *Fusarium oxysporum*, *Botryosphaeria ribis*, *Helminthosporium maydis*, *Phomopsis gossypii*, and *Colletotrichum gloeosporioides*. *Bacillus* antibiotic substances break growing hyphae tips of *Sclerotinia sclerotium* (the stimulant of sunflower white rot), *A. alternata*, *Drechleraoryrae* as soil fungi, and *F. roseum*, as well as *Puccinia graminis* (the inducer of cereals rust). It has been found that *B. subtilis* has broad suppressive properties against more than 23 types of plant pathogens *in vitro* due to its ability to produce a broad range of antibiotics with a wide variety of structures and activities[74]. Some *Bacillus species* may dedicate up to 8% of their

genetic potential to the synthesis of a wide range of antimicrobial compounds, among which non-ribosomally synthesized LPs, lytic enzymes, and lantibiotics are suggested to be crucial for pathogen suppression[75].

3) Synthesis of hydrolytic enzymes

Alternative probable mechanisms of the antagonistic function of bioagent can be attributed to the synthesis of extracellular hydrolases such as chitinases and β 1,3-glucanases capable of destroying the structural polysaccharides in the cell wall (chitin and glucans) of fungus and lysing the hyphae of fungi[76, 77, 78]. For several bacteria, a correlation between antagonistic activity to various pathogenic fungi and the synthesis of cellulases, mannanases, xylanases, proteases, and lipases has also been established. Research on the complex of mycolytic enzymes of *B. subtilis* showed role of chitinase, chitosanase, β -1,3-glucanases, and proteases showed the most contribution to lysis of the native mycelium of various species of phytopathogenic fungi *Alternaria alternata*, *Bipolaris sorokiniana*, *Fusarium culmorum*, and *Rhizoctonia solani*[79, 72].

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4) Induction of Systemic Resistance in the Host

Antagonists suppress the development of different diseases in harvested fruits/vegetables not only directly through the synthesis of metabolites with fungicidal activity, but also indirectly, through the launch of multiple defence response mechanisms[80]. These indirect mechanisms are linked to the formation of ISR and SAR (in whole host plant organisms) and are regulated by phytohormones such as SA, ABA, JA, ethylene as well as CLPs[81, 82, 83]. To date, induction of auxins, cytokinins, gibberellins, ABA, JA, and SA has been detected in various bacteria. The ability of PGPB to synthesize ABA, especially under stressful conditions, and to influence its level in plants was found in many strains of bacteria including the genera *Bacillus*, *Azospirillum*, *Pseudomonas*, *Brevibacterium*, and *Lysinibacillus*[84, 85].

Biocontrol Based Products for post harvest disease management

Although budding research on bioagent based post harvest disease management shows its potential, the application part is still in its infancy. The first product with microorganism as a biocontrol agent effective against brown rot of stone fruits *bacillus subtilis* strain B-3(USA) was patented by [86]. Later on [87] developed another product 'BioSave' with a saprophytic strain of *Pseudomonas syringe* by 'EcoScience' Corp.,

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Orlando, USA, which is highly useful for controlling blue and gray mold on apples and pears (*Pyrus communis* L.). We are summarizing a few products in the following table:

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Table 3: Biocontrol Based Formulations

Product	Microbial agent	Fruits/vegetables	Target disease(s)	Manufacturer/Distributor
AQ-10 biofungicide	<i>Ampelomycesquisqualis</i> Cesati ex Schlechtendahl	Apples, grapes, strawberries, tomatoes and cucurbits	Powdery mildew	Ecogen, Inc., USA
Aspire	<i>Candida oleophila</i> strain 1-182	Apple, pear and citrus	Blue, gray, and green molds	Ecogen, Inc., USA
Rhio-plus	<i>B. Subtilis</i> FZB 24	Potatoes and other vegetables	Powdery mildew and root rots	KFZB Biotechnick
Serenade	<i>B. Subtilis</i> QST713	Apple, pear, grapes, tomato, potato	Powdery mildew, late blight, brown rot, and fire blight	AgraQuest. Inc., USA
Phytopsporin-M Golden Authum, AntiGnilPhytopsporin M	<i>B. Subtilis</i> 26D	Carrot, tomato, cabbage, sugarbeet, potato	Rots, mold	Bashinkom, Russia
Rhapsody®	<i>B. Subtilis</i> QST 713	Tomato	Rots	Bayer, Canada

[88, 89]

Methods of Application

Once an effective and potential antagonist is identified or selected, it is necessary to search for a method which applies it effectively for controlling or suppressing the pathogen. In general, microbial antagonists are applied in two different ways i.e., preharvest application, and postharvest application.

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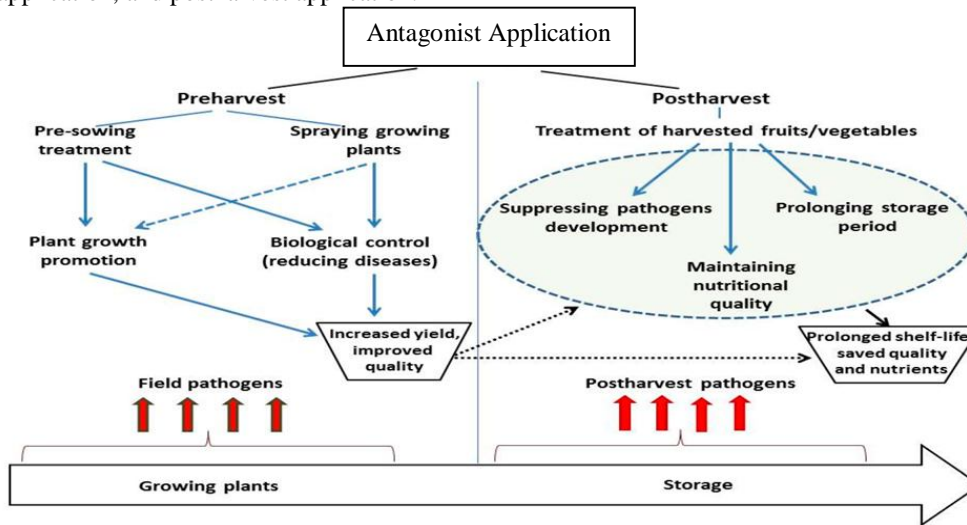


Fig.(1)Antagonists application strategies for diseases management of harvested fruits/vegetables during storage

1) Preharvest Application

In several cases, pathogens infest fruits and vegetables in the field, and these latent infections become a major factor for decay during the transportation or storage of fruits and vegetables. Therefore, preharvest applications of microbial antagonistic culture are often effective to control the postharvest decay of fruits and vegetables. The purpose of the preharvest application is to pre-colonize the fruit surface with an antagonist immediately before harvest so that wounds inflicted during harvesting can be colonized by the antagonist before colonization by a pathogen. Although this approach could not become commercially viable, because of the poor survival of microbial antagonists in the field conditions, however, it has been quite successful in certain cases[90, 91].

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2) Postharvest Application

It appears that the postharvest application of microbial antagonists is a better, practical and useful method for controlling postharvest diseases of fruits and vegetables. In this method, microbial cultures are applied either as postharvest sprays or as dips in an antagonist's

solution. This approach has been more effective than the preharvest application of microbial antagonists and has had several successes. For example, postharvest application of *Trichoderma harzianum*, *Trichoderma viride*, *Gliocladium roseum* and *Paecilomyces variotii* Bainier resulted in better control of Botrytis rot in strawberries and Alternaria rot in lemons than preharvest applications [92]. In lemons, postharvest application of *Pseudomonas variotii* was more effective in controlling *Aspergillus* rot than iprodion treatment, and in potatoes (*Solanum tuberosum* L.), postharvest application of *Trichoderma harzianum* controlled Fusarium rot effectively than benomyl dip treatment [35].

Conclusion and Future Prospects

Microbes are considered as next generation alternative for post harvest pathogen management. A significant amount of literatures demonstrate efficacy of some bacterial and fungal bioagents against post harvest diseases of fruits and vegetables. However, large scale trial of such bioagents/ formulations are required to develop a concrete package. Moreover, effect of such agents on fruit/vegetable quality, nutritional parameters etc also needs investigation. Metagenomic and transcriptomic studies, will provide new insights into biocontrol in postharvest diseases.

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BIBLIOGRAPHY

1. Droby, S. (2006). Biological control of postharvest diseases of fruits and vegetables: difficulties and challenges. *Phytopathol. Pol*, **39**, 105-117.
2. Zhu, S. (2006). Non-chemical approaches to decay control in postharvest fruits. *Advances in postharvest technologies for horticultural crops*, **297**-313.
3. Singh, D., & Sharma, R. R. (2018). Postharvest diseases of fruits and vegetables and their management. In *Postharvest disinfection of fruits and vegetables* (pp. 1-52). Academic Press.
4. Droby, S., Wisniewski, M., Macarasin, D., & Wilson, C. (2009). Twenty years of postharvest biocontrol research: is it time for a new paradigm?. *Postharvest biology and technology*, **52**(2), 137-145.
5. Palou, L. (2014). *Penicillium digitatum*, *Penicillium italicum* (green mold, blue mold). In *Postharvest decay* (pp. 45-102). Academic Press.

6. Smilanick, J. L., Mansour, M. F., Gabler, F. M., & Goodwine, W. R. (2006). The effectiveness of pyrimethanil to inhibit germination of *Penicillium digitatum* and to control citrus green mold after harvest. *Postharvest Biology and Technology*, **42**(1), 75-85.
7. Bora, P., Saikia K and Ahmed S S (2020). Pathogenic fungi associated with storage rot of *Colocasia esculenta* and evaluation of bioformulations against the pathogen. *Pest Management in Horticultural Ecosystem*. **26**(1): 123-130.
8. Droby, S., Wisniewski, M., Teixidó, N., Spadaro, D., & Jijakli, M. H. (2016). The science, development, and commercialization of postharvest biocontrol products. *Postharvest Biology and Technology*, **122**, 22-29.
9. Wisniewski, M., Droby, S., Norelli, J., Liu, J., & Schena, L. (2016). Alternative management technologies for postharvest disease control: The journey from simplicity to complexity. *Postharvest Biology and Technology*, **122**, 3-10.
10. Dimkpa, C., Weinand, T., & Asch, F. (2009). Plant–rhizobacteria interactions alleviate abiotic stress conditions. *Plant, cell & environment*, **32**(12), 1682-1694.
11. Arroyave-Toro, J. J., Mosquera, S., & Villegas-Escobar, V. (2017). Biocontrol activity of *Bacillus subtilis* EA-CB0015 cells and lipopeptides against postharvest fungal pathogens. *Biological control*, **114**, 195-200.
12. Bora, P., Bora, L. C., & Deka, P. C. (2016). Efficacy of substrate based bioformulation of microbial antagonists in the management of bacterial disease of some solanaceous vegetables in Assam. *Journal of Biological Control*, **49**-54.
13. Tripathi, A. N., Singh, D., Pandey, K. K., & Singh, J. (2021). Postharvest diseases of leguminous vegetable crops and their management. In *Postharvest Handling and Diseases of Horticultural Produce* (pp. 387-396). CRC Press.
14. Dean, R., Van Kan, J.A., Pretorius, Z. A., Hammond-Kosack, K.E., Di Pietro, A., Spanu, P.D., ... & Foster, G.D. (2012). The Top 10 fungal pathogens in molecular plant pathology, *13*(4), 414-430.
15. Kumar, D., Tannous, J., Sionov, E., Keller, N., & Prusky, D. (2018). Apple intrinsic factors modulating the global regulator, LaeA, the patulin gene cluster and patulin accumulation during fruit colonization by *Penicillium expansum*. *Frontiers in Plant Science*, **9**, 1094.
16. El Hajj Assaf, C., Snini, S. P., Tadrist, S., Bailly, S., Naylies, C., Oswald, I. P., ... & Puel, O. (2018). Impact of veA on the development, aggressiveness, dissemination and secondary metabolism of *Penicillium expansum*. *Molecular Plant Pathology*, **19**(8), 1971-1983.

17. Eichenlaub, R., & Gartemann, K. H. (2011). The *Clavibacter michiganensis* subspecies: molecular investigation of gram-positive bacterial plant pathogens. *Annual review of phytopathology*, **49**, 445-464.
18. Basim, F., Harold, W., & Gary, A. (2004). Gas potential of selected shale formations in the Western Canadian Sedimentary Basin. *Canadian Resources*, **10**(1), 21-25.
19. Köckerling, J., Hoffmann, C., Biancu, S., Gramm, T., Michl, G., & Entling, M. H. (2017). Can flowering greencover crops promote biological control in German vineyards?. *Insects*, **8**(4), 121.
20. Diallo, H., Monger, W., Kouassi, N., Yoro, T. D., & Jones, P. (2008). Occurrence of Papaya ringspot virus infecting papaya in Ivory Coast. *Plant Viruses*, **2**(1), 52-57.
21. Erkan, M., Pekmezci, M., & Wang, C. Y. (2005). Hot water and curing treatments reduce chilling injury and maintain post-harvest quality of 'Valencia' oranges. *International journal of food science & technology*, **40**(1), 91-96.
22. Hong, I. H., Dang, J. F., Tsai, Y. H., Liu, C. S., Lee, W. T., Wang, M. L., & Chen, P. C. (2011). An RFID application in the food supply chain: A case study of convenience stores in Taiwan. *Journal of food engineering*, **106**(2), 119-126.
23. Schirra, M., D'Aquino, S., Cabras, P., & Angioni, A. (2011). Control of postharvest diseases of fruit by heat and fungicides: efficacy, residue levels, and residue persistence. A review. *Journal of Agricultural and Food Chemistry*, **59**(16), 8531-8542.
24. Mathew, E. N., Muyyarikkandy, M. S., Bedell, C., & Amalaradjou, M. A. (2018). Efficacy of chlorine, chlorine dioxide, and peroxyacetic acid in reducing *Salmonella* contamination in wash water and on mangoes under simulated mango packinghouse washing operations. *Frontiers in Sustainable Food Systems*, **2**, 18.
25. Palou, L., Ali, A., Fallik, E., & Romanazzi, G. (2016). GRAS, plant- and animal-derived compounds as alternatives to conventional fungicides for the control of postharvest diseases of fresh horticultural produce. *Postharvest Biology and Technology*, **122**, 41-52.
26. Hintz, T., Matthews, K. K., & Di, R. (2015). The use of plant antimicrobial compounds for food preservation. *BioMed research international*, **2015**.
27. Askarne, L., Talibi, I., Boubaker, H., Boudyach, E. H., Msanda, F., Saadi, B., ... & Aoumar, A. A. B. (2012). In vitro and in vivo antifungal activity of several Moroccan plants against *Penicillium italicum*, the causal agent of citrus blue mold. *Crop Protection*, **40**, 53-58.
28. Wang, L., Hu, J., Li, D., Reymick, O. O., Tan, X., & Tao, N. (2022). Isolation and control of *Botrytis cinerea* in postharvest green pepper fruit. *Scientia Horticulturae*, **302**, 111159.

29. Sellitto, V. M., Zara, S., Fracchetti, F., Capozzi, V., & Nardi, T. (2021). Microbial biocontrol as an alternative to synthetic fungicides: Boundaries between pre- and postharvest applications on vegetables and fruits. *Fermentation*, **7**(2), 60.
30. Bar-Shimon, M., Yehuda, H., Cohen, L., Weiss, B., Kobeshnikov, A., Daus, A., ... & Droby, S. (2004). Characterization of extracellular lytic enzymes produced by the yeast biocontrol agent *Candida oleophila*. *Current genetics*, **45**, 140-148.
31. Srivastava, A.K., Das, A.K., Jagannadham, P.T.K., Bora, P., Ansari, FA & Bhate R (2022) Bioprospecting Microbiome for Soil and Plant Health Management Amidst Huanglongbing Threat in Citrus: A Review. *Frontiers in Plant Science*, 13:858842. doi: 10.3389/fpls.2022.858842
32. Barkai-Golan, R. (2001). *Postharvest diseases of fruits and vegetables: development and control*. Elsevier.
33. Bora, P., & Bora, L. C. (2020). Disease management in horticulture crops through microbial interventions: An overview. *Indian Journal Of Agricultural Sciences*, **90**(8), 1389-1396.
34. Wilson, C. L., & Wisniewski, M. E. (1989). Biological control of postharvest diseases of fruits and vegetables: an emerging technology. *Annual review of phytopathology*, **27**(1), 425-441.
35. Chalutz, E., & Wilson, C. L. (1990). Postharvest biocontrol of green and blue mold and sour rot of citrus fruit by *Debaryomyces hansenii*. *Plant disease*, **74**(2), 134-137.
36. Tronsmo, A., & Dennis, C. (1977). The use of *Trichoderma* species to control strawberry fruit rots. *Netherlands Journal of Plant Pathology*, **83**, 449-455.
37. Pusey, P. L., & Wilson, C. (1984). Postharvest biological control of stone fruit brown rot by *Bacillus subtilis*. *Plant disease*, **68**(9), 753-756.
38. Qin, G., Tian, S., & Xu, Y. (2004). Biocontrol of postharvest diseases on sweet cherries by four antagonistic yeasts in different storage conditions. *Postharvest biology and technology*, **31**(1), 51-58.
39. Pathak, V. N. (1997). Mundkur Memorial Lecture-Post-harvest Fruit Pathology--Present Status and Future Possibilities. *Indian Phytopathology*, **50**(2), 161-185.
40. Govender, V., Korsten, L., & Sivakumar, D. (2005). Semi-commercial evaluation of *Bacillus licheniformis* to control mango postharvest diseases in South Africa. *Postharvest Biology and Technology*, **38**(1), 57-65.
41. Jiang, Y., Joyce, D. C., & Terry, L. A. (2001). 1-Methylcyclopropene treatment affects strawberry fruit decay. *Postharvest Biology and Technology*, **23**(3), 227-232.

42. Gamagae, S. U., Sivakumar, D., Wijeratnam, R. W., & Wijesundera, R. L. C. (2003). Use of sodium bicarbonate and *Candida oleophila* to control anthracnose in papaya during storage. *Crop Protection*, **22**(5), 775-779.
43. Demoz, B. T., & Korsten, L. (2006). *Bacillus subtilis* attachment, colonization, and survival on avocado flowers and its mode of action on stem-end rot pathogens. *Biological Control*, **37**(1), 68-74.
44. Batta, Y. A. (2007). Control of postharvest diseases of fruit with an invert emulsion formulation of *Trichoderma harzianum* Rifai. *Postharvest Biology and Technology*, **43**(1), 143-150.
45. Wang, Y. S., Tian, S. P., Xu, Y., Qin, G. Z., & Yao, H. (2004). Changes in the activities of pro- and anti-oxidant enzymes in peach fruit inoculated with *Cryptococcus laurentii* or *Penicillium expansum* at 0 or 20 °C. *Postharvest Biology and Technology*, **34**(1), 21-28.
46. Chalutz, E., Cohen, L., Weiss, B., & Wilson, C. L. (1988). Biocontrol of postharvest diseases of citrus fruit by microbial antagonists. In *Citriculture. Proceedings of the Sixth International Citrus Congress Middle-East, Tel Aviv, Israel, 6-11 March 1988. Volume 3. Pests and their management, integrated control in citrus growth, postharvest physiology and pathology.* (pp. 1467-1470). Balaban Publishers.
47. Adeline, T. S. Y., & Sijam, K. (1999). Biological control of bacterial soft rot of cabbage. In *Biological Control in the Tropics: Towards Efficient Biodiversity and Bioresource Management for Effective Biological Control: Proceedings of the Symposium on Biological Control in the Tropics*. CABI Publishing, Wallingford, UK (pp. 133-134).
48. Chanchaichaovivat, A., Ruenwongsa, P., & Panijpan, B. (2007). Screening and identification of yeast strains from fruits and vegetables: Potential for biological control of postharvest chilli anthracnose (*Colletotrichum capsici*). *Biological Control*, **42**(3), 326-335.
49. Colyer, P. D., & Mount, M. S. (1984). Bacterization of potatoes with *Pseudomonas putida*.
50. Wittig, H. P. P., Johnson, K. B., & Pscheidt, J. W. (1997). Effect of epiphytic fungi on brown rot blossom blight and latent infections in sweet cherry. *Plant Disease*, **81**(4), 383-387.
51. Wilson, C. L., & Chalutz, E. (1989). Postharvest biological control of *Penicillium* rots of citrus with antagonistic yeasts and bacteria. *Scientia Horticulturae*, **40**(2), 105-112.

52. Schena, L., Nigro, F., Pentimone, I., Ligorio, A., & Ippolito, A. (2003). Control of postharvest rots of sweet cherries and table grapes with endophytic isolates of *Aureobasidium pullulans*. *Postharvest Biology and Technology*, **30**(3), 209-220.
53. Singh, V., & Deverall, B. J. (1984). *Bacillus subtilis* as a control agent against fungal pathogens of citrus fruit. *Transactions of the British Mycological Society*, **83**(3), 487-490.
54. Zhao, Y Zeng, M., Dong, S., Xu, J., Song, H., & Liu, Z., (2007). Effect of an antifungal peptide from oyster enzymatic hydrolysates for control of graymold (*Botrytis cinerea*) on harvested strawberries. *Postharvest Biology and Technology*, **46**(1), 95-98.
55. Yang, D. M., Bi, Y., Chen, X. R., Ge, Y. H., & Zhao, J. (2006, August). Biological control of postharvest diseases with *Bacillus subtilis* (B1 strain) on muskmelons (*Cucumis melo* L. cv. Yindi). In *IV International Conference on Managing Quality in Chains-The Integrated View on Fruits and Vegetables Quality 712* (pp. 735-740).
56. Vinas, I., Usall, J., Teixidó, N., & Sanchis, V. (1998). Biological control of major postharvest pathogens on apple with *Candida sake*. *International journal of food microbiology*, **40**(1-2), 9-16.
57. Torres, M. A., Jones, J. D., & Dangl, J. L. (2006). Reactive oxygen species signaling in response to pathogens. *Plant physiology*, **141**(2), 373-378.
58. Wilson, C. L., El Ghaouth, A., Chalutz, E., Droby, S., Stevens, C., Lu, J. Y., ... & Arul, J. (1994). Potential of induced resistance to control postharvest diseases of fruits and vegetables. *Plant disease (USA)*.
59. Karabulut, O. A., Smilanick, J. L., Gabler, F. M., Mansour, M., & Droby, S. (2003). Near-harvest applications of *Metschnikowia fructicola*, ethanol, and sodium bicarbonate to control postharvest diseases of grape in central California. *Plant Disease*, **87**(11), 1384-1389.
60. Devi, N. D., & Arumugam, T. (2019). Salinity tolerance in vegetable crops: a review. *Journal of Pharmacognosy and Phytochemistry*, **8**(3), 2717-2721.
61. Sivakumar, D., Wijeratnam, R. W., Wijesundera, R. L. C., Marikar, F. M. T., & Abeysekere, M. (2000). Antagonistic effect of *Trichoderma harzianum* on postharvest pathogens of rambutan (*Nephelium lappaceum*). *Phytoparasitica*, **28**, 240-247.
62. De Matos, A. P. (1984). Chemical and Microbiological Factors Influencing the Infection of Lemons by *Geotrichum candidum* and *Penicillium digitatum*.
63. Kota, M. F., Husaini, A. A. S. A., Lihan, S., Hussain, M. H. M., & Roslan, H. A. *Malaysian Journal of Microbiology*.

64. Droby, S., Chalutz, E., Wilson, C. L., & Wisniewski, M. E. (1992). Biological control of postharvest diseases: a promising alternative to the use of synthetic fungicides. *Phytoparasitica*, **20**, S149-S153.
65. El Ghaouth, A., Wilson, C., & Wisniewski, M. (2004). Biologically-based alternatives to synthetic fungicides for the control of postharvest diseases of fruit and vegetables. *Diseases of Fruits and Vegetables: Volume II: Diagnosis and Management*, **511-535**.
66. Bora, L. C., Khan, P., Borah, P. K., Bora, P., & Talukdar, K. (2018). Efficacy of microbial consortia against bacterial wilt caused by *Ralstonia solanacearum* in hydroponically grown lettuce plant. *International Journal of Current Microbiology and Applied Sciences*, **7**(6), 3046-3055.
67. Belimov, A. A., Dodd, I. C., Safronova, V. I., Dumova, V. A., Shaposhnikov, A. I., Ladatko, A. G., & Davies, W. J. (2014). Abscisic acid metabolizing rhizobacteria decrease ABA concentrations in planta and alter plant growth. *Plant Physiology and Biochemistry*, **74**, 84-91.
68. Rahman Syed-Ab, S. F., Xiao, Y., Carvalhais, L. C., Ferguson, B. J., & Schenk, P. M. (2019). Suppression of *Phytophthora capsici* infection and promotion of tomato growth by soil bacteria. *Rhizosphere*, **9**, 72-75.
69. Castoria, R., De Curtis, F., Lima, G., Caputo, L., Pacifico, S., & De Cicco, V. (2001). *Aureobasidium pullulans* (LS-30) an antagonist of postharvest pathogens of fruits: study on its modes of action. *Postharvest Biology and Technology*, **22**(1), 7-17.
70. Mardanova, A. M., Hadiyeva, G. F., Lutfullin, M. T., Khilyas, I. V. E., Minnullina, L. F., Gilyazeva, A. G., ... & Sharipova, M. R. (2016). *Bacillus subtilis* strains with antifungal activity against the phytopathogenic fungi. *Agricultural Sciences*, **8**(1), 1-20.
71. Saikia, S., Bora, P., & Bora, L. C. (2021). Bioagent mediated management of citrus canker. *Indian Journal of Agricultural Sciences*, **91** (2): 198–201.
72. Maksimov, I. V., Veselova, S. V., Nuzhnaya, T. V., Sarvarova, E. R., & Khairullin, R. M. (2015). Plant growth-promoting bacteria in regulation of plant resistance to stress factors. *Russian Journal of Plant Physiology*, **62**, 715-726.
73. Nagórska, K., Bikowski, M., & Obuchowski, M. (2007). Multicellular behaviour and production of a wide variety of toxic substances support usage of *Bacillus subtilis* as a powerful biocontrol agent. *Acta Biochimica Polonica*, **54**(3), 495-508.

74. Duffy, B., Molina, L., Constantinescu, F., Michel, L., Reimann, C., & Défago, G. (2003). Degradation of pathogen quorum-sensing molecules by soil bacteria: a preventive and curative biological control mechanism. *FEMS microbiology ecology*, **45**(1), 71-81.
75. Stein, T. (2005). Bacillus subtilis antibiotics: structures, syntheses and specific functions. *Molecular microbiology*, **56**(4), 845-857.
76. Singh, B. N., Singh, B. R., Singh, R. L., Prakash, D., Singh, D. P., Sarma, B. K., ... & Singh, H. B. (2009). Polyphenolics from various extracts/fractions of red onion (*Allium cepa*) peel with potent antioxidant and antimutagenic activities. *Food and Chemical Toxicology*, **47**(6), 1161-1167.
77. Kavitha, T., Gopalan, A. I., Lee, K. P., & Park, S. Y. (2012). Glucose sensing, photocatalytic and antibacterial properties of graphene-ZnO nanoparticle hybrids. *Carbon*, **50**(8), 2994-3000.
78. Bora, P., Bora, L. C., Bhuyan, R. P., Hashem, A., & Abd-Allah, E. F. (2022). Bioagent consortia assisted suppression in grey blight disease with enhanced leaf nutrients and biochemical properties of tea (*Camellia sinensis*). *Biological Control*, **170**, 104907.
79. Aktuganov, G. E., Galimzyanova, N. F., Melent'Ev, A. I., & Kuz'mina, L. Y. (2007). Extracellular hydrolases of strain *Bacillus* sp. 739 and their involvement in the lysis of micromycete cell walls. *Microbiology*, **76**, 413-420.
80. Pieterse, C. M., Zamioudis, C., Berendsen, R. L., Weller, D. M., Van Wees, S. C., & Bakker, P. A. (2014). Induced systemic resistance by beneficial microbes. *Annual review of phytopathology*, **52**, 347-375.
81. García-Gutiérrez, L., Zerriouh, H., Romero, D., Cubero, J., de Vicente, A., & Pérez-García, A. (2013). The antagonistic strain *Bacillus subtilis* UMAF 6639 also confers protection to melon plants against cucurbit powdery mildew by activation of jasmonate and salicylic acid dependent defence responses. *Microbial Biotechnology*, **6**(3), 264-274.
82. Pieterse, C. M., Van der Does, D., Zamioudis, C., Leon-Reyes, A., & Van Wees, S. C. (2012). Hormonal modulation of plant immunity. *Annual review of cell and developmental biology*, **28**, 489-521.
83. Bora, P., & Bora, L. C. (2021). Microbial antagonists and botanicals mediated disease management in tea, *Camellia sinensis* (L.) O. Kuntze: an overview. *Crop Protection*, **148**, 105711.
84. Dodd, I. C., Zinovkina, N. Y., Safronova, V. I., & Belimov, A. A. (2010). Rhizobacterial mediation of plant hormone status. *Annals of Applied Biology*, **157**(3), 361-379.

85. Kudoyarova, G. R., Melentiev, A. I., Martynenko, E. V., Timergalina, L. N., Arkhipova, T. N., Shendel, G. V., ... & Veselov, S. Y. (2014). Cytokinin producing bacteria stimulate amino acid deposition by wheat roots. *Plant Physiology and Biochemistry*, **83**, 285-291.
86. Pusey, P.L., & Wilson, C. (1984). Post harvest biological control of stone fruit brown rot by *Bacillus subtilis*. *Plant disease*, **68**(9), 753-756
87. Zhu, S. H., & Zhou, J. (2007). Effect of nitric oxide on ethylene production in strawberry fruit during storage. *Food Chemistry*, **100**(4), 1517-1522.
88. Sharma, R. R., Singh, D., & Singh, R. (2009). Biological control of postharvest diseases of fruits and vegetables by microbial antagonists: A review. *Biological control*, **50**(3), 205-221.
89. Lastochkina, O., Seifikalhor, M., Aliniaiefard, S., Baymiev, A., Pusenkova, L., Garipova, S., & Maksimov, I. (2019). *Bacillus* spp.: efficient biotic strategy to control postharvest diseases of fruits and vegetables. *Plants*, **8**(4), 97.
90. Janisiewicz, W. J., & Korsten, L. (2002). Biological control of postharvest diseases of fruits. *Annual review of phytopathology*, **40**(1), 411-441.
91. Irtwange, S. V. (2006). Application of modified atmosphere packaging and related technology in postharvest handling of fresh fruits and vegetables. *Agricultural Engineering International: CIGR Journal*.
92. Pratella, G. C., Mari, M., Guizzardi, M., & Folchi, A. (1993). Preliminary studies on the efficiency of endophytes in the biological control of the postharvest pathogens *Monilinia laxa* and *Rhizopus stolonifer* in stone fruit. *Postharvest Biology and Technology*, **3**(4), 361-368.