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Bacterial Antagonists Mediated Biocontrol of Post-Harvest Diseases of Horticultural Crops

Ajinath Dukare
Horticultural Crop Processing Division
ICAR-CIPHET, Abohar, Punjab, India-152116
Email: ajinath111@gmail.com

Postharvest pathogens cause considerable damages to harvested fruits and vegetables during storage and transportation. Synthetic chemicals are mostly used to control losses due to postharvest decay. However, recently, more focus is shifted toward safer and more eco-friendly alternatives for postharvest decays control. Among the various biological alternatives, the use of bacterial antagonistic strain is becoming popular throughout the globe. Several postharvest pathogens can now be controlled by bacterial antagonists. Several modes of action have been suggested by which microbial antagonists inhibit the growth of post-harvest pathogens. Competition for nutrients and space is most widely accepted mechanism of their action. In addition, production of antibiotics, direct parasitism, and possibly induced resistance in the harvested produce are other modes of their actions by which they suppress the activity of postharvest pathogens.

Introduction

In developing country, significant level of post-harvest losses has been accounted to decays of fruits and vegetables caused due to fungal attack. It has been estimated that about 20– 25% of the harvested fruits and vegetables are decayed by various post-harvest related fungal pathogens during postharvest handling management operations (Singh and Sharma, 2007). These losses are often more damaging in developing countries due to inadequate storage and transportation facilities. Primarily, chemical fungicides are mostly used for controlling decay/diseases causing fungal pathogens of harvested of fruits and vegetables. However, excessive use of these chemicals has led to negative impacts of on environments, human and animal health's, development of pesticide resistance in major post-harvest fungal pathogens and accumulation of toxic pesticide residue in commodities. Due to all these concerns, there is a strong public and scientific desire to seek safer and eco-friendly biological alternatives for reducing the decay loss in the harvested fruits and vegetables. Among different eco-friendly approaches, biological management of fungal decay of harvested fruits and vegetables is an alternative and environmentally safer alternatives.

Biological control is the reduction in the population or disease/damage causing activity of a pest or a pathogen in its dormant state by one or more organisms that occur naturally or through manipulation of the environment or by mass introduction of antagonists in nature.

Various group of organism such as bacteria, fungi and viruses are being deployed for biological control of post-harvest crop pathogens. Among the various microorganisms, bacterial antagonists who have the ability to quick growth, survive and proliferate in post-harvest fruit surface can be utilized as best candidates for the biocontrol agents. Use of various bacterial antagonists such as *Pseudomonas* spp. *Bacillus* spp., *Pantoea spp* etc., for post-harvest pathogen control is quite promising option.

Selection Criteria for Ideal Postharvest Bacterial Antagonists

A potential bacterial antagonist should have certain desirable characteristics to make it an ideal bio agent. The antagonist should be:

1. Genetically stable
2. At low concentrations, effective against a wide range of post-harvest fungal pathogens
3. Ability to remain survive and active for longer time under adverse environmental conditions
4. Simple and inexpensive nutritional requirements for growth and multiplication
5. Economical to produce and formulate with long shelf-life period
6. Easy to deliver
7. Nonpathogenic for the human health and host commodity

Bacteria Deployed in Post-Harvest Disease Control of Horticultural Crops

During the last few decades, several strains of bacteria used to control postharvest decay of fruits have been extensively studied. Numerous bacterial trains have been able to reduce postharvest disease caused by a variety of fungal pathogens and some of these have been developed into commercial products. Following are the some of the examples of bacterial antagonists used in post-harvest biocontrol. Use of various bacterial antagonists such as *Pseudomonas* spp. *Bacillus* spp., *Pantoea spp*. *Burkholderia spp*. *Entero baqcter* spp. etc., have been successfully used for the control of various post-harvest pathogens of harvested fruits and vegetables (**Table 1**).

Table 1. Bacterial antagonists used for the successful control of postharvest diseases of fruits and vegetables

Bacterial Antagonists	Disease (pathogen)	Fruits/ vegetables	Reference(s)
Bacillus subtilis	Stem end rot (*Botryodiplodia theobromae*)	Avocado	Demoz and Korsten (2006)
	Alternaria rot (*Alternaria alternata*)	Muskmelon	Yang et al. (2006)
	Gray mold (*Botrytis cinerea*)	Strawberry	Zhao et al. (2007)
	Green mold (*Penicillium digitatum*)	Citrus	Singh and Deverall (1984)
Bacillus pumilus	Gray mold (*Botrytis cinerea*)	Pear	Mari et al. (1996)
Enterobacter aerogenes	Alternaria rot (*Alternaria alternata*)	Cherry	Utkhede and Sholberg (1986)
Enterobacter cloacae	Rhizopus rot (*Rhizopus stolonifer*)	Peach	Wilson et al. (1987)
Pseudomonas cepacia	Blue mold (*P. expansum*)	Apple	Janisiewicz and Roitman (1988)
	Green mold (*Penicillium digitatum*)	Orange	Huang et al. (1993)
	Brown rot (*Monilinia fructicola*)	Nectarine	Smilanik et al. (1993)
Pseudomonas aeruginosa	Bacterial soft rot (*Erwinia carotovora*	Cabbage	Adeline and Sijam (1999)

(Source: Sharma *et al*., 2009)

Mode of Action of Bacterial Antagonists against Post-Harvest Pathogen

Several modes of action have been suggested by which microbial antagonists inhibit the growth of post-harvest pathogens. Still, competition for nutrient and space, parasitism and lytic enzymes production, production of antibiotics, hydrogen cyanide production and induced systemic resistance are some mechanisms of the microbial antagonists by which they suppress the activity of postharvest pathogens on fruits and vegetables (Droby and Chalutz, 1994). Biological control of post-harvest diseases involves complex interaction between bacterial antagonists, host and pathogens (**Figure 1**).

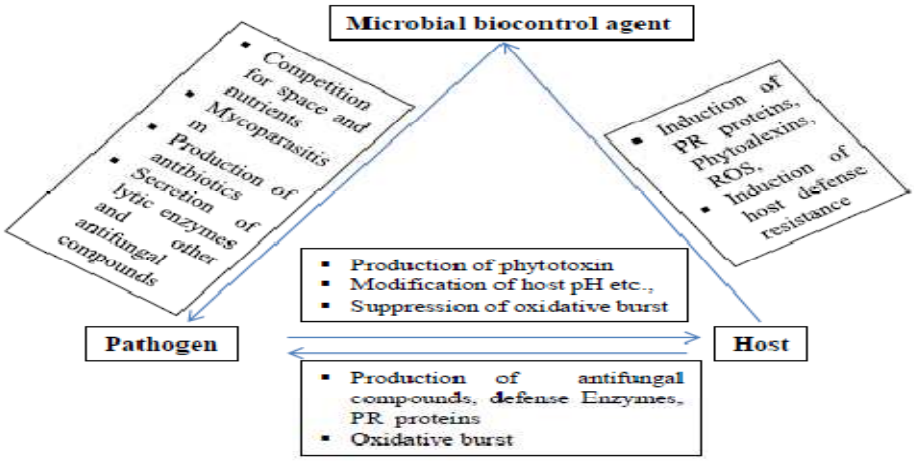

Figure 1. Biocontrol mechanism of bacterial antagonists and its possible interactions with host and post-harvest pathogen of fruits and vegetables.

1. **Competition for nutrients and/or space:** Competition for nutrients and/or space between antagonist microbes and pathogens considered as major mode of action by which microbial antagonists suppresses postharvest pathogens causing decay in harvested fruits and vegetables. The ability of bacterial antagonists to survive and multiply a in specific niches of fruit surfaces or fruit wounds after application increases their capacity to colonize larger areas preventing pathogen colonization. This mechanism has been mostly observed in bacterial antagonists such as *P. agglomerans* CPA-2, *P. syringae* ESC-10, ESC-11 involved in the control of green mold on citrus fruits (Bull *et al*., 1997) and *P. cepacia* LT-4-12 W. Antagonistic *P. syringae* strains occupy wounds on citrus fruits and reduce the disease incidence
2. **Pathogen growth inhibition by secretion of antifungal substances:** The production of one or more antifungal compound is the one the major mechanism associated with the ability of bacterial and fungal antagonist to act as antagonistic agents against post-harvest pathogens. Suppression of the pathogens of harvested fruits and vegetables by bacterial antagonists through production of antibiotics is another major mechanism. An antagonistic bacterium, *Pseudomonas syringae*, effective against *Penicillium* moulds in citrus fruit, produces antibiotics, syringomycin and *Pseudomonas cepacia* and *Serratia plymuthica* produce pyrrolnitrin. *Bacillus subtilis*, which are antagonists against major postharvest diseases of citrus fruit are known to produce antifungal compounds such as antibiotics, predominantly lipopeptides of surfactin, iturin and gramicidin S. Further, an antibiotic (pyrrolnitrin) producing *Pseudomonas cepacia* inhibit the growth of postharvest pathogens like *Botrytis cinerea* and *Penicillium expansum* in apple. Production of cyclic lipodepsi peptides (LDPs)

by *P. syringae* strains has been correlated with the ability of bacteria to control plant diseases caused bypostharvest fungal diseases (Bull *et al*., 1998).

3. **Parasitism and lytic enzymes production:** The attachment and further degradation of fungal cell wall through production of cell wall lytic enzymes is another major mechanism by which bioontrol microorganism control the growth of pathogens in harvested fruits and vegetables. Various antagonist microorganisms are known to produce lytic enzymes such as β-1, 3-glucanase, exo-chitinase, endo-chitinase and proteinase. Strong attachment of microbial antagonist with enhanced activity of cell wall degradation enzymes may be responsible for enhancing the efficacy of microbial agents in controlling the postharvest diseases of fruits and vegetables. Direct parasitism via pathogen cell wall degradation was also reported as a major factor that allows *Pantoeaag glomerans* to control *Monilinia laxa* (Aderh. & Ruhl.) Honey or *Rhizopus stolonifer* decay on stone fruits.
4. **Induced resistance in fruit and vegetables:** Induction of pathogen defense resistance in the harvested fruits and vegetables by the microbial antagonists has been suggested as another way of microbial antagonists for controlling postharvest decay in harvested produce. The resistance induction is due to the antagonist ability to elicit host plant defence responses. These biochemical defense responses associated with induced resistance includes: cell wall thickening by lignification process, production of defense enzymes (e.g., chitinases, glucanases, and peroxidases), pathogenesis related (PR) proteins, production of reactive oxygen species and accumulation of phytoalexins (antimicrobial low-molecular-weight substances). Production of such antifungal compounds by biocontrol bacteria inthe host cells help in inducing defense mechanism and hence provide protection against pathogen.

Conclusion

Use of synthetic fungicides has been the traditional strategy for the management of postharvest diseases in horticultural commodity. The increasing concern for health hazards and environmental pollution due to chemical use has demanded the development of alternative safer strategies for the control of postharvest diseases. Management of postharvest diseases by employing antagonistic bacterial biocontrol agents has been demonstrated to be most suitable strategy to replace the chemicals which are either being banned or recommended for limited use in post-harvest disease managements. This review reported the success of some bacterial biocontrol agents and the mechanism associated with control of post-harvest pathogens in fruits and vegetables.

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