E-ISSN: 2663-1067
P-ISSN: 2663-1075
IJHFS 2022; 4(2): 01-09
Received: 03-04-2022
Accepted: 04-05-2022

Meenu Rani
Division of Food Science and Technology, Sher-e-Kashmir University of Agriculture Science and Technology, Jammu, FoA, Chatha, Jammu and Kashmir, India

Julie D Bandral
Division of Food Science and Technology, Sher-e-Kashmir University of Agriculture Science and Technology, Jammu, FoA, Chatha, Jammu and Kashmir, India

Monika Sood
Division of Food Science and Technology, Sher-e-Kashmir University of Agriculture Science and Technology, Jammu, FoA, Chatha, Jammu and Kashmir, India

Corresponding Author:
Meenu Rani
Division of Food Science and Technology, Sher-e-Kashmir University of Agriculture Science and Technology, Jammu, FoA, Chatha, Jammu and Kashmir, India

Role of biocontrol agents in management of post harvest diseases of fruits and vegetables

Meenu Rani, Julie D Bandral and Monika Sood

Abstract
In recent years, there has been considerable interest in the use of antagonistic microorganisms for the control of postharvest diseases. Such organisms can be isolated from a variety of sources including fermented food products, the surfaces of leaves, fruit and vegetables. Post-harvest diseases need to be controlled to maintain the quality and abundance of fruits and vegetables produced by growers around the world. Post-harvest decay of fruits and vegetables accounts for significant level of post-harvest losses. It is estimated that about 20-25 percent of the harvested fruits and vegetables are decayed by pathogens even in developed countries. A mechanism of action may be explained as the strategy used by a beneficial microorganism against a disease-causing pathogen. Mechanism of this biological control based on ecological interactions, such as competition for space and nutrients, myco parasitism, antibiosis and induction of plant defenses. Microbial antagonists are applied either before or after harvest, but postharvest applications are more effective than pre harvest applications. Biological control is less costly and cheaper than any other methods. They do not cause toxicity to the plants. The present review focuses on post-harvest food losses, post-harvest diseases and methods to control these diseases. In this review various bio-control agents, their characteristics, mode of action and importance in agriculture have been emphasized. Application of microbial antagonistic is a better, practical and useful method for controlling postharvest diseases of fruits and vegetables. Techniques involved in the bio control practices generally include introduction, augmentation and conservation. Microbial cultures are applied either as postharvest sprays or as dip in antagonistic solution. They multiply easily in the soil and leave no residual problem, easy to manufacture and harmless to human beings and animals. These agents not only control the disease but also enhance the root and plant growth by way of encouraging the beneficial soil micro flora and increases crop yield. Biocontrol agents are very easy to handle and apply to the target and can be combined with bio-fertilizers.

Keywords: Biocontrol agents, post-harvest losses, post-harvest diseases, antagonists and antibiosis

Introduction

Fruits and vegetables are known to have nutritional and commercial importance. They play a vital role in human nutrition by supplying some necessary nutritional substances such as vitamins and essential minerals in human daily diet that can help to keep a good and normal health (Eze and Echezona, 2012) [16]. Fruits and vegetables are considered as the perishable crops than cereal, pulses and oil seed crops. Most of them contain very high moisture content (about 70-95% water), usually have large size (5g-5kg), exhibit higher respiration rate, and usually have soft texture, which favour the growth and development of several diseases by the microorganisms between harvest and consumption (Kumar *et al.*, 2006) [36]. Short shelf-life of fruits is one of the main factors that imparts negatively on the economic value of fruits (WFLO, 2010) [61]. There are various factors that affect the shelf life of fruits and vegetables, among them the most prominent is the activity of pathogens. About 20-25% of the harvested fruits are lost by pathogenic activities during post-harvest chain (Spadaro *et al.*,2004 and Droby *et al.*, 1992) [54, 9]. Fruits and vegetables exposure to soil, dust and water and bad handling at harvest or during postharvest processing leads to the microbial contamination. This makes them to harbour a wide range of microorganisms including plant and human pathogens (Dukare *et al.*, 2017) [12].

Post-harvest loss

Postharvest loss can be defined as the degradation in both quantity and quality of a food production from harvest to consumption (Irtwange *et al.*, 2006) [23]. Quality losses include those that affect the nutrient/caloric composition, the acceptability, and the edibility of a given product. These losses are generally more common in developed countries (Kovach *et al.*, 2000) [34].

Quantity losses refer to those that result in the loss of the amount of a product. Loss of quantity is more common in developing countries (Kader, 2005) [29].

In recent years, the Government of India (GOI) has begun to look more seriously at postharvest wastage and has been funding research on how to reduce losses on the farms and in the marketplaces. The most important vegetables are listed first in Table 1 having been investigated in 1993 by S.K Roy and his team at the Indian Agricultural Research Institute (IARI). Vegetables such as potatoes, onions and tomatoes have been the most heavily studied, followed by a few fruit cropa (Waarts *et al.*, 2011) [60].

Post-harvest Food Loss (PHL) is defined as measurable qualitative and quantitative food loss along the supply chain, starting at the time of harvest till its consumption or other end uses (Food and Agriculture Organization, 2004) [19]. Food losses can either be the result of a direct quantitative loss or arise indirectly due to qualitative loss. Food loss and food waste add to contribute to post-harvest food losses as presented in Figure 1.

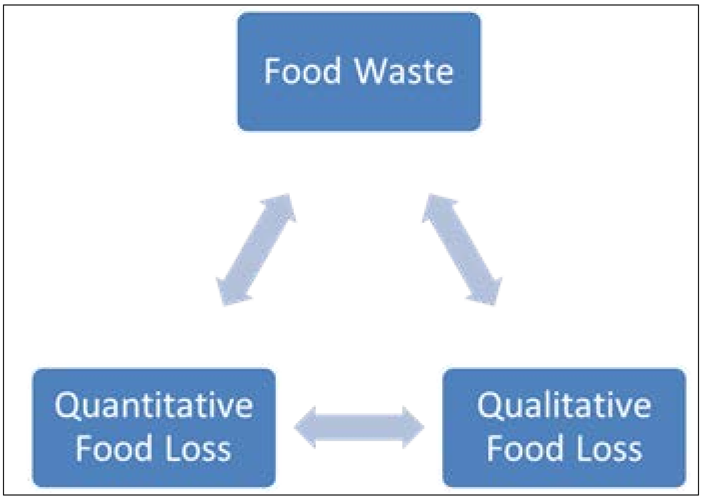

Fig 1: Post-harvest food loss components.

Food losses can be quantitative as measured by decreased weight or volume, or can be qualitative, such as reduced nutrient value and unwanted changes to taste, color, texture, or cosmetic features of food (Bloom *et al.*, 2010) [3]. Quantitative food loss is caused by the reduction in weight due to factors such as spillage, consumption by pest and also due to physical changes in temperature, moisture content and chemical changes (Eni *et al.*, 2010) [15]. Qualitative loss can occur due to incidence of insect pest, mites, rodents and birds, or from handling, physical changes or chemical changes in nutrients and by contamination of mycotoxins, pesticide residues (Quested *et al.*, 2009) **[47]**.

Food waste occurs when the an edible food item goes unutilized as a result of human action or inaction and is often the result of a decision made farm-to-fork by businesses, governments, and farmers (Barkai *et al.*, 2001 and Bloom, 2010) [2, 3]. The definitions of food waste and food losses are not consistent worldwide. Agriculture and Innovation defines food waste to include quality considerations and residual and waste flows in addition to the food loss (Singh *et al.*, 2007) [53]. Post-harvest losses of fruits and vegetables in India depicted in the table1.

Table 1: Postharvest losses reported for fruits and vegetable crops in India

Commodity	Method used	Losses (%) in India	References
Vegetables			
Potato	Sampling	29.4	Kumar *et al.* 2004 [36]
Onion	Sampling	15.7-12.9	Chaugule *et al.* 2004 [7]
Tomato	Sampling	11.9-21.4	Sharma *et al.* 2005 [51]
Cauliflower	Sampling	28.6-35.1	Pal *et al.* 2002
	Interview	15-20	Gajhbiye *et al.* 2008
Cabbage	Sampling	9.4	Wadhwanj and Brogal 2003
Cucumber	Sampling	52	WFLO 2010 [61]
Bell pepper	Sampling	6.7-17.1	Sharma *et al.* 2005 [51]
Fruits			
Citrus	Sampling	27	Roy 1993
Mango	Sampling	20	WFLO 2010 [61]
Guava	Sampling	20	WFLO 2010 [61]
Grapes	Sampling	14.4-21.3	Sreenivasa Murthy *et al.* 2009
Banana	Sampling	28.8	Sreenivasa Murthy *et al.* 2009

Post-harvest diseases

The diseases which develop on harvested parts of the plants like seeds, fruits are known as postharvest diseases. Pathogen attack may take place during harvesting and subsequent handling, storage, marketing, and after consumer purchase (Spadaro *et al.*, 2004) **[54]**. The plant parts may get infected in the field, but expression of symptoms may take place later, at any stage before final consumption (Nunes, 2012) **[41]**. The postharvest diseases that cause spoilage of both durable and perishable commodities are widespread (Sharma *et al.*, 2013) [50]. The integrative strategies for control of postharvest diseases include effectively inhibiting pathogens growth, enhancing resistance of hosts and improving environmental conditions resulting favourable to the host and unfavourable to the pathogen growth (Srinivas *et al.*, 2009) [55]. The strategies that can directly used to inhibit the microbial pathogens may be integrated as, physical + chemical, physical+ biocontrol, biocontrol + chemical and resistance+ biocontrol + physical + chemical methods (Midhun *et al.*, 2017) [38]. The aim of integrating the different effective strategies is to achieve higher level of control of postharvest pathogens and to minimize or replace the use of synthetic fungicides (Nunes, 2012) [41]. Table 2 shows Post harvest diseases of temperate and pome fruits and their causal agents (Nabil *et al.*, 2017) [39].

Factors responsible for post-harvest deteriorations includes: General senescence, Water loss, Diseases and pests. Physical damages (mechanical injury); -Injuries from temperature effects (chilling injuries); and -Other causes.

Table 2: Post harvest diseases of temperate and pome fruits and their causal agents

Name of the disease	Causal pathogens	Affected Temperate fruits
Bitter rot	*Colletotrichum gloeosporioides*	Pome and stone fruits
Black lesions, dark spots	*Stemphylium botryosum*	Pome fruits, grape etc.
Blue mold	*Penicillium expansum*	Mainly pome and stone fruits
Brown rot	*Monilinia fructicola*	Mainly stone fruits
Fruit rot, dark spot sooty mold	*Alternaria alternate*	Apple, pear, peach, plum, cherry
Grey mold	*Botrytis cinerea*	Cherry, grapes. apple, pear, peach, plum
Pink mold	*Trichothecium roseum*	Pome and stone fruits
Watery white rot	*Rhizopus stolonifer*	Apple, pear, peach, plum, cherry

Common practices used for the control of post-harvest diseases of fruit are controlled atmosphere storage, refrigeration and fungicides.

A different type of physical method applies in the control of plant pathogens like Low dose of ultraviolet light especially UV-C hormesis have emerged as alternative technology to avoid chemical fungicides. (Ramos *et al.*, 2013) [49].

Heat treatment: Post-harvest curing at 34–36°C for 48–72 h effectively controls citrus decay and reduces chilling injury symptoms (Adhikari and Sun, 2015) [1].

Irradiated Fruits: Irradiation basically controls the post-harvest diseases by sterilizing the fruits (Xin *et al.*, 2015) [62].

Low Pressure storage: Storage life is influenced by atmospheric pressure and at low pressure it is extended. Low pressure (180-190 mm) has been reported to reduce fruit ripening. Fruits have been kept in the best condition at 13°C (Mahajan *et al.*, 2014) [37].

Chemical agents

Calcium chloride ($CaCl_2$) and Sodium bicarbonate application is safe and effective methods of improving the quality and shelf life of fresh fruits. Selected organic and inorganic salts are active antimicrobial agents and have been widely used in the food industry. Among these, Calcium delays ripening and particularly softening by altering intracellular and extra cellular processes. It also reduces disorder and decay losses (Ramady *et al.*, 2015) [48]. Sodium bicarbonate (SBC) and potassium sorbate are used for controlling pH, taste and texture, and they also exhibit broad-spectrum antifungal activity. The potential of bicarbonate salts for the control of post-harvest pathogens has been demonstrated in citrus, carrot, bell pepper and melon. Sodium bicarbonate at a concentration of 2% (w/v) has potential for controlling *Rhizopus*, *Alternaria* and *Fusarium* decay on 'Galia' and 'Ein Dor' fruit.

Edible coating

Approved FV edible coatings including Chitosan and its derivatives, including glycolchitosan, were reported to inhibit fungal growth and to induce host-defence response in plants and harvested commodities. Chitosan, a high molecular weight cationic polysaccharide, is soluble in dilute organic acids, and have been used as a preservative coating material for fruits. It has ability to form a semi-permeable film and chitosan coating have definite potential to modify the internal atmosphere as well as decrease transpiration losses in fruits. Chitosan coatings have been found to extend the storage life of fresh fruit and that too without causing anaerobiosis. Moreover, they have also been reported to reduce decay by inhibiting the growth of several fungi. (Velickova *et al*, 2013) [59].

Organic Fungicides

A number of fungitoxic chemicals for controlling postharvest diseases have been developed. These chemicals are mostly used as dilute solutions into which the fruit or vegetables are dipped before storage or as solutions used for washing or hydrocooling of fruits or vegetables immediately after harvest. Benomyl, triforine, dichloran etc. are used as dips, sprays or wax formulations. Taken together, all these factors have resulted in reframing of government policies which not only allows restricted use of fungicides but also provides the impetus to develop alternative and effective natural methods of controlling post-harvest diseases. Most of cleaning and sanitizing chemicals used for postharvest treatment of FV includes: chlorine (hypochlorites, chlorine dioxide), ozonation, hydrogen peroxide, trisodium phosphate, organic acids (acetic, lactic, citric and tartaric acid), electrolyzed water and calcium based solutions (Tapia *et al.*, 2015) [57].

Biological agent

Biocontrol

In the recent past, biological control has emerged as an effective strategy to combat major postharvest decays of fruits. However, compared to the long-standing interest in biological control of soil borne pathogens research into biological control of post-harvest decays is still in its infancy. Thus, biological control of post-harvest diseases of fruit and vegetables offers a viable alternative to the use of present day synthetic fungicides. Today biological control of postharvest diseases of fruit has become an important field for research. Microbial antagonists have been reported to protect a variety of harvested perishable commodities against a number of post-harvest pathogens Post-harvest treatment of fruits with microorganisms recovered from fruit surfaces is being developed as an alternative method for control of post-harvest diseases of Citrus, Apples, and other fruits and vegetables. A number of yeasts and bacteria have been reported to inhibit post-harvest decay of fruit effectively. Utilization of antagonistic yeasts as an alternative appears to be a promising technology (J. Brodeur *et al.*, 2013) [24].

Botanicals

Plant extracts and oil from neem (*Azadirachta indica*), tobacco (*Calotropis procera*), garlic (*Allium sativum*), and dried chilies are used to control and repel some insect pests (Eze and Echezona, 2012) [16]. Recently, there have been several attempts to use naturally occurring compounds for the control of postharvest decay. Plants also produce a variety of essential oils and volatile substances that could have potential as antifungal preservatives for harvested commodities. Both plant essential oils as well as similar compounds in wood smoke have shown promise as natural antimicrobials. Essential (volatile) plant oils occur in edible, medicinal and herbal plants, which minimize questions regarding their safe use in food products. Essential oils and their constituents have been widely used as flavouring agents in foods since the earliest recorded history and it is well established that many have wide spectra of antimicrobial action. Some of the essential oils have been reported to inhibit post-harvest fungi in *in vitro* conditions. The potential of essential oils to control post-harvest decay has also been examined by spraying and dipping the fruit and vegetables (Khater, 2012) [30].

What are bio-control agents?

Control of plant pathogens and diseases caused by them through antagonistic microorganisms or botanicals is termed biological control agents. "Biological control is the reduction of inoculums or disease producing activity of a pathogen accomplished by or through h one or more organisms other than man." Antagonistic microorganisms like species of *Trichoderma*, *Penicillium, Bacillus, Pseudomonas* etc. The purposeful utilization of living organisms whether introduced or indigenous, other than the disease resistant host plants, to suppress the activities or populations of one or more plant pathogens is referred to as biocontrol. Among different biological approaches, use of the microbial antagonists like yeasts, fungi, and bacteria is quite promising and gaining popularity (Korsten, 2000) [33].

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:

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

Characteristics of good biocontrol agents

- Must not be pathogenic to plants and animals
- Should have high level of pathogenic control
- Should have live longer in host tissues
- Should be Good competitor
- Should be capable of controlling more than one pathogen
- Should be Suitable for long term storage
- Should be compatible to use with agro-chemical fertilizers, pesticides (Barkai *et al.*, 2001) [2]

Mode of Action of Biocontrol

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 *et al.*, 1992) [9]. Biological control of post-harvest diseases involves complex interaction between bacterial antagonists, host and pathogens.

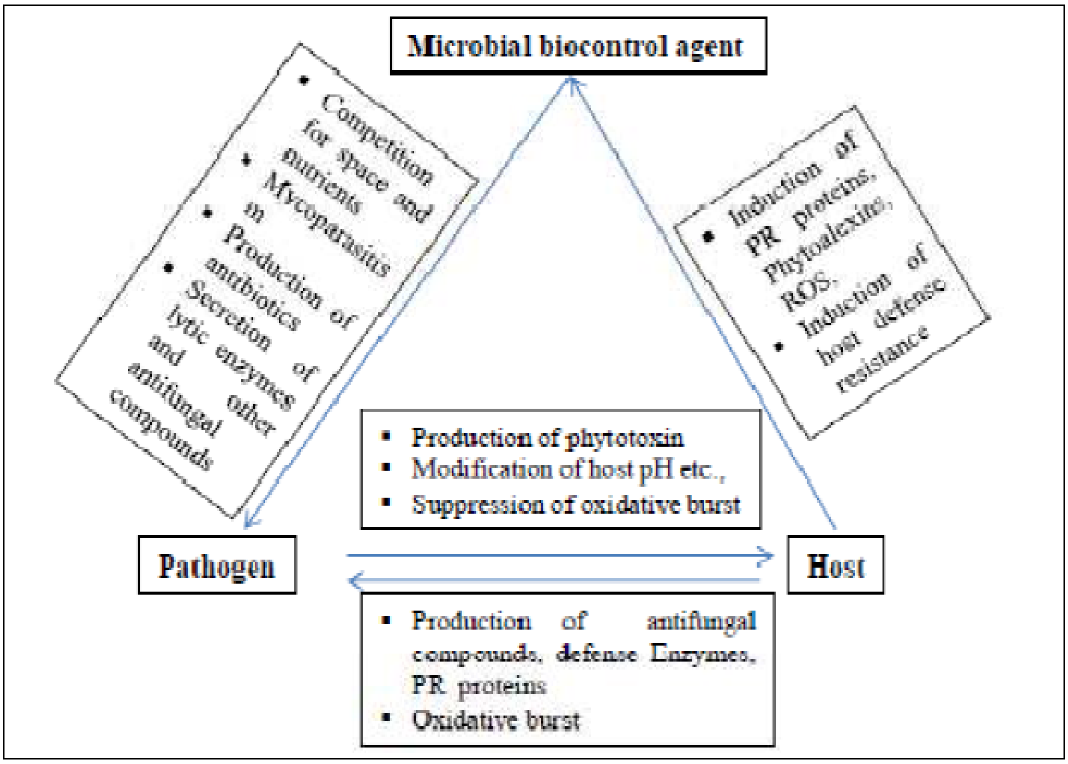

Fig 2: Biocontrol mechanism of bacterial antagonists and its possible interactions with host and postharvest pathogen of fruits and vegetables.

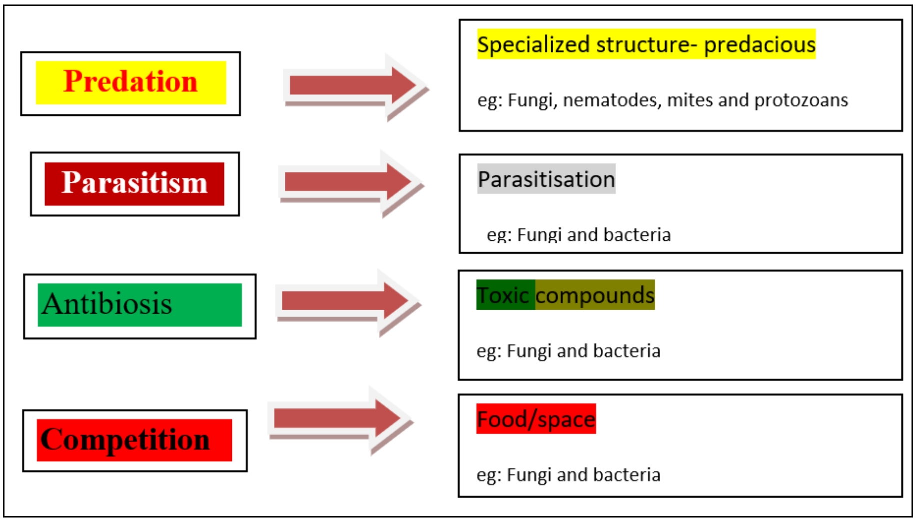

Fig 3: Mechanism of Biological Control

Competition: Microorganism competes for space, minerals and organic nutrients to proliferate and survive in their natural habitats. This has been reported in both rhizosphere as well as phyllosphere. Competition has been suggested to a play a role in the biocontrol of species of *Fusarium* and *Pythium* by some strains of *fluorescent pseudomonas*. Competition for substrates is the most important factor for heterotrophic soil fungi. Success in saprophytic ability (CSA) and inoculums potential of that species. Those fungi with highest number of propagules or the greatest mass of mycelia growth have the greatest competitive advantage. Competitive saprophytic ability is the summation of physiological characteristics that make for success in competitive colonization of dead organic substrates (Pal *et al.*, 2006) [42].

Antibiosis: Antibiosis is defined as antagonism mediated by specific or non – specific metabolites of microbial origin, by lytic agents, enzymes, volatile compounds or other toxic substances. Antibiosis plays an important role in biological control. Antibiosis is a situation where the metabolites are secreted by underground parts of plants, soil microorganism, plant residues etc. It occurs when the pathogen is inhibited or killed by metabolic products of the antagonists. The products include the lyric agents, enzymes, volatile compounds and other toxic substances (Chaube *et al.*, 2003) [6].

Mycoparasitism / Hyperparasitism: Mycoparasitism or hyperparasitism occurs when the antagonist invades the pathogens by secreting enzymes such as chitinases, celluloses, glucanases and other lytic enzymes. Mycoparasitism is the phenomenon of\ one fungus being parasitic on another fungus. The parasiting fungus is called hyperparasite and the parasitized fungus as hypoparasite (Harman, 2000). In mycoparasitism, two mechanisms operate among involved species of fungi. This may be hyphal of inter fungus interaction i.e., fungus-fungus interaction, several events take place which lead to predation *viz*., coiling, penetration, branching and sporulation, resting body production, barrier formation and lyses (Kish, 2003) [31].

Techniques of bio-control practices

- **Introduction:** "The intentional introduction of an exotic, usually co-evolved, biological control agent for permanent establishment and long-term pest control". Biological control through introduction is most frequently used against introduced pests which arrive in a new area and become permanently established without an associated natural enemy complex (Pickett, 2004) [45]. The first example of classical biological control dates back to the end of nineteenth century, when Californian citrus orchards had suffered attacks from the Australian scale, *Icerya purchasi*. This scale was successfully controlled with the introduction of its natural enemy, the coccinellid cardinal ladybird, *Rodolia cardinalis*. The most famous example of this technique within Europe is control of woolly apple aphid, *Eriosoma lanigerum*, through the introduction of its specific parasitoid *Aphelinus mali* and that of San José scale, *Quadraspidiotus perniciosus*, through the introduction of the parasitoid *Prospaltella perniciosi*.

- **Augmentation:** "It is a method of increasing the population of a natural enemy which attacks a pest. This can be done by mass-producing a pest in a laboratory and releasing it into the field at the proper time" (Van Lenteren 2000) [58].

Two basic approaches of augmentation are

- Inoculation
- Inundation.

- **Inoculation biological control:** 'The intentional release of a living organism as a biological control agent with the expectation that it\ will multiply and control the pest for an extended period, but not permanently' (Dukare, 2017) [12]. Inoculative releases are made at the beginning of the season to achieve seasonal control, i.e. to colonise the area for the duration of the\ season or crop and thus prevent pest build-up.

- **Inundation biological control:** 'The use of living organisms to control pests when control is achieved exclusively by the release d organisms themselves'. Inundative control agents are applied for short-term control when pest populations reach damaging levels. This technique is specifically used in greenhouses because of its relatively elevated costs. The most successful agent in this category is the bacterium *Bacillus thuringiensis* used to control pests such as lepidopterans, dipterans and coleoptera, although other entomopathogens based on fungi and viruses have also found niches (Eilenberg *et al*., 2007) [13].

- **Conservation:** "Modification of the environment or existing practices to protect and enhance specific natural enemies or other organisms to reduce the effect of pests". Conservation is probably the most important and readily available biological control practice available to growers (Johnson *et al*., 2008) [25]. The method is generally simple and cost-effective. With relatively little effort the activity of these natural enemies can be observed. For example lacewings, lady beetles, hover fly larvae, and parasitised aphid mummies are almost always present in aphid colonies. Fungus-infected adult flies are often common following periods of high humidity. One of the best examples of conservation biological control is the practice of strip-harvesting hay alfalfa in California. When an entire field of alfalfa is moved during hot weather, the native Western tarnished plant bug, *Lygus hesperus*, migrates within 24 hours, often to cotton where it is a key pest.

Advantages of Biological Control

- Biological control is less costly and cheaper than any other methods.
- Biocontrol agents give protection to the crop throughout the crop period.
- They do not cause toxicity to the plants.
- Application of biocontrol agents is safer to the environment and to the person who applies them.
- Self-perpetuating agents.
- They multiply easily in the soil and leave no residual problem.
- Biocontrol agents not only control the disease but also enhance the root and
- Plant growth by way of encouraging the beneficial soil micro flora. It increases the crop yield also.
- Biocontrol agents are very easy to handle and apsply to the target.
- Biocontrol agent can be combined with bio-fertilizers.
- They are easy to manufacture.
- Known levels of risks identified and evaluated before agent introduction
- It is harmless to human beings and animals (Environmentally safe.)
- Does not create new best problem
- Pest is unable to develop resistance
- Not harmful for environment Long-term management of the target pest (valid for
- Conservation and introduction).
- Limited side-effects.
- Attack of only one or a few related pests (host specific)
- Self-perpetuating agents.
- Non-recurring costs (valid for conservation and introduction).

Disadvantages of Biological Control

- Not always available
- Level of control may not b sufficient
- Research cost is very high
- Sometime may not produce results
- It require expert supervision
- Difficult and expensive to develop and supply

Application methods of microbial antagonist

After a potential microbial antagonist is selected, and its application method is to be found out. Usually, there are two method of application: pre-harvest application and post-harvest application.

- **Pre-harvest application:** In several cases, pathogens infect fruits and vegetables in the field and their latent infection become major factor for decay during transportation or storage of fruits and vegetables. Therefore, pre-harvest application of microbial antagonistic culture is often effective to control post-harvest decay of fruits and vegetables (Hodges *et al.*, 2011) [22] The many purpose of preharvest application is to colonize the antagonist on the surface of fruits so that wounds inflicted during harvesting can be colonized by the antagonist before colonization of the pathogen. Although it is difficult to control post-harvest disease of strawberry even with pre-harvest application of fungicides, some success has been achieved with field application of various microbial antagonist like *Gliocladium roseum* Bainer, *Trichoderma harzianum (*Kitinoja *et al.,* 2010) [32]. Preharvest application of *Aureobasidium pullulans* reduced storage rots in strawberry significantly grapes, cherries and apples.

- **Post-Harvest Application:** Post-harvest application of microbial antagonistic is a better, practical and useful methods for controlling postharvest diseases of fruits and vegetables. In this method, microbial cultures are applied either as postharvest sprays or as dip in antagonistic solution. Post-harvest 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 lemon. A significant reduction in storage decay was achieved by bringing several yeast species in direct contact with wounds in the peel of the harvested fruits. For instance, direct contact of microbial antagonist and infected fruit peel has been quite useful for the suppression of the pathogen *Penicillium digitatum, Penicillium italicum* (Chalutz and Wilson, 1990) [5] *Botrytis cinerea* in apples (Food and agriculture organization, 2004) [19]
- Application of microbial antagonistic is a better, practical and useful methods for controlling postharvest diseases of fruits and vegetables.
- Microbial cultures are applied either as postharvest sprays or as dip in antagonistic solution (Hodges *et al.*, 2011) [22].
- Post-harvest 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 lemon.
- A significant reduction in storage decay was achieved by bringing several yeast species in direct contact with wounds in the peel of the harvested fruits (Chalutz *et al.,* 1990) [5].
- Direct contact of microbial antagonist and infected fruit peel has been quite useful for the suppression of the pathogen *Penicillium digitatum, Penicillium italicum, Botrytis cinerea in apple* (Food and Agriculture Organization, 2004) [19].

Future prospective
Postharvest diseases cause considerable losses to harvested fruits and vegetables during transportation and storage. Synthetic fungicides are primarily used to control postharvest decay loss. The recent trend is shifting toward safer and more eco-friendly alternatives for the control of postharvest decays. Of various biological approaches, the use of antagonistic microorganisms is becoming popular throughout the world. Several postharvest diseases can now be controlled by microbial antagonists. The public's demand for reduced pesticides in our food and the environment has caused an energetic debate over the safeness of our present control practices for postharvest diseases. With people turning more health conscious, Biological control seem to the best alternative to disease suppression. Moreover, the novel concept of bio control needs a space outside the laboratory to see its fruits in present production systems. As researchers, we have the challenge and opportunity to develop safe and effective alternatives to present-day synthetic fungicides. The climate for support of biological control research is now excellent. There is every indication that significant advances will be made and commercially available products will be available for postharvest use in the near future.

Conclusion
Use of postharvest technologies such as maintaining the cold chain and temperature management is inevitable as most of tropical fruits and vegetables are sensitive to temperature and are climacteric. Also, using combined methods is more beneficial for FV postharvest losses reduction, particular with minimally processed FV. Proper use of postharvest technologies such as, controlled temperatures, sanitizing chemicals, edible coating and controlled ripening will lead to increased safety of FV and adherence to quality standards for local and international markets. Although most of postharvest technologies are still unpopular in SSA, they are still a necessary approach to reduce FV losses, build a sustainable food and nutrition security, and alleviate poverty Biological control using microorganisms associated with plants is an efficient and effective approach to control diseases and is considered environmentally friendly. The first step is to screen potential biological control agents (BCA), while the main screening strategy used by many scientists is based on *in vitro* antagonistic activity. 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.

References
1. Adhikari A, Sun. Attachment strength and on-farm die-off rate of *Escherichia coli* on watermelon surfaces. PloS One. 2019;14(1):110-115.
2. Barkai Golan R. Postharvest Diseases of Fruit and Vegetables: Development and Control. Amsterdam The Netherlands: Elsevier Science, 2001.
3. Bloom J. American Wasteland. Da Capo Press, Cambridge: MA, 2010.
4. Buzby JC, Hyman J. Total and per capita value of food loss in the United States. Food Policy. 2012;37(5):561-570.
5. Chalutz E, Wilson CL. Postharvest biocontrol of green and blue mold and sour rot of citrus fruit by

Debaryomyces hansenii. Plant Disease. 1990;74:134-137.
6. Chaube HS, Mishra DS, Varshney S, Singh US. Bio control of plant pathogens by fungal antagonists: a historical background, present status and future prospects. Annual review of plant pathology. 2003;2:1-42.
7. Chaugule RR, Bhonde SR, Pandey UB. Assessment of postharvest losses in onion. News Letter National Horticultural Research and Development Foundation. 2004;24(1):11-16.
8. Cook RJ, Baker KF. The nature and practice of biological control of plant pathogens. American Phytopathological Society. St. Paul, Minnesota, 1983.
9. Droby S, Chalutz E, Wilson CL, Wisnienwski ME. Biological control of postharvest diseases: a promising alternative to the use of synthetic fungicides. Phytoparasitica. 1992;20:1495-1503.
10. Droby S, Chalutz E. Mode of action of biological agents of postharvest diseases. In: Wilson, C.L., Wisniewski, M.E. (Eds.), Biological Control of Postharvest Diseases - Theory and Practice. CRC Press, Boca Raton, 1994, 63-75.
11. Droby S. Biological control of postharvest diseases of fruits and vegetables: difficulties and challenges. Phytopathol. Pol. 2006;39:105-117.
12. Dukare A. Bacterial Antagonists Mediated Biocontrol of Post-Harvest Diseases of Horticultural Crops. 2017;5(1):115-118.
13. Eilenberg J, Hajek A, Lomer C. Suggestions for unifying the terminology in biological control. In: BioControl. 2001;46:387-400.
14. Eilenberg J, Schmidt NM, Meyling NV, Wolsted C. Preliminary survey for insect pathogenic fungi in Greenland. IOBC WPRS Bulletin. 2007;30(1):117.
15. Eni AO, Oluwawemitan TO, Solomon OU. Microbial quality of fruits and vegetables sold in Sango Ota, Ogun State, Nigeria. African Journal of Food Science. 2010;4(5):291-296.
16. Eze SC, Echezona BC. Agricultural pest control programmes, food security and safety. African Journal of Food, Agriculture, Nutrition and Development. 2012;12(5):6582-6592.
17. Fan Q, Tian SP. Postharvest biological control of grey mold and blue mold on apple by *Cryptococcus albidus* (Saito) Skinner. Postharvest Biol. Technology. 2001;21:341-350.
18. Food and Agriculture Organization. Assessment and Collection of Data on Post-harvest Food Grain Losses, FAO Economic and Social Development Paper 13. Rome, 1980.
19. Food and Agriculture Organization. The State of the Food Insecurity in the World. Rome Italy, 2004.
20. Gullino ML, Benzi D, Aloi C, Testoni A. Garibaldi, Biological control of Botrytis rot of apple. In: Williamson B, Verhoeff K, Malatrakis NE. (Eds), Recent advances in Botrytis research. Proceedings of the 10th International Botrytis Symposium, Heraklion, Crete. 1992, 197-200.
21. Harman GE. Myths and dogmas of Bio control: Changes in the perceptions derived from research on *Trichoderma harzianum* T-22. Plant Disease. 2000;84:377-393.
22. Hodges RJ, Buzby JC, Bennett B. Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. Journal of Agricultural Science. 2011;149:37-45.
23. Irtwange S. Application of Biological Control Agents in Pre- and Post-Harvest Operations. Agri Eng. Intl. 2006;8:3.
24. Brodeur J, Cory J, Harwood JD, Hoffmann JH, Jacobsen B, Lewis EE, *et al*. Biological Control Editorial Board. Elsevier Journal website. Copyright © 2013 Elsevier B.V, 2013.
25. Jonsson M, Wratten SD, Landis DA, Gurr GM. Recent advances in conservation biological control of arthropods by arthropods. Biological control. 2008;45(2):172-175.
26. Junaid JM, Dar NA, Bhat TA, Bhat AH, Bhat MA. Commercial Biocontrol Agents and Their Mechanism of Action in the Management of Plant Path. International Journal of Modern Plant & Animal Sciences. 2013;1(2):39-57.
27. Kader AA. (Tech. Ed.). Post-harvest Technology of Horticultural Crops. University of California, Agriculture and Natural Resources, 2002, 3311.
28. Kader AA, Rolle RS. The Role of Post-harvest Management in Assuring the Quality and Safety Horticultural Crops. Food and Agriculture Organization. Agricultural Services Bulletin. 2004;152:52.
29. Kader AA. Increasing food availability by reducing postharvest losses of fresh produce. Acta Horticulture. 2005;682:2169-2176.
30. Khater HF. Prospects of botanical biopesticides in insect pest management. Pharmacologia. 2012;3(12):641-656.
31. Kish L. A review of fungal antagonists of powdery mildews and their potential as bio agents. Pest Management Science. 2003;59:475-483.
32. Kitinoja L, Saran S, Royb SK, Kaderc AA. Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy, 2010. (wileyonlinelibrary.com) DOI 10.1002/jsfa.4295.
33. Korsten L. Advances in control of postharvest diseases in tropical fresh produce. International Journal of Postharvest Technology Innovation. 2000;1:48-61.
34. Kovach R, Petzoldi GE, Harman. Use of honey bees and bumble bees to disseminate *Trichoderma harzianum* to strawberries for *Botrytis* control. Biological Control. 2000;18:235-242.
35. Kumar DK, Basavaraja H, Mahajanshetti SB. An economic analysis of post-harvest losses in vegetables in Karnataka. Indian Journal of Agriculture-Economics. 2006;(1):134-146.
36. Kumar NR, Pandey NK, Dahiya PS, Arun P. Postharvest losses of potato in West Bengal: an economic analysis. Potato Journal. 2004;31(3/4):213-216.
37. Mahajan PV, Caleb OJ, Singh Z, Watkins CB, Geyer M. Postharvest treatments of fresh produce. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 2014;372:20-30.
38. Midhun B, Elizabaith TJ, Golda MS. Biocontrol agents in management of post harvest plant diseases. Life Sciences International Research Journal. 2017;4(1):1-55.

39. Nabil EW, Saleh M, Gaafar N, Elbehery H. Conservation Biological Control Practices. Biological Control of Pest and Vector Insects, 2017. DOI:10.5772/663.
40. Nabi SU, Raja WHL, Kumawat KL, Mir JI, Sharma OC, Singh DB, *et al*. Post-Harvest Diseases of Temperate Fruits and their Management Strategies: A Review, Int. J Pure App. Biosciences. 2017;5(3):885-898.
41. Nunes C. Biological control of postharvest diseases of fruit. Europeon Journal of Plant Pathology. 2012;133:181-196.
42. Pal KK, McSpadden G. Biological Control of Plant Pathogens. The Plant Health Instructor, 2006, 1-25.
43. Pallavi R, Thakur U, Nitin D. Post-harvest fungal diseases of fruits and vegetables in Nagpur, Int. J of Life Sciences. 2014;2:56-58.
44. Pandey NK, Dahiyla PS, Anshuman K, Kumar NR. Marketing and assessment of post-harvest losses in potato in Bihar. Journal of Indian Potato Association. 2003;30(3/4):309-314.
45. Pickett C, Simmons G, Lozano E, Goolsby J. Augmentative biological control of whiteflies using transplants. Biocontrol. 2004;49(6):665-688.
46. Prusky D, McEvoy JL, Leverentz B, Conway WS. Local modulation of host pH by *Colletotrichum* species as a mechanism to increase virulence. Mol. Plant Microbe Interaction. 2001;14:1105-1113.
47. Quested T, Johnson H. Household Food and Drink Waste in the UK: Final Report." Wastes prevention and support system, 2009.
48. Ramady HR, Domokos-Szabolcsy É, Abdalla NA, Taha HS, Fári M. Postharvest management of fruits and vegetables storage. Sustainable agriculture reviews, 2015, 65-152.
49. Ramos B, Miller FA, Brandão TRS, Teixeira P, Silva CLM. Fresh fruits and vegetables an overview on applied methodologies to improve its quality and safety. Innovative Food Science & Emerging Technologies. 2013;20:1-15.
50. Sharma A, Diwevidi VD, Smita S, Pawar KK, Jerman M, Singh LB, *et al*. Biological Control and its Important in Agriculture. International Journal of Biotechnology and Bioengineering Research. 2013;4(3):175-180.
51. Sharma RL, Choudhary M, Shukla A. Post-harvest losses of bell pepper and tomato fruits in Himachal Pradesh. Integrated plant disease-management Challenging problems-in horticultural and forest pathology, Solan, India, 2005, 173-177.
52. Sharma RR, Singh D, Singh R. Biological control of postharvest diseases of fruits and vegetables by microbial antagonists: A review. Biological Control. 2009;50(3):205-221.
53. Singh D, Sharma RR. Postharvest diseases of fruit and vegetables and their management. In: Prasad, D. (Ed.), Sustainable Pest Management. Daya Publishing House, New Delhi, India, 2007.
54. Spadaro D, Garibaldi A, Gullino ML. Control of *Penicillium expansum* and *Botrytis cinerea* on apple combining a biocontrol agent with hot water dipping and acibenzolar-S-methyl, baking soda, or ethanol application. Postharvest Biology and Technology. 2004;33(2):141-151.
55. Srinivas G, Satish K, Madhusudhana R, Seetharama N. Exploration and mapping of microsatellite markers from subtracted drought stress ESTs in *Sorghum bicolor* (L.) Moench. Theor Appl Genet. 2009;118:703-717.
56. Tadesse F. Post-harvest losses of fruits and vegetables in horticultural state farms. Acta Hort. 1991;270:261-270.
57. Tapia M, Gutierrez-Pacheco M, Vazquez-Armenta F, Aguilar GG, Zavala JA, Rahman MS, *et al*. Washing, peeling and cutting of fresh-cut fruits and vegetables minimally processed foods, 2015, 57–78.
58. Van Lenteren JC. Critérios de selecçao de inimigos naturais a serem usados em programas de controle biológico, 2000.
59. Velickova E, Winkelhausen E, Kuzmanova S, Alves VD, Moldão-Martins M. Impact of chitosan-beeswax edible coatings on the quality of fresh strawberries (*Fragaria ananassa cv Camarosa*) under commercial storage conditions. LWT-Food Science and Technology. 2013;52(2):80-92.
60. Waarts Y, Eppink M, Oosterkamp E, Hiller S, Van der Sluis A, Timmermans T. Reducing food waste: obstacles experienced in legislation and regulation. LEI report/LEI Wageningen UR, 2011;(59).
61. WFLO. Identification of Appropriate Postharvest Technologies for Improving Market Access and Incomes for Small Horticultural Farmers in Sub-Saharan Africa and South Asia. WFLO Grant Final Report to the Bill & Melinda Gates Foundation, 2010, 318.
62. Xin Y, Zhang M, Xu B, Adhikari B, Sun J. Research trends in selected blanching pretreatments and quick freezing technologies as applied in fruits and vegetables: A review. International Journal of Refrigeration. 2015;57:11-25.
63. Zhu Z, Zhang Z, Qin, G, Tian S. Effects of brassinosteroids on postharvest disease and senescence of jujube fruit in storage. Postharvest Biology and Technology**.** 2010;56:50-55.
64. Zhu SJ. Non-chemical approaches to decay control in postharvest fruit. In: Noureddine, B., Norio, S. (Eds.), Advances in Postharvest Technologies for Horticultural Crops. Research Signpost, Trivandrum, 2006, 297-313.