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Review Article

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Post Harvest Diseases of Temperate Fruits and their Management Strategies-A Review

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ABSTRACT

The diseases which develop on harvested parts of the plants like seeds, fruits are known as post-harvest diseases. Pathogen attack may take place during harvesting and subsequent handling, storage, marketing, and after consumer purchase. The plant parts may get infected in the field, but expression of symptoms may take place later, at any stage before final consumption. The postharvest diseases that cause spoilage of both durable and perishable commodities are widespread. Losses inflicted throughout the supply chain due to pathogen-induced diseases are the major component of food wastage and may occur at any time from preharvest to consumption. The capability of a microorganism to initiate postharvest diseases, as well as its final outcome, depend on a number of factors that can conveniently be associated with, microorganism, the host and/or the environment. 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. The strategies that can directly act upon the microbial pathogens may be integrated as, physical + chemical, physical+ biocontrol, biocontrol + chemical and resistance+ biocontrol + physical + chemical methods. The possibility of integrating the different effective strategies to achieve higher level of control of postharvest pathogens and to minimize or replace the use of synthetic fungicides has to be explored in certain host–pathogen systems.

Key words: *Temperate fruits, Post-harvest, Diseases, Pathogens, Factors, Management.*

INTRODUCTION

Durable and perishable commodities are prone to widespread postharvest diseases that cause huge spoilage to the produce. Greater losses in developing countries, is due to non-availability of proper storage and transportation facilities and improper handling methods, resulting in greater levels of injuries or wounds during harvesting and transit[31,41]. It is estimated that about 20– 25% of the harvested fruits and vegetables are decayed by pathogens during postharvest handling even in developed countries. In developing countries, postharvest losses are often more severe due to inadequate storage and transportation facilities[48].

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In a report by the United Nations Food and Agricultural Organization, it was estimated that one-third of the food produced worldwide for human consumption is lost after harvest[18]. The harvested produce might have been infected by pathogens prior to harvest under field conditions or they may get infected during transit and storage.

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[46]. Postharvest pathology, earlier termed "market pathology", deals with the science of, and practices for, the protection of harvested produce during harvesting, packing, transporting, processing, storing, and distribution. Diseases caused by microbial pathogens – fungi, bacteria, and viruses account for substantial losses of grains, fruits, and vegetables at both pre- and postharvest stages of crop production. "The responsibilities of the plant pathologists do not end with the harvest of satisfactory yields of plant products and that harvesting marks the termination of one phase of plant protection and the beginning of another"[61]. This statement clearly indicates that the second phase of plant protection – of seeds, fruits, vegetables, and other economic plant parts, from the time of harvest until they reach the consumer – is equally important Postharvest losses for fresh commodities (fruits and vegetables) are about 5% in developed countries and may average 30-50 % in underdeveloped countries[9]. In developing countries losses are more, due to non-availability of proper handling methods, transportation and storage facilities, which results in greater levels of injuries or wounds during harvesting and transit. Fruits are living organisms and their marketable life is largely affected by the prevailing temperature, relative humidity, and the composition of the atmosphere during and after harvest, and type and degree of infection by the microorganisms. They deteriorate during storage through loss of moisture, decay caused by pathogens, rodents, loss of stored energy, loss of nutrients and vitamins[41], physical losses through pests and disease attack, loss in quality from physiological disorders, fibre development etc. Economic gains achieved by improvements in primary production can be less as losses caused by the post-harvest diseases are more under conditions favourable for post-harvest pathogens to act. Studies on postharvest diseases are primarily directed at preventing economic loss from spoilage of harvested commodities during transit and storage[39]. So there is an imperative need to collect information on the microbial pathogens involved in various postharvest diseases of temperate fruits, favourable conditions for disease development, and effective methods for disease management.

Factors Affecting Development of Infection

The surrounding environment of produce plays an important role in development of infection by the pathogens and subsequent postharvest wastage of the produce. The various factors which favor the post-harvest diseases are discussed as under.

Environmental Conditions

It is common knowledge that most diseases appear and develop best during wet, warm and humid days. The postharvest environmental factors that most seriously affect the initiation and symptoms development of infectious fruits are temperature, moisture and air composition (particularly O_2 and Co_2 concentrations).

Temperature

Storage temperature is so critical for controlling postharvest diseases that all other control methods are sometimes described as "supplements" to refrigeration[58]. The high temperature and high humidity favour the development of postharvest decay. However, the speed of either infection or resistant action is significantly related to storage temperature, being the most important environmental factor[9]. With the advent of higher temperatures, pathogens become active as and, when other conditions are favourable, they can quickly infect hosts and cause serious disease. Obviously, temperature management is so critical to postharvest disease control that all remaining control methods can be described as supplements to refrigeration.

Humidity

Relative humidity is a very important environmental factor for harvested fruit in storage. The germination of some fungi and direct penetration to fruit are aided by saturated atmospheres or moisture on the fruit surface[20]. In general, high humidity can promote diseases development if temperatures are favourable[40]. Fresh fruits need high humidity levels (>95% relative humidity) in storage environment in order to minimize the loss of moisture and preventing them from shrivel and losing tissue turgidity[9].

Maturity

Fruits are usually harvested before they are completely ripe, in order to secure sufficient time for long distance transportation and marketing. As fruit ripen they become susceptible to a variety of fungi, whose attacks they were capable to resist, during their development on the tree. Much of decay that develops in storage is derived from spores that deposit on the surface during the growing season, but which are incapable of causing rotting until harvest[59]. Ripe fruits are more susceptible to invasion by specific pathogenic micro-organisms as they are high in moisture and nutrients and no longer protected by the intrinsic factors which conferred resistance during their development phase. Many fruits become easily injured as they reach full maturing, and therefore, are more vulnerable to wound pathogens. Some fungi, such as *Monilinia* spp., *Botrytis cinerea, Rhizopus* spp. or *Penicillium* spp., are most likely to invade after the fruit is completely ripe or has become senescent[60].

Wounds and Bruises

Fungal spore often infect fruit by invading wounds, including cuts punctures, bruises and abrasions, which easily occur during harvest and handling[57]. Various types of injuries can be sustained before, and after the harvest of produce. Injury can be caused by weather, insects, birds, rodents and farm implements. Injuries to the fruits usually occur when produce is dropped on to a hard surface, before, during or after packing, but injury is not usually apparent immediately. Later, bruising may also take place, but it is seen only externally (e.g. apple) or it may be evident only on peeling (e.g. potatoes). Compression bruising may result from the overstocking of bulk produce in store houses or from the overfilling of the packaging (e.g. grapes). The vibration damage can occur in under-filled packs, especially during long distance road transportation. The damaged produce is attacked by various microorganisms, resulting in a progressive decay, which may affect the entire produce[57]. Fresh wounds can support nutrients and humidity for spore germination and colonization by fungi. For example, conidia of *Monilinia fructicola* need moisture and nutrients for spore germination and growth if deposited in fresh wound of stone fruit[46]. Fungal growth and lesion development follow when temperature conditions are favourable. Healed wounds may no longer be highly prone to fungal invasion. Many studies of responses to wounding in a wide assortment of tissues including fruits, leaves, with common traits among plants[9].

Pathogens Causing Postharvest Diseases in Temperate Fruits

Several pathogens such as fungi and bacteria are responsible for causing diseases in temperate fruits. However, it is well known that the major postharvest losses are caused by fungi such as *Alternaria, Aspergillus, Botrytis, Colletotrichum, Diplodia, Monilinia, Penicillium, Phomopsis, Rhizopus, Mucor* and *Sclerotinia* and bacteria such as *Erwinia* and *Pseudomonas* (Table 1)[50]. Most of these organisms are weak pathogens in that they can only invade the damaged produce.

Table 1: Major postharvest diseases of temperate fruits and causal agents

Name of the disease	Causal pathogen	Affected Temperate fruits	Reference (s)
Bitter rot	*Colletotrichum gloeosporioides*	Pome and stone fruits	Masoud *et al*[34].,
Black lesion, dark spots	*Stemphylium botryosum*	Pome fruits, grape etc.	Toselli *et al*[63].,
Blue mold	*Penicillium expansum*	Mainly pome and stone fruits	Masoud *et al*[34].,
Brown rot	*Monilinia fructicola*	Mainly stone fruits	Sisquella *et al*[53].,
Fruit rot, dark spot, sooty mold	*Alternaria alternata*	Apple, pear, peach, plum, cherry,	Kadam[27]
Gray mold	*Botrytis cinerea*	Cherry, grapes, apple, pear, peach, plum,	McLaughlin *et al*[36].,
Lenticel rot	*Gloeosporium album*	Apple, pear etc.	Edney *et al*[14].,
Olive-green moold, sooty mold	*Cladosporium herbarum*	Apple, pear, cherry, plum, peach and stone fruits	Latorre *et al*[28].,
Pink mold	*Trichothecium roseum*	Pome and stone fruits	Wang *et al*[65].,
Watery white rot	*Rhizopus stolonifer*	Apple, pear, peach, plum, cherry	Zhang *et al*.,

Infection Process

Microorganisms either infect the produce while still immature on the plant (pre-harvest infection) or during the harvesting and subsequent handling and marketing operations (post-harvest infection). Postharvest infection process is greatly aided by mechanical injuries to the peel of the produce. The infection may occur by direct penetration of the cuticle or entry through stomata, lenticels, wounds or abscission scar tissue. Furthermore, the physiological condition of the produce, the temperature and the formation of the periderm significantly affect the two types of infection i.e. pre-harvest infection and postharvest infection.

Pre-Harvest Infection

Pre-harvest infection of fruit and vegetables may occur through several avenues, such as direct penetration of the peel, infection through natural openings on the produce and infection through damaged portion. Several types of pathogenic fungi are able to initiate the infection process on the surface of floral parts, and developing fruits. The infection is then arrested, which remains quiescent until after harvest, when the resistance of the host decreases and conditions become favorable for the growth of the pathogen i.e., when the fruit begins to ripen or its tissues become senescent[3]. Such ‘latent infections’ are important in the postharvest wastage of many temperate fruits, such as apple, pear, apricot etc. Weak parasitic fungi and bacteria may also gain access to immature fruits through natural opening such as stomata, lenticels and growth cracks. Again, this infection may not develop until the host becomes less resistant to the invading organism, such as when the fruits ripen. It appears that sound fruits and vegetables can suppress the growth of these organisms for a considerable time[2]. For example, spores of *Phlyctaena vagabunda* penetrate apple lenticels before harvest, which cause fruit rotting around the lenticels during the storage.

Postharvest Infection

Many fungi that cause considerable wastage of produce are unable to penetrate the intact peel of produce, but readily invade via any injury point in the peel. The damage is microscopic, but is sufficient for pathogens present on the crop to grow on it. For infection of postharvest produce, different parts of the plants are infected i.e., floral infection, stem-end infection and quiescent infection. The floral infection occurs through various parts (sepals, petals, stigma etc) in many temperate fruits[47]. The cut stem is a frequent point of entry for microorganisms and stem-end rots are important forms of postharvest spoilage of many fruit[3]. For example, postharvest infection by *Sclerotina* and C*olletotrichum* is very common in many fruits through direct penetration of the peel[12]. Quiescent Infection, the time between initial infection and appearance of disease symptoms is known as the latent or quiescent period. The term refers to 'quiescent' or dormant parasitic relationship, which after some time, changes to an active one[4]. A fungus may become quiescent at initiation of germination, germ tube elongation, appressorium formation, penetration or subsequent colonization. The failure to germinate or to develop beyond any subsequent stage is due to adverse physiological conditions temporarily imposed by the host, either directly on the pathogen or indirectly by modification in its pathogenic capability[61].

Management Strategies

The main objective of postharvest fruit disease management is to keep the fruit disease free or symptom-free until it is marketed or consumed. Hence, the management strategies should aim at prevention, eradication and delaying the symptoms of diseases during transit and storage of fruits and vegetables[58]. To manage postharvest diseases of temperate fruits, the treatments are broadly divided into five groups *i.e.,* cultural, physical, chemical, biological and resistance approaches. The effectiveness of treatment depends on the ability of the treatment or agent to reach the pathogen, the level and sensitivity of the infection and the sensitivity of the host produce[49]. The various methods of postharvest disease control of fruits as described briefly hereunder:

Cultural Methods

Fruits and vegetables that are injured during harvesting, sorting, packaging or transportation, and have succeeded in avoiding infection by wound pathogens, are still liable to come into contact with pathogens during packing or storage. Since disease development requires the presence of a given pathogen along with an available wound for penetration, a reduction in either of these factors will lead to the suppression of disease development[2]. Wounding to the produce can be minimized by careful harvesting, sorting, packaging and transportation, including preventing the fruit from falling at all stages. Regarding the avoidance of wounds one should remember that physiological injuries are also caused by cold, heat, oxygen deficiency, and other environmental stresses, which predisposes the commodity to attack by wound pathogens. A general reduction in wounds also reduces the chances of infection of fruits and vegetables by pathogens during transit and storage, such factors should also be taken into consideration, while packaging or storing the fruits[39]. The source of pathogen should be immediately be removed either by disposal of rotten fruits or immersing it in a disinfectants solution like formaldehyde, isopropyl, alcohol, ammonium compounds, sodium or calcium hypochlorite, in a special container[11].

Physical Methods

The postharvest diseases of fruits may be controlled by various physical treatments, such as, low temperature storage, high temperature treatments, magnetic fields and radiation. The various radiations include sound, ultrasound, radio, microwave, infrared, visible light, ultraviolet, X-rays, gamma rays and cathode ray spectra. Some are highly fungicidal, while others are less effective. Among these, a few have been used potentially as postharvest treatments of fruits as described briefly hereunder.

Use of Gamma Irradiation

Gamma irradiation can penetrate the produce and inactivate the deep-seated pathogens. Mature fruits are relatively resistant to radiation damage because cell division rarely occurs in immature tissues. Doses required to eradicate infections range from 2,000 – 3,000Gy, in some cases as low as 1,000 and in others as high as 6,000Gy, which is far higher than the dose required for disinfection (75 – 300Gy) (Table 2). In crop like apple minimum dose required is 150Gy and in apricot and peaches 200Gy is required to eradicate the post-harvest pathogens[25].

Use of Low Temperature

Use of low temperature is considered very important in controlling decay in several fruits. Low temperature may slow down the growth of the pathogens, but it also slows down fruit ripening process. Temperature management is important in reducing physiological deterioration and preventing moisture loss and shrivelling as well as reducing disease incidence. For this reason, with many commodities refrigeration can be considered supplements to fungicidal treatments in several fruits[2]. In general, it is recommended to store fruits at the lowest possible temperature that does not harm the host. With many fruits, the lowest desirable temperature is just above the freezing temperature. Certain varieties of apple, pears, plums, peaches can thus be stored between 0 and -2 ^{0}C. It is commonly observed that apples and pears stored at slightly below 0 ^{0}C are attacked by *Botrytis cinerea*, *Penicillium expansum* and *Cladosporium*. The pathogenic growth of most fungi, however is completely stopped at temperature near 0 ^{0}C[39].

Use of High Temperature

Heat may be applied to fruits in several ways such as hot water dips, vapour heat, hot dry air or hot water rinsing and brushing[29]. However, the major factors to be considered while developing postharvest heat treatments are:

i. Thermal sensitivity of target organism
ii. Location of the target organism in or on the fruit, and
iii. Thermal sensitivity of the fruit.

These factors largely determine temperature, duration and type of the heat treatment required. Heat treatment in the form of either moist hot air or hot water dips has been commercialized for the control of postharvest diseases in several fruits such as stone fruits. This eco- friendly technique has been used to control postharvest diseases in many fruits (Table 2, 3). Hot water treatment reduces severity of various fruit rots[30]. The advantage of hot water dipping is that it controls surface infections as well as infections that have penetrated deep in the peel, and it leaves no chemical residues in the produce. Hot water dips must be precisely administered as the range of temperature necessary to control disease (50–55 ^{0}C) can damage the produce.

Table 2: Hot water treatments for controlling decay in some fruits

Fruit crop	**Hot water dip**		**Disease controlled**	**Possible injuries**	**References**
	Temperature (^{o}C)	**Duration (Min)**			
A. Hot water dip treatments					
Apple	45	10	Botrytis rot and Penicillium rots	Reduced storage rot	Edney *et al*[15].
Cherry	52	2	Codling moth and Botrytis rot	Slight discoloration	Johnson[26]
Peach	50	2.5 - 3	Brown rot , Rhizopus rot	Motile skin	Singh *et al*[51].,
Plum	45-50	35-30	Rhizopus rot	--	Michailides *et al*[37].,
Pear	47	30	Botrytis rot	--	Michailides *et al*[37].,
B. Hot water rinsing and brushing treatments					
Apple	55	10sec	Storage rots	-	Maxin *et al*[35].,

Table 3: Control of postharvest diseases of fruits by Hot air treatment

Fruit crop	Hot air treatment			Disease	Possible injuries	References
	Temperature (°C)	Duration (Min.)	R. H. (%)			
Apple	55	15s	100	Bitter rot, blue mold rot	Deterioration	Edney and Burchill[15]
Peach	54	15	80	Brown rot , Rhizopus rot	--	Smith *et al*[55].,
Strawberry	43	30	90	Alternaria rot, grey mold rot, Rhizopus rot	---	Smith and Worthington[56]

Chemical Methods

The success of a chemical treatment for disease control depends on the initial spore load, the depth of the infection within the host tissues, the growth rate of the infection, the temperature and humidity and the depth to which the chemical can penetrate the host tissues. Moreover, the applied chemical must not be phototoxic (i.e. it must not cause injury to the host tissues) and must fall within the ambit of the local food additive laws[39]. For controlling postharvest diseases of fruits, fungicides can be applied in different ways as under:

Pre- Harvest Chemical Treatments

In most cases, control of postharvest diseases should start before harvest in the field of orchard itself. The possibility of controlling well-established pathogens by postharvest disinfection is very less since most fungicides are unable to penetrate deeply into the tissues, and effective concentrations of the fungicide would not reach deep-seated infections. Hence, the effective way to reduce infections initiated in the field, including, quiescent infections is the application of broad-spectrum protective fungicides to the fruits on the plant itself. The developing fruits are sprayed to prevent spore germination and subsequent formation of appressoria and infective hyphae, which are quiescent stages of the fungus[52].

Postharvest Chemical Treatments

Injuries to the produce occured during harvesting, handling and packaging, are the major sites of invasion by postharvest wound pathogens, the protection of wounds by chemicals will considerably decrease decay in storage[10]. Other potential sites of infection are the natural openings in the host surface, such as lenticels and stomata, whose sensitivity to infection is increased by wounding or after washing the commodity in water. An efficient disinfection process should reach the pathogenic microorganisms accumulated in all those sites[13]. Different chemicals/fungicides, which are being used to control postharvest decay in developed fruits, are as under (Table 4).

Table 4: Fungicides recommended for the control of postharvest diseases of fruits

Fungicide	Fruit/vegetable	Effect against disease (s)	Rererence (s)
Dicloran	Stone fruits	Soft-watery rot (*Rhizopus stolonifer)*	Ravetto and Ogawa[45]
Thiabendazole & Carbendazim	Sone fruits	Brown rot caused by *Monilinia fructicola*	Eckert[11]
	Apples	Blue mold (*Penicillium expansum*), grey mold (*Botrytis cinerea*) and lenticel rot (*Gloeosporium* spp.)	Eckert[11]
Iprodione	Apple	Penicillium rot	Heaton[19]
	Stone fruits	*Monilinia* and *Rhizopus rots*	Heaton[19]
Imazalil	Apple, pears, persimmon	*Alternaria rot*	Eckert and Ogawa[13]

Methods of Application

There are several methods by which the fungicides can be applied to the fruits for controlling postharvest diseases. These methods include dipping, electrostatic sprays, dusting, fumigation and use of chemical pads described briefly hereunder.

Dipping

In this method, fruits are immersed in water containing an appropriate concentration of a chemical, which is toxic to the disease causing fungi. The produce may be passed below a shower of the diluted chemical, which is called as ‘cascade application’. For improving the effectiveness of dips, additives may be included in the formulation. These include wetting agents (e.g. teepol or Triton-x-100), which reduce the surface tension and allow a better coating of the chemical on the produce, and acids such as citric acid, which lowers the pH of the fungicide and can, make it more effective[39].

Electrostatic sprays

Breaking up the pesticide solution into fine droplets and then giving them an effective electric charge for field sprays. The main advantage of this system is the increased uniformity of application of spraying materials. Similarly, there is no loss of biological activity of the materials with such sprays. The principle on which they work is that all particles have the same electrical charge and thus they repel each other. They are attracted towards crop, and then form a thin even layer/ coat. This method is being used in several fruits in many advanced countries[39].

Fumigation

Fumigation is also considered as an effective method of chemical application in some fruits. It has several promising applications. It can be carried out immediately after harvest to prevent infection of injuries on the fruit to be transported to long distances, degreened before processing or to be held for several days before processing[1].

Chemical pads

Paper pads impregnated with fungicidal chemicals first time were developed to prevent banana infections during transportation. These are also known as crown pads, and are used to prevent the fungal infections on the cut crowns of fruits. The pads are made from several layers of soft paper previously soaked in a fungicide (often thiobendazole) and then dried[6].

Biological Control

In recent years, there has been considerable interest in the use of antagonistic microorganisms for the control of postharvest diseases. The global trend appears to be shifting towards reduced use of fungicides on produce and hence, there is a strong public and scientific desire to seek safer and eco-friendly alternatives for reducing the decay loss in the harvested commodities[32]. Several postharvest diseases can now be controlled by microbial antagonists. The various mechanism(s) most widely accepted by which microbial antagonists suppress the postharvest pathogens is competition for nutrients and space. In addition, production of antibiotics, direct parasitism, and possibly induced resistance in the harvested commodity are other modes of their actions by which they suppress the activity of postharvest pathogens in fruits. Microbial antagonists are applied either pre or post-harvest on produce, but latter applications are more effective than former. Mixed cultures of the microbial antagonists appear to provide better control of postharvest diseases over individual cultures or strains[48]. The postharvest environment provides the following advantages for biological control measures[39].

a) The partially controlled environment in storage may result in a shift in the balance of interactions between host, pathogen, and antagonistic microbe in favour of antagonist
b) The efficacy of antagonist may be enhanced because the biocontrol product can be applied directly onto the site where needed in the harvested product
c) The harvested commodity may be protected relatively free of potential interfering factors

d) Protection is needed for a relatively short period as compared with period of protection required for field crops, and
e) The harvested fruits have high market value, use of a relatively high-cost biocontrol product may be justified.

On the other hand, certain obstacles have to be overcome in the attempts to protect the harvested commodity by using microbial agents:

a) The level of control to be achieved is extremely high (95–98%), since the market value of commodity depends on the blemish-free, attractive appearance.
b) Very strict food safety considerations demand careful examination of products for the possible presence of toxic or unacceptable substances produced by biocontrol agents.
c) The potential market for the use of bioagents against postharvest diseases (bio fungicide) is relatively less as compared to control of soil borne field crop diseases

Microbial Antagonists

Several microbial antagonists have been reported to control postharvest diseases of fruits successfully[48]. For their use, two basic approaches have to be employed. First approach is to promote and manage those antagonistic microbes, which already exist on the fruits itself, and the second approach should be to artificially induce the desirable microbial antagonists against postharvest pathogens. Both these approaches have been discussed briefly hereunder[8]. Many researchers have tried different bio agent for controlling postharvest diseases of temperate fruits (Table 5).

Table 5: Microbial antagonists used for the successful control of postharvest diseases of Temperate fruits

Microbial antagonist	Disease and its causal agent	Fruit	Reference (s)
Bacillus subtilis	Botrytis rot (*Botrytis cinerea*)	Cherry	Utkhede and Sholberg, 1986
Bacillus subtilis	Brown rot (*Lasiodiplodia theobromae*)	Peach, plum & Nectarine	Pusey and Wilson, 1984
Bacillus pumilus	Gray mold (*Botrytis cinerea*)	Pear	Mari et al., 1996
Candida guilliermondii	Gray mold (*Botrytis cinerea*)	Peach & Nectarine	Tian et al., 2002
Candida oleophila	Penicillium rot (*Penicillium expansum*)	Apple	El-Neshawy and Wilson,1997
Candida sake	Penicillium rot (*Penicillium expansum*), grey mold, Rhizopus rot	Apple, Pear	Morales et al., 2008
Cryptococcus laurentii	Bitter rot (*Glomerella cingulata*)	Apple	Blum et al., 2004
	Brown rot (*Monilinia fructicola*)	Cherry	Qin et al., 2006
	Rhizopus rot (*Rhizopus stolonifer*) & gray mold (*Botrytis cinerea*)	Peach	Zhang et al., 2007a
	Gray mold (*Botrytis cinerea*)	Pear	Zhang et al., 2005
Pantoea agglomerans	Penicillium rot (*Penicillium expansum*)	Apple	Morales et al., 2008
Pichia guilliermondii	Blue mold (*Penicillium expansum*) & Gray mold (*Botrytis cinerea*)	Apple	McLaughlin et al., 1990
Pseudomonas cepacia	Blue mold (*P. expansum*) & Gray mold (*Botrytis cinerea*)	Apple , Pear	Janisiewicz and Roitman,1988
	Brown rot (*Monilinia fructicola*)	Peach nectarine	Smilanick et al.,1993
Pseudomonas syringae	Blue mold (*Penicillium expansum*)	Apple	Zhou et al., 2002
	Gray mold (*Botrytis cinerea*)	Apple	Zhou et al., 2001
	Brown rot (*Monilinia laxa*)	Peach	Zhou et al., 1999
Rhodotorula glutinis	Bluemold(*Penicillium expansum*) &	Apple	Zhang et al., 2009
	Blue rot (*Penicillium expansum*) & Gray mold (*Botrytis cinerea*)	Pear	Zhang et al. (2008)

Mode of action of microbial antagonists

There are two reasons to understand about the mode of action of the microbial antagonists (i) it will help us in developing more reliable procedure for better results from the known antagonists, and (ii) it would help in providing more rationale for selecting more effective antagonists. The available information indicates that antibiotic production is the major mode of action of antagonists, which are used for controlling postharvest diseases[24] (Table 6). In addition, nutrient competition, direct parasitism, and possibly induced resistance are other actions of antagonists, which suppress the activity of pathogens in fruits during postharvest handling[16].

Table 6: Mode of actions of microbial antagonists

Fruit crop	Disease	Antagonist	Reference (s)
1. **Antibiotic production**			
Apple	Blue mold	*Pseudomonas cepacia*	Janisiewicz *et al*[23].,
	Mucor rot	*Pseudomonas cepacia*	Janisiewicz and Roitman[22]
Apricot	Brown rot	*Bacillus subtilis*	Pusey *et al*[42].,
Cherry	Brown rot	*Bacillus subtilis*	Utkhede and Sholberg[64]
	Alternaria rot	*Enterobacter aerogenes*	Utkhede and Sholberg[64]
Peach	Brown rot	*Bacillus subtilis*	Pusey *et al*[42].,
Nectarine	Brown rot	*Bacillus subtilis*	Pusey *et al*[42].,
Pear	Blue mold	*Pseudomonas cepacia*	Janisiewicz and Roitman[22]
	Grey mold	*Pseudomonas cepacia*	Janisiewicz and Roitman[22]
Plum	Brown mold	*Bacillus subtilis*	Pusey *et al*[42].,
II. **Nutritional competition (N) and/or Induction of host resistance (HR)**			
Apple	Blue mold	*Pseudomonas cepacia* (HR)	Janisiewicz[21]
	Grey mold	*Aceromonium breve* (HR)	Janisiewicz[21]
	Grey mold	*Debaromyes hansenii* (N+HR)	Wisniewski *et al*[66].,
Peach	Rhizopus rot	*Enterobacter cloacaei* (N)	Wisniewski *et al*[66].,
Strawberry	Gray mold	*Cryptococcus laurentii* (N)	Castoria *et al*[7].,

Resistance approach

Development and use of resistant varieties against pathogens is considered as the most reliable method of disease management. Unfortunately, a little attention has been paid to develop resistant varieties against postharvest pathogens in horticultural crops. In general, those varieties are preferred, which have thin peel, have low tannin content and high sugar content, and unfortunately, all these factors favour susceptibility to postharvest pathogens. Plant breeder needs to recognize the resistance to postharvest diseases, which is different from the field resistance and hence, breeding programme should be developed to use only this type of resistance[39].

Future Perspective

The management of postharvest diseases is a not an easy task and there is intensive need to focus upon by scientists, administrators and policy makers. The future investigations should be focused on, Proper diagnosis and detection of postharvest diseases and pathogens, exploring the possibility and potentiality of use of non-pathogenic or attenuated strains of post-harvest pathogens, Identification of compounds, which when injected into the trunk or sprayed on foliage long before harvest, are translocated to the fruit, making it resistant to infection by postharvest pathogen ,use of biotechnological tools for identification of genes that promote epiphytic antagonists and producing resistant fruits with good quality characters.

CONCLUSION

It is essential to ensure that close coordination, constant surveillance, and efficient technical support for rapid detection and precise identification of microbial pathogens, and feedback on the effectiveness of corrective measures taken to restrict the incidence and subsequent spread of diseases, are available. Avoidance of wounds to the harvested produce is the basic precaution, to be strictly enforced in all cases. Though these methods are nonspecific, they will effectively reduce the chances of infection by microbial pathogens.

The strategies that can directly act on the microbial pathogens may be integrated broadly into four combinations: (1) physical + chemical, (2) physical + biocontrol, (3) biocontrol + chemical, and (4) Resistance + biocontrol + physical + chemical methods. Various strategies for the management of postharvest diseases have been found to be effective to varying levels under wide range of conditions which interact with each other. The possibility of integrating the different effective strategies to achieve higher level of control of postharvest pathogens and to minimize or replace the use of synthetic fungicides has to be explored in certain host–pathogen systems. The usefulness of integrating different strategies to provide better control of diseases and to obtain safe, disease- and residue-free food products is the need of hour.

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