APPLICATION OF ANTAGONISTIC MICROORGANISMS FOR THE CONTROL OF POSTHARVEST DECAYS IN FRUITS AND VEGETABLES

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ABSTRACT

Over the years, synthetic fungicides are primarily used to control postharvest decays of fruits and vegetables because of their effectiveness and low cost. Nevertheless, the health and safety of synthetic fungicides as a biological control agent in delicate foods like fruits and vegetables as well its impact on the natural environment has created legal and consumer concerns. This however, has called for a safer and more environmentally friendly alternative for the control of postharvest decays in fruits and vegetables. The application of antagonistic microorganisms as an alternative to solve the challenges in the control of postharvest diseases in fruits and vegetables is becoming increasingly popular worldwide. The mechanism(s) by which microbial antagonists suppress the postharvest diseases is still unknown, but competition for nutrients and space, production of antibiotics, direct parasitism, and induced resistance are most widely accepted mechanisms of their action. Microbial antagonists are applied either before or after harvest, but postharvest applications are more effective than pre-harvest applications. The new paradigm shift proposed in the biocontrol research includes the integration of low risk chemical fungicides, natural anti-microbial substances, and physical means such as hot water treatment, irradiation with ultraviolet light, microwave, and infrared treatment in the bio-control process; the enhancement in the expression of crucial biocontrol genes and/or combining genes from different biocontrol agents in the mass production, formulation and storage, or in response to exposure and contact with host plant tissue after application; the use of genetically modified organisms as biocontrol agents; and the research towards discovering new antagonists instead of the ones currently used in practice. This review critically assesses the use of wide array of antagonistic microorganisms to control postharvest decays of fruits and vegetables. Particularly, the efficacy of the technology, the effect of the method on the quality of the fruits and vegetables, and the new paradigm shift proposed after 20 years of biocontrol research. The major obstacles that have influenced the commercialization of biocontrol products have also been highlighted.

KEYWORDS: antagonistic microorganisms, fruits and vegetables, postharvest decays.

INTRODUCTION

A Postharvest decay of fruits and vegetables is a major challenge throughout the world. The degree of postharvest loss through decay is well documented. In the industrialized countries, it is estimated that about 20–25% of the harvested fruits and vegetables are decayed by pathogens during postharvest handling (Sharma et al., 2009; Singh and Sharma, 2007; Droby, 2006; Zhu, 2006; El-Ghazouli et al., 2004). The situation is far more exasperating in the developing countries, where postharvest decays are often times over 35%, due to inadequate storage, processing and transportation facilities (Abano and Sam-Amoah, 2009). The use of synthetic fungicides such as benomyl and iprodione to control postharvest diseases of fruits and vegetables are well known in scientific literature (Zhang et al., 2007; Singh and Sharma, 2007; Korsten, 2006; Zhu, 2006; El-Ghazouli et al., 2004; Fan et al., 2000). However, the health and environmental concerns associated with the continuous use of synthetic fungicides have alarmed legal enforcers and consumers to demand green technology and quality products from the food industry as well as the scientific community. This called for a new paradigm shift from the use of synthetic fungicides to a safer and environmentally friendly alternative for reducing the postharvest decay in fruits and vegetables (Mart et al., 2007; Ragsdale & Sisler, 1994). Among the replete of bio-control approaches, the use of the microbial antagonists like yeasts, fungi, and bacteria is quite promising and gaining popularity (Sharma et al., 2009; Zhang et al., 2007; Droby, 2006; Korsten, 2006; Zhang et al., 2005; Janisiewicz & Korsten, 2002; Roberts, 1990; Droby et al., 1991; Wisniewski and Wilson, 1992). The objective of this review was to critically assess the use of microbial antagonists for controlling postharvest diseases of fruits and vegetables with particular focus on their efficacy, the influence of it application on the quality of fruits and vegetables, and the new paradigm shift proposed after 20 years of biocontrol research.

Basic approaches for using the microbial antagonists

Two basic approaches have been reported for using the microbial antagonists against the postharvest diseases of fruits and vegetables (Sharma et al., 2009). These are the use of microorganisms which already exist on the produce itself, which can be promoted and managed, and those that
can be artificially introduced against postharvest pathogens.

**Natural microbial antagonists**

The antagonistic microorganisms that are naturally present on the surfaces of fruits and vegetables, which when after being isolated are used for the control of postharvest diseases are called naturally occurring antagonists (Janisiewicz, 1987; Sobieczewski et al., 1996). Investigation by Chalutz and Wilson (1990) revealed that when the concentrated washings from the surface of citrus fruit were plated out on agar medium, only bacteria and yeast appeared while after dilution of these washings, several rot fungi appeared on the agar, indicating that yeast and bacteria may be suppressing fungal growth. They therefore concluded that washed fruits and vegetables are more predisposed to postharvest decays than the unwashed ones.

**Recent microbial antagonist product development**

A review by Droby et al (2009) has well documented commercial antagonistic microorganisms available in the global market for postharvest control of decays in fruits and vegetable. These are Biosave (Pseudomonas syringae Van Hall), which are registered in the USA and used mostly for the control of sweet potato and potato diseases (Stockwell and Stack, 2007), and “Shemer” (Metschnikovia fructicola Kurtzman & Droby) registered in Israel and used commercially for the control of sweet potato and carrot storage diseases (Kurtzman and Droby, 2001; Blachinsky et al., 2007). The two yeast-based products, AspireTM (Ecogen, US) and Yield Plus (Anchor Yeast, South Africa) developed in the USA and South Africa is no longer available (Droby et al, 2009). Currently, BioNext (Belgium) and Leasaffre International (France) have developed a commercial product, based on the same yeast used in AspireTM, Candida oleophila. A similar yeast-based product, Candida saitoana was developed by Neova Technologies (Abbotsford, British Columbia, Canada). Additionally, Spain has also developed a commercial formulation of Candida sake for use on pome fruit under the name “Candifruit”.

**Characteristic traits of an Ideal microbial antagonist**

Several reviews have provided the good characteristic traits desired in microbial antagonist in the disease controlling process (Droby et al., 2009; Sharma et al., 2009). Wilson and Wsinswieski (1989) recommended a guideline to select an ideal antagonist, which are as follows:

1. Must be stable
2. Should be effective at low concentrations
3. Must not be demanding in terms of required nutrients
4. Must be able to survive under adverse environmental conditions
5. Should be effective against a wide spectrum of commodities and pathogens under different conditions
6. Should be amenable to production on inexpensive growth media
7. Should be amendable to formulations with a long shelf life
8. Should be easy to dispense without being hazardous to human health
9. Must be resistant to chemical used in the postharvest environment
10. Must be environmentally friendly
11. Must be compatible with commercial processing practices.
12. Should not be detrimental to the quality of the fruits and vegetables it preserves.

**Isolation and selection of antagonistic microorganisms**

Isolation of the antagonistic microorganisms is an important step in the bio-control processes of postharvest decays in fruits and vegetables. Since antagonistic microbes are limited in commercial supplies in many part of the world, and the fact that various attempts to develop commercial products produced limited success (Droby et al., 2009), isolation prior to its bio-control activity is very critical. Typically, microorganisms are isolated from the leaves and the natural environment of the fruits and vegetables grown under organic conditions. In some instances antagonistic microorganisms are isolated from soil samples beneath the immediate vicinity of the fruits and vegetables. Zhang et al (2007) isolated antagonistic yeast Cryptococcus. Laurenti (Kufferath) Skinner with nutrient yeast dextrose agar (NYDA) from the surfaces of pears harvested in an unsprayed orchard. In the isolation of the target yeast, 8g nutrient broth, 5g yeast extract, 10g glucose and 20g agar in a litre of distilled water was used and incubated at 28 °C for 20hrs.

In a similar experiment by Zhang et al (2008) the antagonistic Rhodotorula glutinis was isolated from the surfaces of strawberries harvested in an unsprayed orchard and identified by the VITEK 2 Automicrobic system by a France company bioMérieux for the control of blue mold in pears. In another research, Manso and Nunes (2011) isolated epiphytic microorganisms from the surfaces of leaves from pome and citrus fruit picked from different orchards. They also used NYDA in same amount except the agar (15 g) and incubated at 25 °C for 24 hrs. The isolates were purified and maintained at 4±1 °C. In addition, R. glutinis and C. laurentii were isolated from the surface of apple fruit whereas P. membranaefaciens was isolated from the surface of peach (Tian et al., 2004; Xu, Qin and Tian, 2008). In many research, selection of the target microbial antagonist was based on the isolate with greater antagonism in the controlling process at a minimum effective concentration against the target pathogens. To select and develop a successful biocontrol agent, it is essential to evaluate its effectiveness under wide spectrum of pathogens and under different conditions typically used in practice (Manso and Nunes, 2011). The relatively long time used and the expensiveness of the isolation, development, and commercialization of biocontrol agents still remain a challenge (Droby et al., 2009, Blachinksy et al., 2007).

**Pre-harvest and postharvest application of antagonistic microorganisms**

Following the selection of the potential microbial antagonist, the next step is look for an application method effective enough to control or suppress the disease causing pathogens (Sharma et al., 2009). Till date, antagonists are applied either before harvest or after harvest. Many investigators have provided strong evidence that several pathogens infest fruits and vegetables in the field, and
these infestations become critical factors for decays during transportation or storage of the commodities and hence argued that preharvest application(s) of microbial antagonistic culture are often effective to controlling postharvest decays in fruits and vegetables ([Ippolito and Nigro, 2000; Janisiewicz and Korsten, 2002; Ippolito et al., 2004; Irtwange, 2006].) Typically, preharvest application is done to pre-colonize the fruit surface with the antagonistic microbes so that bruses inflicted during harvesting can be colonized by the antagonists before colonization by the pathogens (Ippolito and Nigro, 2000). Reports indicate that this application method could not become commercially viable, because of the poor survival of microbial antagonists in the field conditions. (Sharma et al, 2009). However, successes were chopped in certain cases. For example, (Benbow and Sugar, 1999) reported that a 3-week preharvest application of the antagonists Cryptococcus infirmo-miniatus (Okamuki) Pfaff & Fell, Cryptococcus laurentii, and Rhodopholus glutinis (Fresenius) Harrison, to ‘d Anjou’ and ‘Bosc’ pears was found to reduce gray mold from 7% to nearly 1% and 13% to 4% respectively. In another experiment, Teixido et al. (1999) found Candida sake CPA-1 to reduce blue mold in wounded apples by nearly 50% when they were inoculated with the antagonist 2 days before harvest and storage with Penicillium expansum and cold storage for 4 months.

Preharvest applications with various microbial antagonists like Gliocladium roseum Bainier (Sutton et al., 1997), Trichoderma harzianum (Tronsmo and Denis, 1977; Kovach et al., 2000) and Epicoccum nigrum Link (Larena et al. (2005) have achieved successes in postharvest control of strawberries where synthetic fungicides proved ineffective. The application of secondary metabolite such as pyrrolnitrin produced by Pseudomonas cepacia was reported to achieve the highest levels of postharvest control of diseases (Janisiewicz and Rothman, 1988; Janisiewicz and Korsten, 2002). Additionally, studies by (Karabulut et al., 2003) found that applications close to harvest with Metschnikowia fructicola Kurzman & Droby alone or in combination with ethanol and sodium bicarbonate controlled postharvest decays of grapes significantly over the control. Also, preharvest spray of Metschnikowia fructicola Kurtzman & Droby was found to be effective in controlling preharvest and postharvest fruit rots in strawberry (Karabulut et al., 2004). In a different study, the preharvest application of Aureobasidium pullulans reduced significantly the storage rots in strawberry (Lima et al., 1997), grapes (Schena et al., 1999, 2003), cherries (Wittig et al., 1997; Schena et al., 2003), and apples (Leibinger et al., 1997). There was a related reducing trend of incidence of green mold (Penicillium digitatum) on grapefruit by preharvest spray of Pichia guilliermondii (Droby et al., 1992).

In pear, field application(s) of Cryptococcus laurentii and Candida oleophila was reported to reduced storage rots (Benbow and Sugar, 1999) whereas preharvest applications of Pantoea agglomerans CPA-2 and Epicoccum nigrum were reported to be effective against citrus rots and peach brown rot under laboratory and field conditions respectively (Sharma et al, 2009). Similarly, Canamas et al. (2008) reported that preharvest application of different concentrations of Pantoea agglomerans was effective against Penicillium digitatum during storage of oranges [(Citrus sinensis (L.) Osbeck.] However, this method was seen to have many limitations and commercially applied to avocado (Sharma et al., 2009).

In recent times, a postharvest application of antagonistic microorganisms are common and appears to be better for controlling post harvest diseases of fruits and vegetables. In the application process, the antagonists are sprayed directly onto the surfaces of the fruits and vegetables or are applied by dipping (Sharma et al., 2009; Irtwange, 2006; Barkai-Golan, 2001). Investigations by many authors show that the postharvest application of microbial antagonists for controlling diseases in fruits and vegetables are more effective than the preharvest approach for citrus (Long et al., 2007), apples ( Morales et al., 2008; Zhang et al., 2009; Mikani et al. , 2008), peach (Mandal et al., 2007), banana (Lassois et al., 2008), mango (Keftalew and Ayalew, 2008), tomato (Zhao et al., 2008), and cabbage (Adeline and Sijam, 1999). In strawberries and lemons for example, Pratella and Mari (1993) found that postharvest application of Trichoderma harzianum, Trichoderma viride, Gliocladium roseum and Paecilomyces variotii Bainier resulted in a better control of Botrytis and Alternaria rots respectively than preharvest application(s).

In a related development, postharvest applications of Pseudomonas variotii and Trichoderma harzianum were more effective in controlling Aspergillus and Fusarium rots in lemons and potatoes than their respective dips in iprodion and benomy. A significant reduction in storage decay was reported for microbial antagonist yeast species in direct contact with wounds in the peel of harvested fruits against pathogens such as P. digitatum, P. italicum in citrus (Chalutz and Wilson, 1990); B. cinerea in apples (Gullino et al., 1992; Mercier and Wilson, 1995; Roberts, 1990; Wisniewski et al., 1988), B. cinerea and P. expansum in pears (Chand-Goyal and Spotts, 1996, 1997; Sugar and Spotts, 1999), and B. cinerea, Rhizopus stolonifer and Alternaria alternata in tomatoes (Chalutz et al., 1988). Nevertheless, there were different pathogenic reactions to a given antagonist (Sharma et al, 2009).

Major obstacles in the commercialization of microbial antagonistic products

1. Small number of companies in the development of biocontrol products
2. Lack of financial resources and established market networks
3. Small size of postharvest market and the fact that the microorganism need to control a wide spectrum of pathogens on different fruits and vegetables.
4. The expensiveness and too much time required to register a biocontrol agent
5. The robustness of the registration package in that it must clean safety records for humans and the environment, basic toxicological tests on the formulated products on the eyes, skin and ingestion
6. The complexities surrounding registration of biocontrol agent in some countries. For example Europe
7. The existing health and safety concerns regarding the introduction of antagonists into our diet
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8. The dilemma of cell physiology and metabolism after rehydration

9. Lack of packaging technology that is capable of preventing contamination of the biocontrol agents with high water retention.

10. The lack of standard quality assurance guidelines for determining the acceptability of the products

11. The inability of the biocontrol agents to achieve 95-98% control efficiency as a standalone agent.

12. The skepticism with which agriculturalists view the use of microorganisms to biologically control postharvest diseases in fruits and vegetables.

Efficacy of antagonistic yeast against disease incidence under storage conditions

Many authors have reported the efficacy results against disease incidence in fruit and vegetables. In a study by Zhang et al. (2010a), the application of antagonistic Aureobasidium pullulans PL5 at $10^8$ cells/mL on the postharvest pathogens of peach, apple, and plum reported a 45% disease incidence on M. laxa in plums, 63% on M. laxa in peaches, and 56% and 46% on B. cinerea and P. expansum in apple respectively, under storage conditions of 1.2°C and 95% relative humidity (RH) for 28 days. A combination of R. glutinis and Salicylic acid was also found to prevent fungal spoilage in strawberries, which reduced the incidence of fungal spoilage of the fruit to 6.3% and 6.3% respectively compared to 37% and 46.7% for the untreated controls for fruit stored at 20°C for 3 days or 4°C for 7 d followed by 20°C for 2 days (Zhang et al., 2010b).

In a similar experiment, Zhang et al. (2006) found that at storage condition of 25°C for 6 days for apple, a microwave treatment for 2-3 min combined with yeast antagonist was able to reduce the disease incidence of blue mold in pear from 100% to 20.2% and lesion diameter from 2.81mm to 1.1 mm. Manso and Nunes (2011) used Metschnikowia anaauensis strain NCYC 3728 (PBC-2) to control blue mold Rhizopus stolonifer, P. expansum and B. cinerea, on pears and on different apple cultivars and against Penicillium digitatum and Penicillium italicum on mandarins and oranges observed inhibitory activity of over 75% reduction of disease incidence and severity when the fruits were stored at 20±1°C and 80±5% relative humidity for 7 days. In a related study by Zhang et al. (2009), the application of R. glutinis resulted in low average decay incidence of 28.3% in apples compared with 75% in the control when stored at 20°C for 5 days. In the same experiment, the R. glutinis treated apple fruits stored at 4°C for 30 days followed by 20°C for 4 days recorded a decay incidence of 6.67%, while the control fruit had 58.3% decay incidence. A combination of 46°C hot water treatment and Rhodotorula glutinis was found to control completely the blue mould decay of pears (Hongyn et al., 2008). This combination achieved reduction in decay of 66.7% in the control fruit to 13.3% after 15 days at 20°C, and from 46.7 to 6.7% after 4°C for 60 days followed by 20°C for 15 days on naturally infected and intact fruit respectively. Similarly, a combination of microwave (0.45KW) and C. laurentii ($10^8$ cells/mL) treatment, was capable of reducing percentage of decayed pear fruits to 12.1% (Zhang, Zheng, and Su, 2006).

Antagonistic microorganism’s mechanism in the control of diseases

The mechanism under which antagonistic microorganisms control pathogens in fruits and vegetables is still been researched. Over the years, seven main modes through which the antagonistic microbes fights the disease incidence caused by fungi have been reported (Sharma et al., 2009). The bio-control mechanisms are achieved through space and nutrient competition, production of antibiotics, attachments, population of the microbial antagonists, direct parasitism, and induced resistance. In the case of space, the microbial antagonistic grow more rapidly and survive under unfavorable conditions than the disease causing pathogens. It is reported that biocontrol activity of microbial antagonists increases with antagonistic concentrations, which consequently decrease the concentration of the pathogens (McLaughlin et al., 1990; Zhang et al., 2009). For example, antagonistic Cryptococcus laurentii was effective at a concentration of $10^8$ CFU/ml for controlling Penicillium expansum in peach, and in apple storage for 5 days at 20°C or for 30 days 4°C followed by 20°C for 4 days, Rhodotorula glutinis ($10^8$ / CFU/ml ) was the most effective at controlling the gray mold and blue mold decays in apples (Zhang et al., 2007; 2009). Similarly, Zhang et al. (2010) reported that for Aureobasidium pullulans, a concentration of $10^8$ CFU/ml was better in controlling Monilinia laxa on plums and peaches, Botrytis cinerea and Penicillium expansum on apples.

The second most important mechanism by which antagonistic microbes inhibit the pathogens of fruits and vegetables is through production of antibodies (Sharma et al., 2009). For example, (Gueldner et al., 1988; Pusey, 1989) found the bacterial antagonists such as Bacillus subtilis and Pseudomonas c epacia Burkh to kill pathogens by producing the antibiotic iturin. The antagonism produced by Bacillus Subtilis was reported to be effective against fungal rot in citrus (Singh and Deverall, 1984) and Monilinia fructicola (Winter) Honey in peaches and cherries (Pusey and Wilson, 1984; Ukthedhe and Sholberg, 1986). Additionally, in apples rot, Pseudomonas cepacia inhibited the growth of postharvest pathogens like B. cinerea and P. expansum in the fruits by producing an antibiotic, pyrrolnitrin (Janisiewicz and Roitman, 1988; Janisiewicz et al., 1991), Pseudomonas cepacia was also effective in controlling green mold (Penicillium digitatum) in lemon (Citrus limon L.). In the case of attachment mechanism, there are different research findings relating to their bio-control activity. One group of authors reported that the antagonistic microorganism attaches itself directly to the disease causing pathogens for competition for nutrients. Interaction studies done using components of the Enterobactor cloacae (Jordon) Hormaeche and Edwards, and Rhizopus stolonifer (Ehrenberg: Fries) Lind ( Wisniewski et al, 1989), and Pichia guilliermondii Wickerham, and Penicillium italicum Wehmer (Arras et al, 1998) revealed that direct attachment caused antagonistic yeasts and bacteria to consume more nutrients rapidly than the target pathogens and as a result prevented spore germination and growth of the pathogens (Droby et al, 1989, 1998; Wisniewski et al, 1998). Another group of researchers reported that direct physical attachment does not affect antagonistic activity.
of *Aureobasidium pullulans* (de Bary) Arnaud against *Botrytis cinerea* Pers.: Fries, *Penicillium expansum* Link, *Rhizopus stolonifer*, and *Aspergillus niger* van Tieghem; infecting table grapes (*Vitis vinifera* L.) and *Botrytis cinerea* and *Penicillium expansum* on apple (*Malus domestica Borkh.*) fruit (Castoria et al., 2001). However, they attributed the microbial antagonism to antibiotics.

Studies that support the competition for nutrient as one of the bio-control mechanism in microbial antagonistic is well documented (Hongyn et al., 2007; Grebenisan et al., 2008; Droby et al., 1998). In a postharvest decay study using apple through ion depletion, (Saravanakumar et al., 2008) revealed that antagonistic yeast *Metschnikowia pulcherrima* consumed more nutrients than the disease causing microorganisms like *B. cinerea* and *P. expansum*. As a result of its effectiveness to inhibit postharvest decays, recommendations have been made regarding its potential usage for controlling fruit rots (Kurtzman and Droby, 2001; Grebenisan et al., 2008). When several nutrients were added the biocontrol efficacy of *M. pulcherrima* on gray mold (*Botrytis cinerea*) on apple increased indicating that competition for nutrients plays a significant role in the biocontrol capability of *M. pulcherrima* against *Botrytis cinerea* (Piano et al., 1997).

A similar antagonism was observed for non-pathogenic species of Erwinia, such as, *E. cyripedii* (Hori) Bergey, against various isolates of *Erwinia caratovora* sub sp. *Caratovora* (Jones) Bergey, the pathogens of soft rot of many vegetables like carrot, tomatoes (*Lycopersicon esculentum* L.) and pepper (*Capsicum annuum* L.) (Moline, 1991; Moline et al., 1999). In vitro studies by several authors have confirmed the antagonistic microorganisms’ biocontrol mechanism through rapid nutrients uptake more rapidly than their disease causing counterpart. This enables them to get established quickly and inhibit spore germination of the pathogens at the wound site (Hongyn et al., 2007; Wisniewski et al., 1989; Droby and Chalutz, 1994; Droby et al., 1998). Microbial antagonists was reported to induce disease resistance in harvested avocado (*Persea americana* Mill) fruit by the production of antifungal compounds (Prusky et al., 1994; Yakoby et al., 2001), and accumulation of phytoalexins, like scoparone and scoopoletin in citrus fruit (Rodov et al., 1994; Arras, 1996).

**Application of microbial antagonists on the quality of fruits and vegetables**

As indicated early on, the quality of the fruits and vegetables subjected to antagonistic microbial treatments should be preserved during the process. A Review by Vadivambal and Jayas (2007) indicated that quality includes three principal areas: nutritional value, acceptability, and safety. Good quality is judged by freshness, firmness, expected appearance, colour, flavour, and texture etc. Zhang et al (2009) investigated the effects of *R. glutinis* on postharvest quality parameters of apples and reported no significant differences in mass loss, firmness, total soluble solids (TSS), ascorbic acid (AA), and titratable acidity (TA) when the apple fruits were stored at 20 °C for 5 days or at 4 °C for 30 days followed by 20 °C for 4 days. In pears, no significant differences in quality was observed by Zhang et al (2008) when they studied the effect of combined hot water treatment and antagonistic *R. glutinis* on pears mass loss, fruits firmness, TSS, AA and TA, whether the pears were stored at 20 °C for 15 days or at 4°C for 60 days followed by 20 °C for 15 days. These results were similar to another study by Zhang et al (2008) on peach using antagonistic yeast with salicylic acid on the quality of stored products. They reported no significant reduction in weight loss, fruit firmness, TSS, AA or TA when the peach was stored at 20 °C for 7 days. These quality results are in agreement with a similar study with antagonistic *C. laurentii* (10⁶ cells/mL) under microwave (0.45 kW) treatments for 2-3 min when pears were stored for two months at 2 °C and additional 15 days at 20 °C (Zhang, Zheng, and Su, 2006). Additionally, no significant reduction in the above quality parameters was observed when pears were treated with antagonistic *C. laurentii* after 60 days storage at 2 °C followed by 15 days at 20 °C. This research revealed that not many researchers concern themselves with intrinsic quality attributes after microbial antagonistic treatment. Perhaps, many authors use physical quality indicators to assume the general quality of fruits and vegetables that have undergone bio-antagonism. A lot more research is needed in this direction to re-affirm the existing believe that microbial antagonists do not influence negatively the natural quality of fruits and vegetables.

**A new paradigm shift in the science of microbial antagonistic bio-control**

A review by Droby et al. (2009) provides the biocontrol scientific community with insight regarding the new paradigm shift necessary to effectively control decays in fruits and vegetables. A number of ideas proposed includes: (1) the need to view biological control as a process rather than the control of one organism (2) the need to integrate low risk chemical fungicides, natural antimicrobial substances, and physical means such as hot water, microwave, infrared, and ultrasonic treatment in the bio-control process (3) the use of more efficient DNA-based methods to monitor bio-control agent fate and activity after application (4) the application of proteomics and functional genomics to determine and follow changes in the physiological status of biocontrol agents and the effect of environmental stress, (5) Enhancement in the expression of crucial biocontrol genes and/or combining genes from different biocontrol agents in the mass production, formulation and storage, or in response to exposure and contact with host plant tissue after application (6) the use of genetically modified organisms as biocontrol agents (7) the research towards discovering new antagonists instead of the ones currently used in practices in that only a small portion of the earth microbiota has been identified and characterized.

**CONCLUSION**

The applications of antagonistic microorganisms for the control of preharvest and postharvest control of diseases in fruits and vegetables have been reviewed. It was clear in this review that the use of antagonistic microbes is a promising alternative to synthetic chemicals fungicides. However, the approach has not achieved desired successes because of the dilemma and the complexities surrounding its products development and application in delicately foods like the fruits and vegetables. The efficacy levels typically
achieved is not as high as the synthetic chemical fungicides and requires a new paradigm shift to enhance its biocontrol efficiency, efficacy and consistency. The review revealed that not much research is done on the intrinsic quality attributes of fruits and vegetables after microbial antagonistic treatment. Rather, many authors do not make further attempt to determine the intrinsic quality characteristics but only assume the general quality of fruits and vegetables that have undergone bio-antagonism. A lot more research is needed to make certain the current notion that microbial antagonists do not influence negatively the natural quality of fruits and vegetables.

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