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Alternative management technologies for postharvest disease control: The journey from simplicity to complexity

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ABSTRACT

Finding safe and effective alternatives to synthetic fungicides for reducing postharvest losses of harvested commodities has been a focus of much research over the past three decades. Identifying alternatives that are widely accepted and commercially viable has, however, been a challenge. The search to identify alternative approaches to postharvest disease management must be viewed in relation to a complex regulatory environment, the need to address disease problems in a wide array of commodities and conditions, industry and consumer acceptance, and last but not least, commercial viability. In order for companies to invest in new technologies, they must be able to clearly see both the value of a product and the financial return on their investment. The present review attempts to highlight how the search for alternative postharvest disease management technologies has been a journey from simplicity to complexity. Plant pathologists developing alternative technologies are slowly moving away from the "silver bullet" concept where a single intervention can be used to control a disease to viewing plant disease as a process where multiple interventions may be required at different points in the disease process. Over the past thirty years, alternatives have moved from the simple idea of applying high concentrations of biocontrol agents to a harvested commodity, to using a wide array of other alternatives, and integrating them together into a systems approach based on the multiple decrement or multiple hurdle concept. The ease of sequencing genomes and obtaining related genotypic, transcriptomic, proteomic, and metabolomic information is leading to the development of new commercial technologies where problems are solved "biologically."

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1. Introduction

And so, from hour to hour we ripe and ripe,
And then from hour to hour we rot and rot,
And thereby hangs a tale.
William Shakespeare (As You Like It, Act II, Scene vii)

Finding safe and effective alternatives to synthetic, chemical fungicides for reducing postharvest losses of harvested commodities has been the focus of much research over the past three decades (Table 1). Finding alternatives that are widely accepted and commercially viable has, however, been a challenge. Nevertheless, there is a real imperative to continue this line of research, since regulations on the use of new and existing fungicides are becoming more and more stringent. For example, depending on the commodity, the postharvest use of fungicides is completely prohibited in some European countries or limited to just a few registered chemicals. Even if their use is allowed to some limited degree, many large supermarket chains and wholesale fruit suppliers are setting their own standards for chemical residues and the number of active ingredients allowed to be present on harvested commodities. As detailed by Sanzani et al. (2016), safety concerns about mycotoxins and foodborne pathogens also increase the need to find viable alternatives. Additionally, potential restrictions on the use of some fungicides used before harvest could also result in increased levels of inoculum of postharvest pathogens and the number of latent infections that are established.

The search to identify alternative approaches to postharvest disease management must be viewed in relation to a complex regulatory environment, the need to address disease problems in a wide array of commodities and conditions, industry and consumer

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Table 1
Alternative management technologies for postharvest disease control.[a]

Treatment	Fruit host	Target pathogen	Reference
Biological Control			
Yeast antagonist			
Candida oleophila	Apple	*Penicillium expansum, Botrytis cinerea*	Mercier and Wilson (1995), Liu et al. (2012b)
Candida sake	Apple, Grape	*P. expansum, B. cinerea*	Morales et al. (2008), Cañamás et al. (2011)
Metschnikowia fructicola	Grapefruit, Apple	*Penicillium digitatum, P. expansum*	Hershkovitz et al. (2013), Liu et al. (2011)
Cryptococcus albidus	Apple	*P. expansum, B. cinerea*	Fan and Tian (2001)
Cryptococcus laurentii	Strawberry	*B. cinerea*	Wei et al. (2014)
Pichia anomala	Banana	*Colletotrichum musae, Fusarium moniliforme*	Lassois et al. (2008)
Pichia guilliermondii	Apple, Kiwifruit	*B. cinerea*	Wisniewski et al. (1991), Sui and Liu (2014)
Aureobasidium pullulans (yeast-like fungus)	Peach, Apple, Plum	*Monilinia laxa, P. expansum, B. cinerea, Colletotrichum acutatum*	Zhang et al. (2010), Mari et al. (2012)
Bacterial antagonist			
Pantoea agglomerans	Apple	*P. expansum*	Morales et al. (2008)
Bacillus subtilis	Tomato	*Rhizopus stolonifer*	Ma et al. (2015)
Pseudomonas syringae	Banana	*Fusarium pallidoroseum, F. proliferatum*	Williamson et al. (2008)
Bacillus amyloliquefaciens	Citrus	*Penicillium italicum, P. digitatum*	Hao et al. (2011)
Physical Treatments			
Heat			
Hot water dipping	Peach Apple	*Monilia fructicola, M. laxa, P. expansum*	Liu et al. (2012a), Spadoni et al. (2014, 2015)
Hot water rinsing	Apple	*Neofabraea alba*	Maxin et al. (2012)
Hot water brushing	Grapefruit	*P. digitatum*	Pavoncello et al. (2001)
Hot air treatment	Sweet cherry	*P. expansum*	Wang et al. (2015)
Vapor heat treatment	Table grape	*B. cinerea*	Lydakis and Aked (2003)
UV-C			
	Tomato	*Rhizopus stolonifer, B. cinerea*	Stevens et al. (2004), Charles et al. (2009)
	Papaya	*Colletotrichum gloeosporioides*	Cia et al. (2007)
	Melon	*Fusarium oxysporum, Alternaria alternata*	Huang et al. (2015)
Modified Atmosphere			
	Sweet cherry	*M. fructicola*	Spotts et al. (2002)
	Peach	*P. expansum, B. cinerea*	Karabulut and Baykal (2004)
	Apple	*P. expansum*	Conway et al. (2007), Janisiewicz et al. (2008a,b)
Ozone Treatment			
	Table grape	*B. cinerea*	Milkota Gabler et al. (2010a,b)
	Longan	Naturally occurring decay	Whangchai et al. (2006), Whangchai et al. (2010), Boonkorn et al. (2012)
	Tangerine	*P. digitatum*	
Natural Compounds			
Chitosan			
	Tomato	*P. expansum, B. cinerea*	Liu et al. (2007)
	Table grape	*B. cinerea*	Romanazzi et al. (2007)
	Strawberry	*B. cinerea*	Feliziani et al. (2015)
Oligochitosan			
	Jujube	*M. fructicola, A. alternata*	Yan et al. (2012)
	Apple	*M. fructicola*	Yang et al. (2010)
	Orange	*C. gloeosporioides*	Deng et al. (2015)
Salts			
Potassium sorbate Sodium bicarbonate (SBC) potassium phosphite	Lemon	*P. digitatum, P. italicum, Lasiodiplodia theobromae, Geotrichum citri-aurantii*	Cerioni et al. (2013)
Sodium carbonate (SC) Potassium bicarbonate Potassium carbonate Potassium sorbate Calcium chloride Calcium chelate	Citrus	Naturally occurring decay	Youssef et al. (2012)
Potassium sorbate	Citrus	*P. digitatum, P. italicum*	Montesinos-Herrero and Palou (2016)
Sodium ethylparaben	Citrus	*P. digitatum, P. italicum*	Moscoso-Ramírez et al. (2013)
SC/SBC	Citrus	*P. digitatum*	Usall et al. (2008)
Calcium chloride	Apple	*Monilinia fructigena*	Holb et al. (2012)
Sodium selenate	Tomato	*B. cinerea*	Zhu et al. (2016)