Stewart Postharvest Review
An international journal for reviews in postharvest biology and technology

Alternatives to conventional fungicides for the control of citrus postharvest green and blue moulds

Lluís Palou,[1*] Joseph L Smilanick[2] and Samir Droby[3]
[1]Centre de Tecnologia Postcollita, Institut Valencià d'Investigacions Agràries (IVIA), Apartat Oficial, Montcada, València, Spain
[2]USDA-ARS San Joaquin Valley Agricultural Sciences Center, 9611 South Riverbend Avenue, Parlier, CA, USA
[3]Department of Postharvest Science of Fresh Produce, Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel

Abstract

Purpose of review: This article reviews research based on the evaluation of postharvest control methods alternative to conventional chemical fungicides for the control of citrus green and blue moulds, caused by the pathogens *Penicillium digitatum* and *P. italicum*, respectively. Emphasis is given to advances developed during the last few years. Potential benefits, disadvantages and commercial feasibility of the application of these methods are discussed.

Findings: Substantial progress has been accomplished in selecting and characterising new effective physical, chemical and biological control methods. However, their widespread commercial implementation relies, in general, on the integration of different treatments of the same or different nature in a multifaceted approach. For satisfactory penicillium decay control, this postharvest approach should be part of an integrated disease management (IDM) programme in which preharvest and harvest factors are also considered.

Limitations: The lack of either curative or preventive activity, low persistence, high variability, inconsistency or excessive specificity are general limitations associated with the use of alternatives to synthetic fungicides as stand-alone treatments. Furthermore, the risk of adverse effects on fruit quality, technological problems for cost-effective application, or the availability of new conventional fungicides for traditional markets are additional reasons that may hinder the broad commercial use of such treatments.

Directions for future research: As we learn more about the fundamental basis underlying host-pathogen interactions and how they are influenced by direct or indirect protective effects of existing or new single alternative treatments, more effective methods of applying and combining complementary approaches for additive or synergistic effects will emerge. Research should provide appropriate tools to tailor the application of these nonpolluting postharvest control systems and, further, the complete IDM strategy for each specific situation (ie, citrus species and cultivar, climatic and seasonal conditions, destination market, etc).

Keywords: *Penicillium digitatum*; *P. italicum*; physical control; low-toxicity chemical control; biocontrol; integrated disease management

***Correspondence to:** Dr Lluís Palou, Centre de Tecnologia Postcollita, Institut Valencià d'Investigacions Agràries (IVIA), Apartat Oficial, 46113 Montcada, València, Spain. Tel.: (+34) 963424000; Fax: (+34) 963424001; email: lluis.palou@ivia.es

Stewart Postharvest Review 2008, 2:2

doi: 10.2212/spr.2008.2.2

Online ISSN:1945-9656
www.stewartpostharvest.com

Abbreviations

AZX	Azoxystrobin
CA	Controlled Atmosphere
FLU	Fludioxonil
GRAS	Generally Regarded as Safe
IDM	Integrated Disease Management
IZ	Imazalil
PS	Potassium Sorbate
RH	Relative Humidity
SB	Sodium Benzoate
SBC	Sodium Bicarbonate
SC	Sodium Carbonate
SOPP	Sodium ortho-phenyl phenate
TBZ	Thiabendazole
UV-C	Far Ultraviolet Radiation

Introduction

Green and blue moulds, caused by *Penicillium digitatum* (Pers.:Fr.) Sacc. and *Penicillium italicum* Wehmer, respectively, are the most economically important postharvest diseases of citrus in all production areas that like Spain, California or Israel, are characterised by low summer rainfall [1*]. Actual losses due to these diseases are quite variable and depend on the area of production, citrus variety, tree age and condition, weather conditions during the growing and harvest season, the extent of physical injury to the fruit during harvest and subsequent handling, the effectiveness of antifungal treatments, and postharvest environment. Both *P. digitatum* and *P. italicum* are strict wound pathogens that can infect the fruit in the grove, the packinghouse, and during distribution and marketing. They reproduce very rapidly, and their spores are ubiquitous in the atmosphere and on fruit surfaces and are readily disseminated by air currents. Therefore, the source of fungal inoculum in citrus groves and packinghouses is practically continuous during the season. The surface of virtually every citrus fruit that arrives at the packinghouse is contaminated with conidia and the inoculum may build up to high levels if appropriate packinghouse sanitation measures are not adopted [2]. Furthermore, citrus fruit can become "soiled" with conidia of the two fungi that are loosened in handling of diseased fruit. The conidia situated in injuries that rupture oil glands or penetrate into the albedo of the peel usually bring irreversible infection within 48 h at 20–25ºC [1*, 3]. The germination of conidia of both *Penicillium* species inside rind wounds requires free water and nutrients [4, 5], and is stimulated by volatiles emitted from the host tissue [6, 7]. Disease development is mediated by complex interactions between pathogen virulence mechanisms and host defence responses. Extensive research work is being conducted to analyse and understand such interactions at either the biochemical or molecular level [8*–16].

Worldwide, both diseases have been primarily controlled for many years by the application of conventional fungicides such as imazalil (IZ), sodium ortho-phenyl phenate (SOPP), thiabendazole (TBZ) or different mixtures of these compounds. Currently, new active ingredients such as fludioxonil (FLU), pyrimethanil, azoxystrobin (AZX) and trifloxystrobin, most of which are classified by the United States Environmental Protection Agency as "reduced-risk" fungicides, have been extensively assayed in Europe or the USA [2, 17–23]. Postharvest treatments with these synthetic chemicals are typically relatively inexpensive, easy to apply, have curative action against pre-existing or established infections and persistent preventive action against potential new infections that can occur after their application in the packinghouse, and many also inhibit the sporulation from lesions on decaying fruit that reduces airborne inoculum production to break infection cycles. Among fruits treated with conventional fungicides, losses are typically 2–4%, while without postharvest treatment or refrigeration, losses of 15–30% occur within 1–3 weeks after harvest [24, 25**]. However, concerns about environmental contamination and human health risks associated with fungicide residues periodically led to regulatory reviews and potential restrictions or cancellations. Likewise, traditional citrus export markets are increasingly demanding products with lower levels of pesticides in order to satisfy the safety demands from the general public. In addition, new higher-value markets based on organically grown, sustainable, environmentally friendly, ecological or green agricultural produce are currently arising and becoming more popular. Furthermore, the widespread and continuous use of these synthetic compounds has led to the proliferation of resistant biotypes of both *P. digitatum* and *P. italicum* and the build-up of single, double and even triple-resistant isolates in the population of the pathogens in commercial packinghouses seriously compromises the effectiveness of these treatments [26–29]. There is, therefore, a clear and increasing need to find and implement control methods alternative to conventional fungicides for the control of postharvest green and blue moulds of citrus fruit. If conventional chemicals are not used, the goal is to accomplish satisfactory decay control by adopting integrated disease management (IDM) programmes [30, 31*]. The purpose of such strategy, based on the knowledge of pathogen biology and epidemiology and the consideration of all preharvest, harvest and postharvest factors that may influence disease incidence, is to minimise decay losses with no adverse effects on fruit quality by taking cost-effective action on every one of those factors at the right moment. Besides preharvest, harvest and transport considerations, attention should be devoted during the postharvest phase to three basic aspects when establishing a penicillium decay control programme: effective fruit and packinghouse sanitation to reduce atmospheric and superficial inoculum levels of *P. digitatum* and *P. italicum*; appropriate practices during handling and storage to maintain fruit resistance to infection; and adoption of suitable nonpolluting antifungal treatments to replace the use of conventional fungicides [1*, 25**]. According to their nature, these alternative decay control methods can be physical, chemical or biological. The purpose of this article is to review significant research work, giving emphasis to that published during the last few years, in which the most important of these control methods have been evaluated for the control of citrus postharvest green and blue moulds, either alone or in combination with other treatments. Potential benefits, disadvantages and commercial feasibility of the application of these methods are discussed.

Physical control methods

Major benefits from the use of physical treatments for fungal control are doubtlessly the total absence of residues on/in the treated produce and minimal environmental impact. General disadvantages, however, include limited and variable efficacy and lack of preventive activity and persistence. Nevertheless, it has been observed that the application of heat, far ultraviolet radiation (UV-C) or other physical treatments may, under certain conditions, initiate some defence mechanisms in citrus fruit tissues. Cold storage and controlled atmospheres (CAs) are complementary physical tools to reduce or inhibit the development of the pathogens and maintain fruit resistance to infection.

Heat treatments: curing and hot water

Typical procedures for thermal curing treatment of citrus employ exposure of fruit for 2–3 days to an air atmosphere heated to temperatures higher than 30ºC at high relative humidity ([RH] > 90%). Since it was first reported by Hopkins and Loucks in 1948 [32], numerous studies demonstrated the elevated curative activity of curing treatments against green mould in a variety of citrus species and cultivars [33–37*, 38*, 39*]. Control of blue mould, however, was less satisfactory when fruit were cold-stored for long periods after treatment [34]. In spite of their good efficacy, commercial implementation of curing treatments for citrus decay control is rare, firstly because of the expense of heating and immobilising large amounts of fruit for relatively long periods and, secondly, because excessive or uncontrolled treatments may harm fruit quality [40, 41]. Fruit weight loss and heat phytotoxicity are major potential risks whose incidence depend not only on treatment conditions but also on the type of fruit and their initial condition. In fact, only early season citrus fruit from Florida, Brazil or other high rainfall areas are nowadays commercially cured because these fruit are degreened with ethylene at temperatures of about 30ºC. Besides combination with other control methods, which will be discussed later in this review, new technological approaches for curing treatment include intermittent curing (two 18-h cycles at 38ºC) [42], curing at higher temperatures for reduced periods of time (18 h at 40ºC) [43] or, in the case of low rainfall areas where early season mandarins are degreened with 5–10 µL/L ethylene at about 20ºC for 2–3 days, the integration of curing treatment in the degreening process [44*]. On the other hand, it has been recently determined that exposure to hot air at 50ºC and RH higher than 75% for 1 day effectively killed spores of *P. digitatum* and could be a good sanitation practice for empty storage rooms [45].

Treatments with hot water are a technology easier, cheaper, and more feasible for heat application than curing. Relatively brief immersions (2–5 min) in water at 45–55ºC have repeatedly shown value in reducing citrus green and blue moulds [35, 46–52*, 53*]. Likewise, good results have been obtained with packingline machinery where hot water at 55–65ºC is applied for 10–30 s over rotating brushes [54–56*]. However, commercial application of hot water as a stand-alone treatment for citrus decay control is limited to small fruit like kumquat, whose peel is also eaten, or some organically-grown fruit [57*]. This is primarily because hot water treatments are not fungicidal or very persistent, the range of effective yet non-phytotoxic temperatures is very narrow, and the effectiveness is greatly dependent on type, age, and physical and physiological condition of the fruit [51, 52*, 58].

The mode of action of heat can be direct on the pathogen by inhibiting spore germination or mycelial growth of *P. digitatum* or *P. italicum* or indirect on the host by inducing different mechanisms of resistance in the rind wounds such as melting of peel waxes, maintenance of the activity of preformed antifungal compounds, and biosynthesis of lignin-like materials, phytoalexins, pathogenesis-related proteins or heat shock proteins [8*, 57*, 59, 60*, 61**, 62**].

Irradiation treatments: UV-C and ionising radiation

Exposure to low doses (0.5–8 kJ/m^2) of UV-C (wavelength from 100 to 280 nm) has significantly reduced the incidence of green or blue moulds in different citrus species and cultivars, although the effectiveness of the treatment and the risk of phytotoxicity varied with irradiation dose and duration, fruit type and maturity, and fruit harvest season and storage conditions [39*, 63–65*, 66*]. Despite the direct germicidal effects of illumination with UV-C at 254 nm on conidia and mycelia of both *P. digitatum* and *P. italicum* [67, 68], the prevalent mode of action of this treatment for penicillium control in citrus fruit is the stimulation of beneficial responses in the host when applied at sublethal doses (hormesis). Responses to UV-C caused, in many ways similar to heat treatment, induction in rind tissues of resistance to fungal infection. Some of these fruit defensive reactions have been identified: alteration of the levels of preformed antifungal flavonoids such as some polymethoxyflavones or flavonones [69], accumulation of pathogenesis-related proteins such as chitinase or β-1,3-endoglucanase [8*, 70], or induction of the activity of enzymes such as phenylalanine ammonia lyase or peroxidase that are related to the activation of plant defence mechanisms such as the biosynthesis of phytoalexins [65*, 66*, 71*]. Although an on-line UV-C apparatus to treat harvested fresh fruit was developed [72] and currently there is increasing commercial interest to design suitable prototypes for either intact or fresh-cut produce, a number of issues will have to be addressed before realising the practical implementation of UV-C systems in citrus packinghouses. Illumination devices should be appropriately integrated in the packinglines to provide continuous effective treatment of the entire area of the fruit rapidly enough for commercial purposes. At the same time, the system should be flexible enough to change treatment conditions as a function of particular fruit attributes and destination. Currently, considerable attention is on pulsed light (synonyms: pulsed UV light, pulsed white light), which use short time pulses of intense broad spectrum, rich in UV-C light, and is claimed as an improved technology compared with classic continuous-wave UV-C light delivering [73*]. To our knowledge, however, this technique has not been specifically tested against citrus penicillium moulds. In any case, besides scaling-up efficacy trials, additional research on the effects of UV-C on fruit physiology, sensory quality and consumer acceptance is also needed before attempting to use this technology at a commercial scale.

Ionising radiation of fresh fruits and vegetables is not permitted at doses exceeding 1,000 Gy (100 krad) [74] and can be performed with radioactive (^{60}Co or ^{137}Cs, γ-rays) or machine sources (electron beams and X-rays). Conidia of both *P. digitatum* and *P. italicum* were found in early research to be highly sensitive to γ-irradiation [75*, 76], but effective control of their established infections on oranges or lemons required irradiation doses higher than 1,000 Gy and, in general, such doses induced apparent rind injury [77–79*]. It is primarily for this reason that ionising radiation as a single treatment for decay suppression cannot be commercially adopted, despite the fact that some beneficial effects have been associated with radiation exposure, including: high penetration power, stimulation of the synthesis of bioactive or functional phenolic components including different antifungal compounds, and extension of shelf-life by delaying ripening and senescence [79*–81].

Complementary physical methods

In general, conventional cold storage or storage in controlled or modified atmospheres can be considered as complementary physical tools for postharvest decay control of fresh fruits and vegetables. These systems cannot be used as stand-alone antifungal treatments because typically they only provide fungistatic activity by inhibiting or delaying the growth and development of the pathogens. In addition, they considerably reduce the metabolic activity of the host, delay its senescence, and therefore contribute to the maintenance of fruit resistance to fungal infection.

The optimal growth temperature for both *P. digitatum* and *P. italicum* is 24ºC. Green mould is predominant at ambient temperatures, but blue mould becomes more important when citrus fruit are cold-stored for long periods because *P. italicum* grows faster than *P. digitatum* below 10ºC [82]. However, the development of both pathogens is greatly suppressed at typical orange or mandarin storage temperatures of 3–5ºC. Citrus cold storage in conventional CA (5–10% O_2 + 0–5% CO_2 for oranges and mandarins and 5–10% O_2 + 0–10% CO_2 for lemons, limes and grapefruits) [83] has not been generally adopted because potential benefits do not compensate the high installation and maintenance costs. Results of early research are contradictory and both positive [84] and negative [85, 86] effects of CA on the incidence of postharvest decay have been reported. Other technological options involving CA such as modified atmosphere packaging, storage in either carbon monoxide CA (5% O_2 + 5–10% CO) [83], low-pressure (hypobaric) CA [87*], or ethylene removal from storage rooms [88, 89] may have beneficial effects on decay suppression, but they are not economically viable for fresh citrus fruit.

Storage in ozonated atmospheres and general ozone applications for sanitation and control of postharvest diseases of fresh fruits and vegetables have been recently reviewed [90*]. Ozone (O_3) is a highly reactive, potent biocide that has recently received regulatory approval for many food contact applications. It is a residue-free effective sanitiser, but its efficacy in controlling postharvest diseases cannot be predicted by its toxicity against free fungal spores and hyphae. Continuous or intermittent exposure to ozone gas at non-phytotoxic concentrations of 0.3–1.0 µL/L does not control infection of fruit by *P. digitatum* and *P. italicum* in wounds and consequently does not reduce final disease incidence after storage. Gaseous ozone, however, inhibits aerial mycelial growth and sporulation of these fungi, which can help to reduce the proliferation of fungicide-resistant strains of the pathogens [91]. Nevertheless, these effects are transitory and limited to infected citrus fruit stored in highly vented packages or open-top containers that allow direct contact with the gas [92, 93]. Ozone, like other strong oxidant sanitisers such as hypochlorite or chlorine dioxide, readily kills free *Penicillium* conidia when they are immersed in ozonated water, but it fails to control infections in wounds already established in citrus fruit [90*, 94]. Like all oxidising agents, ozone can harm humans if there is exposure to high concentrations for a sufficient duration. Therefore, issues related to the safety of workers and personnel must be addressed before the installation of ozone in air or water application systems in fresh citrus packinghouses.

Chemical control methods

Chemical alternatives to conventional fungicides for postharvest disease control should be natural or synthetic compounds with known and minimal toxicological effects on mammals and the environment. The origin of these alternatives includes classifications such as food additives and substances listed as GRAS (Generally Regarded as Safe) by the United States Food and Drug Administration, natural compounds obtained from plants, animals or microorganisms including some volatiles and essential oils, phenolic compounds, plant extracts, peptides, alkaloids, lectins, antibiotics, propolis, latex or chitosan [95**, 96*], and other chemicals such as calcium polysulfide or ammonium molybdate.

Food additives and GRAS compounds

In California for over 75 years, the standard method of cleaning oranges or lemons was to soak fruit for 2–4 min in a heated (43°C) solution of 4% borax (sodium tetraborate decahydrate) and 2% boric acid or 3% sodium carbonate (SC) within a day or two after harvest [97–99]. Soap or a detergent was usually added and the fruit were rinsed with a fresh water spray to remove salt residues from the surface. The borax bath treatment was abandoned because of residue issues and disposal of rinse water containing boron. SC (soda ash,

Na_2CO_3) or sodium bicarbonate (SBC, baking soda, $NaHCO_3$) treatments remain in common use to today because they are effective and inexpensive food additives allowed with no restrictions for many applications including organic agriculture [100–102**]. While they can also be applied effectively through high-pressure washer nozzles [103], low-volume spray applications over rotating brushes are avoided because their efficacy is lower and calcium carbonate scale accumulates on the brushes. Although their effectiveness is lower in mandarins than lemons or oranges, good control of penicillium moulds and fair control of sour rot, caused by *Geotrichum citri-aurantii*, is obtained with these treatments, especially if heated solutions and prolonged immersion times are used [51, 52*, 101, 102**, 104, 105]. The mechanism of action of carbonate salts against penicillium decay is unclear. It appears to be due in part to the presence of an alkaline residue in wounds [3, 106, 107], although equimolar solutions of the same pH prepared from SC or SBC were more effective than those prepared from potassium or ammonium salts, which suggested that the sodium cation and other factors may be important [102**]. In contrast, it was found in other work [108] that the effectiveness of potassium bicarbonate against green mould was equivalent to that of SBC at the same concentration.

Besides carbonates, other common food preservatives have been evaluated for the control of citrus green or blue moulds. Some short-chain organic acids such as formic, acetic or propionic acid have been assayed as fumigants [109–111*] and some organic acid salts such as sodium propionate, sodium benzoate (SB) or potassium sorbate (PS) have been applied as aqueous solutions [112, 113**]. Among more than forty food additives and low-toxicity chemicals tested, PS and SB were the most effective on oranges and lemons [113**]. They were about equal in activity to each other and to SC. PS ($C_6H_7O_2K$) was firstly evaluated against fungicide-resistant strains of *Penicillium* spp. [114, 115] and it has been applied to citrus fruit in commercial packinghouses to control decay, although its use for this purpose is rare and some regulatory approvals may not be current [116*]. Immersion of fruit in heated solutions is the most effective method of application [116*–118]. Advantages of PS are that *P. digitatum* and *P. italicum* developed little or no tolerance after prolonged and repeated exposure to it [119] and that disposal of used solutions would have fewer regulatory issues than the sodium salts SC or SBC [116*].

In general, handicaps associated with the use of GRAS salt solutions include lack of preventive activity, limited persistence [51, 52*, 102**, 113**, 116*, 118], risk of fruit injury or weight and firmness losses during long-term storage if treated fruit have not been rinsed, reduction of treatment effectiveness by high-pressure water washing or rinsing, and disposal issues associated with high pH and sodium or potassium content [102**, 120*, 121]. Moreover, chlorine (200 µg/mL) should be added and maintained to kill conidia of *Penicillium* spp. in the solutions and on fruit surface [102**, 122]. Some of these problems could be solved by the development of new technologies such as the incorporation of antifungal GRAS compounds as ingredients of new edible coatings or synthetic waxes.

Natural compounds

Volatiles and essential oils

A large variety of volatile compounds with antifungal activity have been isolated from plants: acetaldehyde, benzaldehyde, benzyl alcohol, ethanol, methyl salicylate, ethyl benzoate, ethyl formate, hexanal, (E)-2-hexenal, lipoxygenases, jasmonates, allicin, glucosinolates and isothiocyanates, etc [123]. Among them, jasmonates [124*] and some aroma components like acetaldehyde, benzaldehyde, ethanol, ethyl formate, nerolidol and 2-nonanone [100, 125*, 126] have been specifically tested against *P. digitatum* or *P. italicum*. A method based on the use of allyl-isothiocyanate on citrus fruit has been patented in Japan [127].

Aromatic plants, such as citrus, produce essential oils that basically contain volatile C_{10} and C_{15} terpenes derived from isoprene units. Caccioni *et al.* [128*] stated that citral was the most potent monoterpene in citrus essential oils, although its two isomers geranial and neral were similarly toxic [129]. Citral has been described as a preformed antifungal component in the flavedo of citrus fruit associated with a first line of resistance to infection by *P. digitatum* [130, 131*]. Other constitutive components present in oil glands are phenolic compounds such as flavanones (eg, nariturin, didymine, hesperidin), polymethoxylated flavones (eg, nobiletin, tangeretin, sinensetin) or *p*-coumaric acid (a precursor of coumarins) [132, 133**]. A second line of defence would include the synthesis of phytoalexins (mainly coumarins such as scoparone, scopoletin, scopolin) in the fruit rind as a response to fungal challenge. Stress triggered by certain physical, chemical or biological postharvest treatments can induce the retention or biosynthesis of both preformed and induced volatile antifungal compounds with subsequent maintenance or induction of fruit resistance to disease [60*, 66*, 69, 71*, 133**–135]. Products to control green or blue moulds with components of essential oil from citrus peel as active ingredients have been described. The efficacy of citral against *P. digitatum* and *P. italicum in vitro* depended on the method of application [136], but exogenous application *in vivo* was phytotoxic and not promising [130]. Angioni *et al.* [137*] isolated 7-geranoxy coumarin from grapefruit peel, a phenolic compound that effectively reduced decay and was not phytotoxic. Recently, a product containing essential oils and limonene hydroperoxides from citrus flavedo was developed that controlled green mould after either natural or artificial inoculation with *P. digitatum* [138].

Inhibitory activity of essential oils from plants other than citrus against *P. digitatum* and *P. italicum* has also been reported. Compounds from species of thyme, oregano, cinnamon, clove, dictamus or mint were very effective *in vitro*, but results from *in vivo* experiments were contradictory and applications to citrus fruit were often ineffective or phytotoxic [139–143*, 144*, 145**, 146*]. In fact, despite their potent antifungal activity, commercial implementation of treatments with essential oils is strongly restricted in citrus because of problems related to potential phytotoxicity, intense sensory attributes or technological application as fumigants or in aqueous solutions. The mode of action of essential oils on *P. digitatum* and *P. italicum* and other fungi has not been determined, and many aspects of essential oil toxicity remain unresolved [138]. It has been shown that their antimicrobial activity is dependent on their hydrophobicity and partition in microbial membranes [147]. Compounds with saturated carbonyl groups had less antifungal activity than their corresponding alcohols [138].

Plant extracts

Strictly, most of the volatiles, essential oils or phenolic compounds that have been mentioned are included in this section because they are active phytochemical components that can be isolated from certain extracts of plant tissues. Powders, gels and aqueous or organic solvent extracts of plants from different origins are reported to have activity against *P. digitatum* or *P. italicum* under different experimental conditions. These plants include *Aloe vera* [148], garlic [149], Huamuchil [150], *Thymus* sp., *Eucaliptus* sp., *Cistus* sp., *Juglans* sp., *Myrtus* sp. [146*], *Acacia* sp., *Whitania* sp. [151*] and a variety of weeds from Jordania [152].

Peptides and proteins

Plants and animals produce a variety of peptides and small proteins with antimicrobial activity that are presumed to be part of constitutive or inducible defence mechanisms against fungal infection [153, 154]. Their mechanism of action is presumed to involve the interaction of the amphipathic cationic peptide with the target cell membrane, followed by membrane disruption [155]. Several peptides from different origins have been identified, characterised and tested for activity against *P. digitatum* or *P. italicum*, and some have shown promise for the control of the diseases caused by these fungi [156–159*, 160**]. These researchers identified PAF26, a tryptophan-rich, cationic hexapeptide, which moderately controlled penicillium decay even caused by fungicide-resistant strains of the pathogens. Strategies envisioned to be feasible employ peptide synthesis by transgenic plants, either to protect the plant or to economically produce the peptides, since at present the high cost of synthetic peptides is a barrier to their practical application. Some new peptides derivatives of PAF26 with broader spectrum activity have also been recently obtained [161].

Chitosan and derivatives

Chitin is a primary constituent of crustacean shells, insect cuticles and fungal cell walls [162]. Chitosan, its deacetylated soluble form, has wide antifungal properties and, at low concentrations, can elicit defensive responses in fresh fruit against phytopathogenic fungi. Chitosan and its derivatives such as glycolchitosan can be used in solution, powder form or as wettable coatings [96*]. Antifungal activity against *P. digitatum* or *P. italicum*, *in vivo* significant reduction of citrus penicillium decay, and fruit senescence retardation during long-term cold storage of different citrus species and cultivars have been observed after application of certain chitosan formulations [163–166*].

Other chemicals

Liquid lime sulphur solution, an inexpensive and widely available fungicide that contains calcium polysulfide, is often used by organic growers on many crops before harvest. As a postharvest treatment, it was approved for use on citrus fruit in California and Arizona because, if heated, it is equal or superior in effectiveness to SCs for the control of green mould and sour rot. However, it has not become popular because of the objectionable sulphide odour it emits and its corrosiveness to some packinghouse equipment [104]. The fertiliser ammonium molybdate [113**] and the inducer of disease resistance β-aminobutyric acid [167*] have also shown activity against citrus penicillium moulds. Schirra *et al.* [168] developed a new effective postharvest antifungal product by complexation of IZ with beta-cyclodextrin. On the other hand, it has been repeatedly observed that fumigation with the ethylene inhibitor 1-methylcyclopropene to prolong postharvest life of stored citrus fruit increased the incidence of postharvest decay [13, 169, 170].

Biological control methods

In this review, this category will be restricted to the utilisation of microbial antagonists. Substantial progress has been made in developing antagonistic microorganisms for the control of postharvest diseases [171–175*, 176*, 177**]. During the last two decades, numerous strains of yeasts (eg, *Candida oleophila* [178**–180], *Candida guilliermondii* (syn.: *Pichia guilliermondii*, *Debaryomyces hansenii*) [181–185**], *Candida saitoana* [163, 186*, 187*], *Candida famata* [188*, 189], *Metschnikowia fructicola* [190*, 191], *Metschnikowia mulcherrima* [192*], *Rhodotorula glutinis* [193], *Cryptococcus laurentii* [194*], *Kloeckera apiculata* [195, 196*], *Pichia anomala* [197]), bacteria (eg, *Pseudomonas syringae* [198**–201], *Pseudomonas cepacia* [202–204], *Pseudomonas glathei* [205*], *Pantoea agglomerans* [206–209*], *Bacillus subtilis* [210–214*, 215*], *Bacillus pumilus* [216], *Serratia plymuthica* [217]) and filamentous fungi (eg, *Trichoderma viride* [218], *Verticillium lecanii* [164], *Aureobasidium pullulans* [219, 220]) have been selected, identified and characterised because of their biocontrol activity against citrus green or blue moulds. However, by the early 2000s, there were only two postharvest biological products registered for use against postharvest rots of citrus fruit that were available on the market: Aspire™ (*C. oleophila*, limited to the USA and Israel) and BioSave™ (*P. syringae*, limited to the USA). Other products (Biocure, Bio-Coat) were developed with *C. saitoana* [221], but have not reached the marketplace yet. Another recently developed product is based on the use of a heat-tolerant strain of *M. fructicola* and is marketed under the name Shemer™ in Israel by the company AgroGreen Ltd.

(Ashdod, Israel). Besides *Penicillium* spp., it has been shown to be also effective against rots caused by *Botrytis cinerea*, *Rhizopus* spp., and *Aspergillus* spp. on citrus, strawberries and grapes [190*, 222–224]. Depending on the antagonist, the pathogen and the fruit host, different modes of action might explain the biocontrol activity of antagonistic microorganisms: competition for nutrients and space, secretion of antibiotics, direct effects of the antagonist on the pathogen or induction of host defence mechanisms [8*, 175*, 225, 226*, 227**]. In general, microbial antagonists are used as aqueous cell suspensions in postharvest spray, drench or dip applications. On citrus fruit, some of them have been tested as preharvest treatments [225] and others as active ingredients in fruit coatings [163, 185**, 187*, 221, 228–230]. An unusual case is the control of citrus penicillium decay by biofumigation with volatile compounds produced by grain cultures of the fungus *Muscodor albus* [231**].

In spite of the large volume of research published about postharvest biocontrol of citrus rots, the commercial use of these products was and remains limited and accounts for only a very small fraction of the potential market. As discussed in several reviews [173, 174, 176*, 177**, 232], the main shortcoming of the use of postharvest biocontrol products has been inconsistency in their performance, especially when used as a stand-alone product to replace synthetic fungicides. Furthermore, another important handicap for current commercial adoption in EU countries of such products is the strict regulatory issues that prevent registration [233]. The combination of biological control with other control methods is one of the most promising means of establishing effective nonpolluting integrated control systems [173, 234–236*] and will be later discussed in this review. Other approaches to enhance the biocontrol activity of antagonistic microorganisms include the addition of nutrients such as certain nitrogenous compounds [172] or genetic manipulation of the antagonists. Efforts to identify genetic traits of the yeast *C. oleophila* and determine its potential to enhance biocontrol activity showed that both chitinase and glucanase activities are constitutively produced by the yeast in culture and in planta. *CoEXG1,* a exo-β-1,3-glucanase gene of the yeast biocontrol agent *C. oleophila* was cloned from a partial genomic library as a segment containing the open reading frame and the promoter [237*]. Trasformants with double copy of *CoEXG1* exhibited two fold exo-β-1,3-glucanase activity compared with the wild type. When tested on citrus fruit against *P. digitatum*, biocontrol efficacy of the transformant overexpressing glucanase gene was not significantly enhanced [238*]. Another important aspect to improve the commercial performance and generalise the use of biocontrol agents is the development of stable, reliable and economically acceptable product formulations [207, 239, 240].

Combination of treatments for integrated disease management

Successful commercial control of postharvest diseases of fruits and vegetables must be extremely efficient, in the range of 95–98%, unlike the control of tree, field crop or soil borne diseases. Consistent performance to such levels of control cannot presently be achieved by alternatives to fungicides as stand-alone treatments, so strategies where they are combined are needed to attain commercially acceptable performance. Therefore, researchers have devoted considerable attention to the integration of different treatments in order to overcome the variable performance and augment the efficacy of existing alternative approaches. In general, three objectives may be pursued by the integration of two or more treatments: additive or synergistic effects to increase the effectiveness or the persistence of individual treatments; complementary effects to combine preventive and curative activities; and potential commercial implementation of effective treatments that are too impractical, costly or risky as single treatments. For example, combinations of treatments can be made to reduce the length and cost of curing treatments or reduce the dose and phytotoxicity risk of irradiation treatments.

Most of the research on the combination of alternative treatments to control citrus green and blue moulds included postharvest heat or biocontrol treatments as components of an integrated strategy, so particular subsections will focus on these combinations. Ionising radiation at low doses combined with reduced levels of either conventional fungicides (eg, SOPP, diphenyl) [241, 242] or GRAS compounds (eg, SC) [121], and conventional fungicides at low doses combined with GRAS compounds or sanitisers (eg, SBC, PS, chlorine) [20, 22, 116, 243–245*] are other options that have been assessed.

On the other hand, there is an increasing interest in the application of antifungal preharvest treatments to reduce field populations of *Penicillium* spp. or induce fruit resistance as part of IDM programs. Therefore, fungicides such as benomyl, cyprodinil, thiophanate methyl, pyraclostrobin, AZX, FLU and phosphorous acid, and other chemicals such as several carbonates, calcium chloride ($CACl_2$), dichlorophenoxyacetic acid, gibberellic acid and a mannaoligosaccharide (ISR 2000®) have been recently evaluated for these purposes [39*, 192*, 244, 246–249*].

Combination of heat with other control methods

Combination with other physical control methods

In order to reduce potential negative impacts of antifungal treatments on citrus fruit quality, curing or hot water treatments have been combined with variable results with individual plastic packaging of fruit [33, 54], ionising radiation at low doses [47, 78, 250*], UV-C treatments [39*, 251, 252] or brief CO_2 shocks [253*].

Combination with chemical control methods

It has been repeatedly reported that heating aqueous solutions of either conventional fungicides [17, 20, 58, 243–245*, 254–257] or low-toxicity alternative chemicals such as SC, SBC [51, 52*, 100–102**, 105, 245*, 258**], PS [113**, 116*–118, 259], SB, sodium and ammonium molybdates [113**], ethanol, sulphur dioxide [100] or calcium polysulfide [104] significantly enhanced their effectiveness against penicillium moulds and other citrus postharvest diseases. Heat probably facilitates the uptake of the active ingredient through the fruit cuticle [61**] in a similar way that it is facilitated by dip treatments in comparison to spray or drench applications [257, 260]. The most appropriate solution temperature should be specifically determined for each combination of active ingredient and fruit species and cultivar, but in general, if compared with hot water alone, similar effectiveness is obtained at much lower solution temperatures, which considerably reduces the risk of heat injury to the fruit. The combination of curing treatments with conventional fungicides [36, 39*], GRAS compounds such as SC [38*, 261*] or ethanol [38*], or postharvest surfactants such as dodecylbenzenesulfonate [37*] also resulted in improved control of citrus green or blue moulds.

Combination with biocontrol antagonists

Heat treatments and the application of antagonistic microorganisms are complementary treatments that often show synergistic effects for the control of postharvest diseases. In some cases, both are components of complex integrated control strategies that also include other control means [234–236*].

Thermal curing or hot water treatments have been successfully combined with microbial antagonists for citrus penicillium decay control, including *C. oleophila* [38*, 258**], *C. famata* [189], *M. mulcherrima* [192*], *P. glathei* [205*], *B. subtilis* [214*] and *P. agglomerans* [262*].

Combination of biocontrol antagonists with other control methods

Combination with physical control methods

Besides heat treatments, other physical control means that have been combined with the application of antagonistic microorganisms to control of citrus green or blue moulds include UV-C illumination and storage in CAs. The application of UV-C in combination with the yeast antagonist *D. hansenii* completely inhibited the development of *P. digitatum* on Dancy tangerines [263*]. While similar results were obtained on navel oranges with the combination of UV-C and the yeast *C. oleophila*, no synergistic effects were observed when UV-C was combined with the bacterium *B. subtilis* [264]. Satisfactory decay control was found on clementine mandarins previously treated with the bacterium *P. agglomerans* and stored for 60 days at 3.5ºC in 5 kPa O_2 + 3 kPa CO_2. These storage conditions did not adversely affect the viability of the antagonist on fruit surface wounds (Palou, Usall, and Viñas, unpublished results).

Combination with low levels of conventional fungicides

In laboratory and large scale tests, biocontrol products such as Aspire^{TM} and BioSave^{TM} often provide a level of control equivalent to synthetic fungicides only when combined with low doses of these fungicides [178**, 192*, 265–268*]. For instance, *C. oleophila* in combination with 200 µg/mL of TBZ controlled citrus decay at the level equivalent to a commercial fungicide treatment, where TBZ is often used at 10 to 20 times this concentration, and reduced the variability often observed when using the antagonistic yeast alone [178**].

Combination with food additives and other chemicals

Among the low toxicity chemicals examined to enhance biocontrol efficacy against *P. digitatum* or *P. italicum* were ethanol [38*], peracetic acid [191] and oxalic acid [180]. However, SCs (especially SBC) are the additives that have been most widely evaluated for synergistic activity with microbial antagonists. Their combination with *P. syringae* [102**], *P. agglomerans* [209*, 269**, 270], *C. oleophila* [38*, 258**], *B. subtilis* [214*] or *C. laurentii* [194*] was superior to either treatment alone in controlling green or blue moulds on different citrus species and cultivars.

The addition of calcium chloride to citrus fruit increased the protective effect of the antagonist *P. guilliermondii* and also greatly reduced the populations of yeasts required to give effective control [271**]. The combination of *C. saitoana* with a low dose of 0.2% (w/v) of the sugar analog 2-deoxy-D-glucose applied to fruit wounds before inoculation was more effective in controlling decay of orange and lemon caused by *P. digitatum* than either *C. saitoana* or 2-deoxy-D-glucose alone [186*]. These results were confirmed in semicommercial trials [272].

Combination with chitosan and derivatives

A biocontrol preparation termed "bioactive coating" that consists of a unique combination of the antagonistic yeast *C. saitoana* with chemically-modified chitosan (0.2% glycolchitosan) was evaluated in laboratory and semicommercial studies against *P. digitatum* on oranges and lemons. The biocontrol activity of *C. saitoana* was markedly enhanced by the addition of glycolchitosan and the combination made it possible to synergistically exploit the antifungal properties of both treatment components [163, 187*].

Conclusion

As this review makes evident, extensive research work has been conducted worldwide for many years and continues today to identify, evaluate, select, characterise and eventually implement alternative means to conventional synthetic fungicides for the control of postharvest penicillium moulds of citrus fruit. These sustained efforts are warranted by the economical importance of postharvest losses caused by *P. digitatum* and *P. italicum* in all citrus growing areas and the increasing market and social pressure to adopt safe nonpolluting technologies for fresh fruit production. Particularly, consumer safety concerns are more important for postharvest pesticide treatments than for field applications, because the residues are likely to be present on the fruit at the time of consumption.

Despite the evident substantial progress that has been accomplished, the commercial use of available alternative postharvest antifungal treatments has been rather limited given the potential market. The lack of either curative or preventive activity, low persistence, high variability, cost, inconsistency or excessive specificity are general limitations associated with the nature of alternative physical, chemical or biological control methods. As stated once by a student: "… it is not going to be easy to kill with no poison…". Furthermore, the risk of adverse effects on fruit quality, technological problems for cost-effective application or the availability of new conventional fungicides for traditional markets are additional reasons that may hinder the broad commercial use of such treatments. As we learn more about the fundamental basis underlying host-pathogen interactions and how they are influenced by direct or indirect protective effects of existing or new alternative treatments, more effective methods of applying and combining complementary approaches for additive or synergistic effects will emerge. So far the results obtained with combinations of antifungal treatments demonstrate the promise of this multifaceted integrated approach to become a viable alternative to the use of synthetic fungicides. Once developed, these alternatives should prove durable and valuable. The complexity of the mode of action associated with combined alternative treatments should make the development of pathogen resistance unlikely and provide higher levels of stability and effectiveness than approaches relying on single mode of action treatments.

Acknowledgements

The authors thank all public and private organisations in Spain, California (USA) and Israel that have contributed to funding their research work in this topic during the past years.

References

Papers of interest have been highlighted as:
* Marginal importance
** Essential reading

1 *Eckert JW and Eaks IL. Postharvest disorders and diseases of citrus fruits. In: The citrus industry. Reuter W, Calavan EC, Carman GE (editors). Berkeley, CA, USA: University of California Press; 1989 vol 5.: pp. 179–260.

2 Kanetis L, Förster H and Adaskaveg JE. Comparative efficacy of the new postharvest fungicides azoxystrobin, fludioxonil, and pyrimethanil for managing citrus green mold. Plant Disease 2007: 91:1502–1511.

3 Green FM. The infection of oranges by *Penicillium*. Journal of Pomology and Horticultural Science 1932: 10:184–215.

4 Plaza P, Usall J, Teixidó N and Viñas I. Effect of water activity and temperature on germination and growth of *Penicillium digitatum, P. italicum* and *Geotrichum candidum.* Journal of Applied Microbiology 2003: 94:549–554.

5 Lahlali R, Serrhini MN, Friel D and Jijakli MH. *In vitro* effects of water activity, temperature and solutes on the growth rate of *P. italicum* Wehmer and P. *digitatum* Sacc. Journal of Applied Microbiology 2006: 101:628–636.

6 Stange RR Jr, Midland SL, Sims JJ and McCollum TG. Differential effects of citrus peel extracts on growth of *Penicillium digitatum*, *P. italicum*, and *P. expansum*. Physiological and Molecular Plant Pathology 2002: 61:303–311.

7 Droby S, Eick A, Macarisin D, Cohen L, Rafael G, Stange RR Jr, McCollum TG, Dudai N, Nasser A, Wisniewski M and Shapira R. The role of volatiles in germination and growth of *Penicillium digitatum* and *Penicillium italicum*. Postharvest Biology and Technology 2008: in press.

8 *Porat R, McCollum TG, Vinokur V and Droby S. Effects of various elicitors on the transcription of a β-1,3-endoglucanase gene in citrus fruit. Journal of Phytopathology 2002:150:70–75.

9 Ariza MR, Larsen TO, Petersen BO, Duus JO and Barrero AF. *Penicillium digitatum* metabolites on synthetic media and citrus fruits. Journal of Agricultural and Food Chemistry 2002: 50:6361–6365.

10 Lai S, Lai A, Stange RR Jr, McCollum TG and Schirra M. Characterization of the wound-induced material in *Citrus paradisi* fruit peel by carbon-13 CP-MAS solid state NMR spectroscopy. Phytochemistry 2003: 63:177–183.

11 Hasdai A, Elmaci C, Goldschmidt EE, Droby S and Porat R. Isolation of a thioredoxin h cDNA from grapefruit peel tissue that is induced upon infection by *Penicillium digitatum* and elicitation of pathogen resistance. Physiological and Molecular Plant Pathology 2004: 65:277–283.

12 Prusky D, McEvoy JL, Saftner RA, Conway WS and Jones R. Relationship between host acidification and virulence of *Penicillium* spp. on apple and citrus fruit. Phytopathology 2004: 94:44–51.

13 Marcos JF, González-Candelas L and Zacarías L. Involvement of ethylene biosynthesis and perception in the susceptibility of citrus fruits to *Penicillium digitatum* infection and the accumulation of defence-related mRNAs. Journal of Experimental Botany 2005: 56:2183–2193.

14 Marcos JF, Sánchez-Torres P, Alamar S, Zacarías L and González-Candelas L. High-throughput approaches to the identification of citrus genes involved in fruit response to *Penicillium digitatum* infection. Acta Horticulturae 2007: 738:229–233.

15 Ballester AR, Lafuente MT and González-Candelas L. Spatial study of antioxidant enzymes, peroxidase and phenylalanine ammonia-lyase in the citrus fruit-*Penicillium digitatum* interaction. Postharvest Biology and Technology 2006: 39:115–124.

16 Macarisin D, Cohen L, Eick A, Rafael G, Belausov E, Wisniewski M and Droby S. *Penicillium digitatum* suppresses production of hydrogen peroxide in host tissue during infection of citrus fruit. Phytopathology 2007: 97:1491–1500.

17 Schirra M, D'Aquino S, Palma A, Marceddu S, Angioni A, Cabras P, Scherm B and Migheli Q. Residue level, persistence and storage performance of citrus fruit treated with fludioxonil. Journal of Agricultural and Food Chemistry 2005: 53:6718–6724.

18 Schirra M, D'Aquino S, Palma A, Angioni A, Cabras P and Migheli Q. Residues of the quinone outside inhibitor fungicide trifloxystrobin after postharvest dip treatments to control *Penicillium* spp. on citrus fruit. Journal of Food Protection 2006: 69:1646–1652.

19 D'Aquino S, Schirra M, Palma A, Angioni A, Cabras P and Migheli Q. Residue levels and effectiveness of pyrimethanil vs imazalil when using heated postharvest dip treatments for control of *Penicillium* decay on citrus fruit. Journal of Agricultural and Food Chemistry 2006: 54:4721–4726.

20 Smilanick JL, Mansour MF, Mlikota Gabler F and Goodwine WR. The effectiveness of pyrimethanil to inhibit germination of *Penicillium digitatum* and to control citrus green mold after harvest. Postharvest Biology and Technology 2006: 42:75–85.

21 Zhang J. The potential of a new fungicide fludioxonil for stem-end rot and green mold control on Florida citrus fruit. Postharvest Biology and Technology 2007: 46:262–270.

22 Kanetis L, Förster H and Adaskaveg JE. Optimizing efficacy of new postharvest fungicides and evaluation of sanitizing agents for managing citrus green mold. Plant Disease 2008: 92:261–269.

23 Kanetis L, Förster H and Adaskaveg JE. Baseline sensitivities for new postharvest fungicides against *Penicillium* spp. on citrus and multiple resistance evaluations in *P. digitatum*. Plant Disease 2008: 92:301–310.

24 Naqvi SAMH. Diagnosis and management of pre and post-harvest diseases of citrus fruit. In: Diseases of fruits and vegetables – Diagnosis and management. Naqvi SAMH (editor). Dordrecht, The Netherlands:

Springer Netherlands; 2004 vol 1: pp. 339–359.

25 **Smilanick JL, Brown GE and Eckert JW. Postharvest citrus diseases and their control. In: Fresh citrus fruits. Wardowski WF, Miller WM, Hall DJ Grierson W (editors). Longboat Key, FL, USA: Florida Science Source Inc; 2006 2nd edition: pp. 339–396.

26 Bus VG, Bongers AJ and Risse LA. Occurrence of *Penicillium digitatum* and *Penicillium italicum* resistant to benomyl, thiabendazole, and imazalil on citrus fruit from different geographic origins. Plant Disease 1991: 75:1098–1100.

27 Eckert JW, Sievert JR and Ratnayake M. Reduction of imazalil effectiveness against citrus green mold in California packinghouses by resistant biotypes of *Penicillium digitatum*. Plant Disease 1994: 78:971–973.

28 Holmes GJ and Eckert JW. Sensitivity of *Penicillium digitatum* and *P. italicum* to postharvest citrus fungicides in California. Phytopathology 1999: 89:716–721.

29 Kinay P, Mansour MF, Mlikota Gabler F, Margosan DA and Smilanick JL. Characterization of fungicide-resistant isolates of *Penicillium digitatum* collected in California. Crop Protection 2007: 26:647–656.

30 Ismail M and Zhang J. Post-harvest citrus diseases and their control. Outlooks in Pest Management 2004: 15:29–35.

31 *Narayanasamy P. Integrated systems for the management of postharvest diseases. In: Postharvest pathogens and disease management. Hoboken, NJ, USA: John Wiley and Sons Inc, Wiley-Interscience; 2006: pp. 537–554.

32 Hopkins EF and Loucks KW. A curing procedure for the reduction of mold decay in citrus fruits. University of Florida Agricultural Experiment Station Bulletin 1948: 450.

33 Ben-Yehoshua S, Barak E and Shapiro B. Postharvest curing at high temperatures reduces decay of individually sealed lemons, pomelos, and other citrus fruit. Journal of the American Society for Horticultural Science 1987: 112:658–663.

34 Plaza P, Usall J, Torres R, Lamarca N, Asensio A and Viñas I. Control of green and blue mould by curing on oranges during ambient and cold storage. Postharvest Biology and Technology 2003: 28:195–198.

35 Erkan M, Pekmezci M, Karasahin I and Uslu H. Reducing chilling injury and decay in stored ‘Clementine’ mandarins with hot water and curing treatments. European Journal of Horticultural Science 2005: 70:183–188.

36 Zhang J and Swingle PP. Effects of curing on green mold and stem -end rot of citrus fruit and its potential application under Florida packing system. Plant Disease 2005: 89:834–840.

37 *Stange RR Jr and Eckert JW. Influence of postharvest handling and surfactants on control of green mold of lemons by curing. Phytopathology 1994: 84:612–616.

38 *Lanza G, Di Martino Aleppo E and Strano MC. Evaluation of alternative treatments to control green mold in citrus fruit. Acta Horticulturae 2004: 632:343–349.

39 *Kinay P, Yildiz F, Sen F, Yildiz M and Karacali I. Integration of pre- and postharvest treatments to minimize *Penicillium* decay of Satsuma mandarins. Postharvest Biology and Technology 2005: 37:31–36.

40 Barkai-Golan R and Phillips DJ. Postharvest heat treatment of fresh fruits and vegetables for decay control. Plant Disease 1991: 75:1085–1089.

41 Mulas M, Mereu V, Ligios G and Schirra M. Impact of heat treatments on respiration and ethylene production rates and on etanol and acetaldehyde accumulation in the juice or their release by ‘Valencia Late’ oranges during storage. In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

42 Pérez AG, Luaces P, Olmo M, Sanz C and García JM. Effect of intermittent curing on mandarin quality. Journal of Food Science 2005: 70:64–68.

43 Nunes C, Usall J, Manso T, Torres R, Olmo M and García JM. Effect of high temperature treaments on growth of *Penicillium* spp. and development on ‘Valencia’ oranges. Food Science and Technology International 2007: 13:63–68.

44 *Plaza P, Sanbruno A, Usall J, Lamarca N, Torres R, Pons J and Viñas I. Integration of curing treatments with degreening to control the main postharvest diseases of clementine mandarins. Postharvest Biology and Technology 2004: 34:29–37.

45 Smilanick JL and Mansour MF. Influence of temperature and humidity on survival of *Penicillium digitatum* and *Geotrichum citri-aurantii*. Plant Disease 2007: 91:990–996.

46 Smoot JJ and Melvin CF. Hot water as a control for decay of oranges. Proceedings of the Florida State Horticultural Society 1963: 76:322–327.

47 Spalding DH and Reeder WF. Effect of hot water and gamma radiation on postharvest decay of grapefruit. Proceedings of the Florida State Horticultural Society 1985: 98:207–208.

48 Rodov V, Ben-Yehoshua S, Albagli R and Fang DQ. Reducing chilling injury and decay of stored citrus fruit by hot water dips. Postharvest Biology and Technology 1995: 5:119–127.

49 Schirra M and D’hallewin G. Storage performance of Fortune mandarins following hot water dips. Postharvest Biology and Technology 1997: 10:229–238.

50 Hong S, Lee H and Kim D. Effects of hot water treatment on the storage stability of satsuma mandarin as a postharvest decay control. Postharvest Biology and Technology 2007: 43:271–279.

51 Palou L, Smilanick JL, Usall J and Viñas I. Control of postharvest blue and green molds of oranges by hot water, sodium carbonate, and sodium bicarbonate. Plant Disease 2001: 85:371–376.

52 *Palou L, Usall J, Muñoz JA, Smilanick JL and Viñas I. Hot water, sodium carbonate, and sodium bicarbonate for the control of postharvest green and blue molds of clementine mandarins. Postharvest Biology and Technology 2002: 24:93–96.

53 *Schirra M, Mulas M, Fadda A and Cauli E. Cold quarantine responses of blood oranges to postharvest hot water and hot air treatments. Postharvest Biology and Technology 2004: 31:191–200.

54 Rodov V, Agar T, Peretz J, Nafussi B, Kim JJ and Ben-Yehoshua S. Effect of combined application of heat treatments and plastic packaging on keeping quality of 'Oroblanco' fruit (*Citrus grandis* L. x *C. paradisi* Macf.). Postharvest Biology and Technology 2000: 20:287–294.

55 Smilanick JL, Sorenson D, Mansour M, Aieyabei J and Plaza P. Impact of a brief postharvest hot water drench treatment on decay, fruit appearance, and microbe populations of California lemons and oranges. HortTechnology 2003: 13:333–338.

56 *Porat R, Daus A, Weiss B, Cohen L, Fallik E and Droby S. Reduction of postharvest decay in organic citrus fruit by a short hot water brushing treatment. Postharvest Biology and Technology 2000: 18:151–157.

57 *Ben-Yehoshua S and Porat R. Heat treatments to reduce decay. In: Environmentally friendly technologies for agricultural produce quality. Ben-Yehoshua S (editor). Boca Raton, FL, USA: CRC Press, Taylor and Francis Group; 2005: pp. 11–42.

58 Schirra M, D’hallewin G, Cabras P, Angioni A and Garau VL. Seasonal susceptibility of Tarocco oranges to chilling injury as affected by hot water and thiabendazole postharvest dip treatments. Journal of Agricultural and Food Chemistry 1998: 46:1177–1180.

59 Sen F, Kinay P and Karacali I. Effects of chlorine and heat applications after harvest on the quality and resistance capacity of ‘Satsuma’ mandarins. In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

60 *Kim JJ, Ben-Yehoshua S, Shapiro B, Henis Y and Carmeli S. Accumulation of scoparone in heat-treated lemon fruit inoculated with *Penicillium digitatum* Sacc. Plant Physiology 1991: 97:880–885.

61 **Schirra M, D’hallewin G, Ben-Yehoshua S and Fallik E. Host-pathogen interactions modulated by heat treatment. Postharvest Biology and Technology 2000: 21:71–85.

62 **Pavoncello D, Lurie S, Droby S and Porat R. A hot water treatment induces resistance to *Penicillium digitatum* and promotes the accumulation of heat shock and pathogenesis-related proteins in grapefruit flavedo. Physiologia Plantarum 2001: 111:17–22.

63 Stevens C, Wilson CL, Lu JY, Khan VA, Chalutz E, Droby S, Kabwe MK, Haung Z, Adeyeye O, Pusey LP, Wisniewski ME and West M. Plant hormesis induced by ultraviolet light-C for controlling postharvest diseases of tree fruits. Crop Protection 1996: 15:129–134.

64 D'hallewin G, Schirra M, Pala M and Ben-Yehoshua S. Ultraviolet C irradiation at 0.5 kJ·m^{-2} reduces decay without causing damage or affecting postharvest quality of star ruby grapefruit (*C. paradisi* Macf.). Journal of Agricultural and Food Chemistry 2000: 48:4571–4575.

65 *Droby S, Chalutz E, Horev B, Cohen L, Gaba V, Wilson CL and Wisniewski M. Factors affecting UV-induced resistance in grapefruit against the green mould decay caused by *Penicillium digitatum*. Plant Pathology 1993: 42:418–424.

66 *D'hallewin G, Schirra M, Manueddu E, Piga A and Ben-Yehoshua S. Scoparone and scopoletin accumulation and ultraviolet-C induced resistance to postharvest decay in oranges as influenced by harvest date. Journal of the American Society for Horticultural Science 1999: 124:702–707.

67 Asthana A and Tuveson RW. Effects of UV and phototoxins on selected fungal pathogens of citrus. International Journal of Plant Science 1992: 153:442–452.

68 Fernández YJ and Hall DJ. In vitro response of *Penicillium digitatum* and *Geotrichum candidum* to ultraviolet (UV-C) exposure. Proceedings of the Florida State Horticultural Society 2004: 117:380–381.

69 Arcas MC, Botía JM, Ortuño A and Del Río JA. UV irradiation alters the levels of flavonoids involved in the defence mechanism of *Citrus aurantium* against *Penicillium digitatum*. European Journal of Plant Pathology 2000: 106:617–622.

70 Porat R, Lers A, Dori S, Cohen E, Weiss B, Daus A, Wilson CL and Droby S. Induction of chitinase and β-1,3-endoglucanase proteins by UV irradiation and wounding in grapefruit peel tissue. Phytoparasitica 1999: 27:233–238.

71 *Ben-Yehoshua S, Rodov V, Kim JJ and Carmeli S. Preformed and induced antifungal materials of citrus fruits in relation to the enhancement of decay resistance by heat and ultraviolet treatments. Journal of Agricultural and Food Chemistry 1992: 40:1217–1221.

72 Wilson CL, Upchurch B, El-Ghaouth A, Stevens C, Khan V, Droby S and Chalutz E. Using an on-line UV-C apparatus to treat harvested fruit for controlling postharvest decay. HortTechnology 1997: 7:278–282.

73 *Gómez-López VM, Ragaert P, Debevere J and Devlieghere F. Pulsed light for food decontamination: a review. Trends in Food Science and Technology 2007: 18:464–473.

74 US FDA (United States Food and Drug Administration). Irradiation in the production, processing and handling of food: final rule. Federal Register 2004: 69:76844–76847.

75 *Sommer NF, Maxie EC, Fortlage RJ and Eckert JW. Sensitivity of citrus fruit decay fungi to gamma irradiation. Radiation Botany 1964: 4:317–322.

76 Maxie EC, Sommer NF and Eaks IL. Effect of gamma radiation on citrus fruit. Proceedings of the First International Citrus Symposium 1969: 3:1375–1387.

77 Bramlage WJ and Couey HM. Gamma radiation of fruit to extend market life. United States Department of Agriculture, Agricultural Research Service, Marketing Research Report 1965: 717.

78 Barkai-Golan R and Padova R. Eradication of *Penicillium* on citrus fruits by electron radiation. Proceedings of the International Society of Citriculture 1981: 2:799–801.

79 *Barkai-Golan R. Suppression of postharvest pathogens of fresh fruits and vegetables by ionizing radiation. In: Electromagnetic radiations in fruit science. Rosenthal I (editor). Berlin, Germany: Springer-Verlag; 1992: pp. 155–193.

80 Mahrouz M, Lacroix M, D'Aprano G, Oufedjikh H, Boubekri C and Gagnon M. Effect of γ-irradiation combined with washing and waxing treatment on physicochemical properties, vitamin C, and organoleptic quality of *Citrus clementina* Hort. Ex. Tanaka. Journal of Agricultural and Food Chemistry 2002: 50:7271–7276.

81 Patil BS. Irradiation applications to improve functional components of fruits and vegetables. In: Irradiation of food and packaging. Recent developments. Komolprasert V, Morehouse KM (editors). Washington, DC, USA: American Chemical Society Symposium Series 875; 2004: pp. 117–137.

82 Brown GE and Eckert JW. Penicillium decays. In: Compendium of citrus diseases. Timmer LW, Garnsey SM, Graham JH (editors). St. Paul, MN, USA: APS Press; 2000 2nd edition: pp. 41–42.

83 Kader AA and Arpaia ML. Postharvest handling systems: subtropical fruits. In: Postharvest technology of horticultural crops. Kader AA (editor). Oakland, CA, USA: University of California Agriculture and Natural Resources, Publication 3311; 2002: pp. 375–383.

84 Smoot JJ. Decay of Florida citrus fruit stored in controlled atmospheres and in air. Proceedings of the First International Citrus Symposium 1969: 3:1285–1293.

85 Chace WG Jr. Controlled atmosphere storage of Florida citrus fruit. Proceedings of the First International Citrus Symposium 1969: 3:1365–1373.

86 Aharoni Y and Lattar FS. The effect of various storage atmospheres on the occurrence of rots and blemishes on Shamouti oranges. Phytopathologische Zeitschrift 1972: 73:371–374.

87 *Spalding DH and Reeder WF. Low pressure (hypobaric) storage of limes. Journal of the American Society for Horticultural Science 1976: 101:367–370.

88 McGlasson WB and Eaks IL. A role for ethylene in the development of wastage and off-flavors in stored "Valencia" oranges. HortScience 1972: 7:80–81.

89 Wild BL, McGlasson WB and Lee TH. Effect of reduced ethylene levels in storage atmospheres on lemon keeping quality. HortScience 1976: 11:114–115.

90 *Palou L, Smilanick JL and Margosan DA. Ozone applications for sanitation and control of postharvest diseases of fresh fruits and vegetables. In: Recent advances in alternative postharvest technologies to control fungal diseases in fruits and vegetables. Troncoso-Rojas R, Tiznado-Hernández ME, González-León A (editors). Trivandrum, Kerala, India: Transworld Research Network; 2007: pp. 39–70.

91 Palou L, Smilanick JL, Crisosto CH and Mansour MF. Effect of gaseous ozone exposure on the development of green and blue molds on cold stored citrus fruit. Plant Disease 2001: 85:632–638.

92 Harding PR Jr. Effect of ozone on *Penicillium* mold decay and sporulation. Plant Disease Reporter 1968: 52:245–247.

93 Palou L, Smilanick JL, Crisosto CH, Mansour MF and Plaza P. Ozone gas penetration and control of the sporulation of *Penicillium digitatum* and *Penicillium italicum* within commercial packages of oranges during cold storage. Crop Protection 2003: 22:1131–1134.

94 Smilanick JL, Margosan DM and Mlikota Gabler F. Impact of ozonated water on the quality and shelf-life of fresh citrus fruit, stone fruit, and table grapes. Ozone Science and Engineering 2002: 24:343–356.

95 **Barkai-Golan R. Postharvest diseases of fruits and vegetables. Development and control. Amsterdam, The Netherlands: Elsevier Science BV; 2001.

96 *Troncoso-Rojas R and Tiznado-Hernández ME. Natural compounds to control fungal postharvest diseases. In: Recent advances in alternative postharvest technologies to control fungal diseases in fruits and vegetables. Troncoso-Rojas R, Tiznado-Hernández ME, González-León A (editors). Trivandrum, Kerala, India: Transworld Research Network; 2007: pp. 127–156.

97 Barger WR and Hawkins LA. Borax as a disinfectant for citrus fruit. Journal of Agricultural Research 1925: 30:189–192.

98 Winston JR. Reducing decay in citrus fruits with borax. United States Department of Agriculture Technical Bulletin 1935: 488.

99 Eckert JW. Application and use of postharvest fungicides. In: Fungicides. Torgeson DC (editor). New York, USA: Academic Press Inc; 1967 vol 1: pp. 287–378.

100 Smilanick JL, Margosan DA and Henson DJ. Evaluation of heated solu-

tions of sulfur dioxide, ethanol, and hydrogen peroxide to control postharvest green mold of lemons. Plant Disease 1995: 79:742–747.

101 Smilanick JL, Mackey BE, Reese R, Usall J and Margosan DA. Influence of concentration of soda ash, temperature, and immersion period on the control of postharvest green mold of oranges. Plant Disease 1997: 81:379–382.

102 **Smilanick JL, Margosan DA, Mlikota Gabler F, Usall J and Michael IF. Control of citrus green mold by carbonate and bicarbonate salts and the influence of commercial postharvest practices on their efficacy. Plant Disease 1999: 83:139–145.

103 Sorenson D, Smilanick JL and Margosan DA. Postharvest high pressure washing of citrus fruit with sodium bicarbonate to control green mold. Phytopathology 1999: 89:S74 (Abstract).

104 Smilanick JL and Sorenson D. Control of postharvest decay of citrus fruit with calcium polysulfide. Postharvest Biology and Technology 2001: 21:157–168.

105 Lesar KH. The potential role of GRAS (Generally Regarded as Safe) chemicals, alone and in combination with the post-harvest fungicides, in the control of the major post-harvest citrus pathogens, *Penicillium digitatum* (citrus green mold) and *Geotrichum candidum* (sour rot). In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

106 Marloth R. The influence of hydrogen-ion concentration and of sodium bicarbonate and related substances on *Penicillium italicum* and *P. digitatum.* Phytopathology 1931: 21:169–198.

107 Hwang L and Klotz LJ. The toxic effect of certain chemical solutions on spores of *Penicillium italicum* and *P. digitatum*. Hilgardia 1938: 12:1–38.

108 Zhang J and Swingle PP. Control of green mold on Florida citrus fruit using bicarbonate salts. Proceedings of the Florida State Horticultural Society 2003: 116:375–378.

109 Sholberg PL and Gaunce AP. Fumigation of fruit with acetic acid to prevent postharvest decay. HortScience 1995: 30:1271–1275.

110 D'Aquino S, Palma A, Mura D, Tedde M and Schirra M. The use of acetic acid to prevent decay in citrus fruit. In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

111 *Sholberg PL. Fumigation of fruit with short-chain organic acids to reduce the potential of postharvest decay. Plant Disease 1998: 82:689–693.

112 Hall DJ. Comparative activity of selected food preservatives as citrus postharvest fungicides. Proceedings of the Florida State Horticultural Society 1988: 101:184–187.

113 **Palou L, Usall J, Smilanick JL, Aguilar MJ and Viñas I. Evaluation of food additives and low-toxicity compounds as alternative chemicals for the control of *Penicillium digitatum* and *Penicillium italicum* on citrus fruit. Pest Management Science 2002: 58:459–466.

114 Smoot JJ and McCornack AA. The use of potassium sorbate for citrus decay control. Proceedings of the Florida State Horticultural Society 1978: 91:119–122.

115 Nelson PM, Wheeler RW and McDonald PD. Potassium sorbate in combination with benzimidazoles reduces resistant *Penicillium digitatum* decay in citrus. Proceedings of the International Society of Citriculture 1983: 2:820–823.

116 *Smilanick JL, Mansour MF, Mlikota Gabler F and Sorenson D. Control of citrus postharvest green mold and sour rot by potassium sorbate combined with heat and fungicides. Postharvest Biology and Technology 2008: 47:226–238.

117 Wild BL. Fungicidal activity of potassium sorbate against *Penicillium digitatum* as affected by thiabendazole and dip temperature. Scientia Horticulturae 1987: 32:41–47.

118 Palou L, Montesinos-Herrero C, Pastor C and del Río MA. Brief potassium sorbate dips to control citrus postharvest green and blue molds. In: Proceedings of the 2007 Australasian Postharvest Conference. Ekman J (editor). Gosford, NSW, Australia: NSW Department of Primary Industries; 2007, Electronic source: CD-ROM.

119 Schroeder LL and Bullerman LB. Potential for development of tolerance by *Penicillium digitatum* and *Penicillium italicum* after repeated exposure to potassium sorbate. Applied and Environmental Microbiology 1985: 51:919–923.

120 *Larrigaudiere C, Pons J, Torres R and Usall J. Storage performance of clementines treated with hot water, sodium carbonate, and sodium bicarbonate dips. Journal of Horticultural Science & Biotechnology 2002: 77:314–319.

121 Palou L, Marcilla A, Rojas-Argudo C, Alonso M, Jacas J and del Río MA. Effects of X-ray irradiation and sodium carbonate treatments on postharvest *Penicillium* decay and quality attributes of clementine mandarins. Postharvest Biology and Technology 2007: 46:252–261.

122 Smilanick JL, Aiyabei J, Mlikota Gabler F, Doctor J, Sorenson D and Mackey B. Quantification of the toxicity of aqueous chlorine to spores of *Penicillium digitatum* and *Geotrichum citri-aurantii.* Plant Disease 2002: 86:509–514.

123 Tripathi P and Dubey NK. Exploitation of natural products as an alternative strategy to control postharvest fungal rotting of fruit and vegetables. Postharvest Biology and Technology 2004: 32:235–245.

124 *Droby S, Porat R, Cohen L, Weiss B, Shapiro B, Philosoph-Hadas S and Meir S. Suppressing green mold decay in grapefruit with postharvest jasmonate application. Journal of the American Society for Horticultural Science 1999: 124:184–188.

125 *Yuen CMC, Paton JE, Hanawati R and Shen LQ. Effect of ethanol, acetaldehyde and ethyl formate vapour on the growth of *Penicillium italicum* and *P. digitatum* on oranges. Journal of Horticultural Science 1995: 70: 81–84.

126 Utama IMS, Wills RBH, Ben-Yehoshua S and Kuek C. In vitro efficacy of plant volatiles for inhibiting the growth of fruit and vegetable decay microorganisms. Journal of Agricultural and Food Chemistry 2002, 50, 6371–6377.

127 MITN-C (Mitsubishi Gas Chem Co Inc). Method for retaining freshness of fruit and vegetables e.g. citrus fruit, involves preserving fruits and vegetables in presence of preset concentration of allyl-isothiocyanate. Japan: Patent No. JP2004208558–A; 2004.

128 *Caccioni DRL, Guizzardi M, Biondi DM, Renda A and Ruberto G. Relationship between volatile components of citrus fruit essential oils and antimicrobial action on *Penicillium digitatum* and *Penicillium italicum*. International Journal of Food Microbiology 1998: 43:73–79.

129 Wuryatmo E, Klieber A and Scott ES. Inhibition of citrus postharvest pathogens by vapor of citral and related compounds in culture. Journal of Agricultural and Food Chemistry 2003: 51:2637–2640.

130 Rodov V, Ben-Yehoshua S, Fang DQ, Kim JJ and Ashkenazi R. Preformed antifungal compounds of lemon fruit: citral and its relation to disease resistance. Journal of Agricultural and Food Chemistry 1995: 43:1057–1061.

131 *Ben-Yehoshua S and Mercier J. UV irradiation, biological agents, and natural compounds for controlling postharvest decay in fresh fruits and vegetables. In: Environmentally friendly technologies for agricultural produce quality. Ben-Yehoshua S (editor). Boca Raton, FL, USA: CRC Press, Taylor and Francis Group; 2005: pp. 265–299.

132 Del Río JA, Arcas MC, Benavente-García O and Ortuño A. Citrus polymethoxylated flavones can confer resistance against *Phytophthora citrophthora*, *Penicillium digitatum*, and *Geotrichum* species. Journal of Agricultural and Food Chemistry 1998: 46:4423–4428.

133 **Del Río JA and Ortuño A. Biosynthesis of flavonoids in citrus and its involvement in the antifungal defense mechanisms. In: Crop management and postharvest handling of horticultural products, vol 4, Diseases and disorders of fruits and vegetables. Dris R, Niskanen R, Mohan Jain S (editors). Enfield, NH, USA: Science Publishers Inc; 2004: pp. 185–220.

134 Ben-Yehoshua S, Rodov V, Fang DQ and Kim JJ. Preformed antifungal compounds of citrus fruit: effect of postharvest treatments with heat and growth regulators. Journal of Agricultural and Food Chemistry 1995:

43:1062–1066.

135 Venditti T, Molinu MG, Dore A, Agabbio M and D'hallewin G. Sodium carbonate treatment induces scoparone accumulation, structural changes, and alkalinization in the albedo of wounded citrus fruits. Journal of Agricultural and Food Chemistry 2005: 53:3510–3518.

136 Klieber A, Scott E and Wuryatmo E. Effect of method of application on antifungal efficacy of citral against postharvest spoilage fungi of citrus in culture. Australasian Plant Pathology 2002: 31:329–332.

137 *Angioni A, Cabras P, D'hallewin G, Pirisi FM, Reniero F and Schirra M. Synthesis and inhibitory activity of 7-geranoxycoumarin against *Penicillium* species in citrus fruit. Phytochemistry 1998: 47:1521–1525.

138 Ben-Yehoshua S and Rodov V. Developing a novel environmentally friendly microbiocidal formulation from peel of citrus fruit. Acta Horticulturae 2006: 712:275–284.

139 Dixit SN, Chandra H, Tiwari R and Dixit V. Development of a botanical fungicide against blue mould of mandarins. Journal of Stored Products Research 1995: 31:165–172.

140 Plaza P, Torres R, Usall J, Lamarca N and Viñas I. Evaluation of the potential of commercial post-harvest application of essential oils to control citrus decay. Journal of Horticultural Science & Biotechnology 2004: 79:935–940.

141 Hall DJ and Fernández YJ. In vitro evaluation of selected essential oils as fungicides against *Penicillium digitatum* sacc. Proceedings of the Florida State Horticultural Society 2004: 117:377–379.

142 Szczerbanik M, Jobling J, Morris S and Holford P. Essential oil vapours control some common postharvest fungal pathogens. Australian Journal of Experimental Agriculture 2007: 47:103–109.

143 *Daferera DJ, Ziogas BN and Polissiou MG. GC-MS analysis of essential oils from some Greek aromatic plants and their fungitoxicity on *Penicillium digitatum*. Journal of Agricultural and Food Chemistry 2000: 48:2576–2581.

144 *Arras G and Usai M. Fungitoxic activity of 12 essential oils against four postharvest citrus pathogens: chemical analysis of *Thymus capitatus* oil and its effect in subatmospheric pressure conditions. Journal of Food Protection 2001: 64:1025–1029.

145 **Tripathi P, Dubey NK, Banerji R and Chansouria JPN. Evaluation of some essential oils as botanical fungitoxicants in management of postharvest rotting of citrus fruits. World Journal of Microbiology & Biotechnology 2004: 20:317–32.

146 *Ameziane N, Boubaker H, Boudyach H, Msanda F, Jilal A and Ait Benaoumar A. Antifungal activity of Moroccan plants against citrus fruit pathogens. Agronomy for Sustainable Development 2007: 27:273–277.

147 Lanciotti R, Gianotti A, Patrignani F, Belletti N, Guerzoni ME and Gardini F. Use of natural aroma compounds to improve shelf-life and safety of minimally processed fruits. Trends in Food Science and Technology 2004: 15:201–208.

148 Saks Y and Barkai-Golan R. *Aloe vera* gel activity against plant pathogenic fungi. Postharvest Biology and Technology 1995: 6:159–165.

149 Obagwu J and Korsten L. Control of citrus green and blue molds with garlic extracts. European Journal of Plant Pathology 2003: 109:221–225.

150 Barrera-Necha L, Bautista-Baños S, Bravo-Luna L, Bermúdez-Tores K, García-Suárez S, Jiménez-Estrada M and Reyes-Chilpa R. Antifungal activity against postharvest fungi by extracts and compounds of *Pithecellobium dulce* seeds (Huamuchil). Acta Horticulturae 2003: 628:761–766.

151 *Mekbib SB, Regnier TJC and Korsten L. Control of *Penicillium digitatum* in citrus fruit using two plant extracts and study of their mode of action. Phytoparasitica 2007: 35:264–276.

152 Qasem JR and Abu-Blan HA. Antifungal activity of aqueous extracts from some common weed species. Annals of Applied Biology 1995: 127:215–219.

153 Broekaert WF, Terras FR, Cammue BP and Osborn RW. Plant defensins: novel antimicrobial peptides as components of the host defense system. Plant Physiology 1995: 108:1353–1358.

154 Broekaert WF, Cammue BP, De Bolle MF, Thevissen K, De Samblanx GW and Osborn RW. Antimicrobial peptides from plants. Critical Reviews in Plant Science 1997: 16:297–323.

155 Blondelle SE and Houghten RA. Design of model amphipathic peptides having potent antimicrobial activities. Biochemistry 1992: 31:12688–12694.

156 López-García B, Pérez-Payá E and Marcos JF. Identification of novel hexapeptides bioactive against phytopathogenic fungi through screening of a synthetic peptide combinatorial library. Applied and Environmental Microbiology 2002: 68:2453–2460.

157 López-García B, Veyrat A, Pérez-Payá E, González-Candelas L and Marcos JF. Comparison of the activity of antifungal hexapeptides and the fungicides thiabendazole and imazalil against postharvest fungal pathogens. International Journal of Food Microbiology 2003, 89, 163–170.

158 Muñoz A and Marcos JF. Activity and mode of action against fungal phytopathogens of bovine lactoferricin-derived peptides. Journal of Applied Microbiology 2006: 101:1199–1207.

159 *López-García B, González-Candelas L, Pérez-Payá E and Marcos JF. Identification and characterization of a hexapeptide with activity against phytopathogenic fungi that cause postharvest decay in fruits. Molecular Plant-Microbe Interactions 2000: 13:837–846.

160 **Muñoz A, López-García B, Marcos JF. Comparative study of antimicrobial peptides to control citrus postharvest decay caused by *Penicillium digitatum*. Journal of Agricultural and Food Chemistry 2007: 55:8170–8176.

161 Muñoz A, López-García B, Pérez-Payá E and Marcos JF. Antimicrobial properties of derivatives of the cationic tryptophan-rich hexapeptide PAF26. Biochemical and Biophysical Research Communications 2007: 354:172–177.

162 Wu T, Zivanovic S, Draughon FA, Conway WS and Sams CE. Physicochemical properties and bioactivity of fungal chitin and chitosan. Journal of Agricultural and Food Chemistry 2005: 53:3888–3894.

163 El-Ghaouth A, Smilanick JL and Wilson CL. Enhancement of the performance of *Candida saitoana* by the addition of glycolchitosan for the control of postharvest decay of apple and citrus fruit. Postharvest Biology and Technology 2000: 19:103–110.

164 Benhamou N. Potential of the mycoparasite, *Verticillium lecanii*, to protect citrus fruit against *Penicillium digitatum*, the casual agent of green mold: a comparison with the effect of chitosan. Phytopathology 2004: 94:693–705.

165 Chien PJ, Sheu F and Lin HR. Coating citrus (Murcott tangor) fruit with low molecular weight chitosan increases postharvest quality and shelf life. Food Chemistry 2007: 100:1160–1164.

166 *Chien PJ and Chou CC. Antifungal activity of chitosan and its application to control post-harvest quality and fungal rotting of Tankan citrus fruit (*Citrus tankan* Hayata). Journal of the Science of Food and Agriculture 2006: 86:1964–1969.

167 *Porat R, Vinokur V, Weiss B, Cohen E, Daus A, Goldschmidt EE and Droby S. Induction of resistance to *Penicillium digitatum* in grapefruit by β-aminobutyric acid. European Journal of Plant Pathology 2003: 109:901–907.

168 Schirra M, Delogu G, Cabras P, Angioni A, D'hallewin G, Veyrat A, Marcos JF and González-Candelas L. Complexation of imazalil with beta-cyclodextrin, residue uptake, persistence, and activity against *Penicillium* decay in citrus fruit following postharvest dip treatments. Journal of Agricultural and Food Chemistry 2002: 50:6790–6797.

169 Porat R, Weiss B, Cohen L, Daus A, Goren R and Droby S. Effects of ethylene and 1-methylcyclopropene on the postharvest qualities of 'Shamouti' oranges. Postharvest Biology and Technology 1999: 15:155–163.

170 Dou H, Jones S and Ritenour M. Influence of 1-MCP application and concentration on post-harvest peel disorders and incidence of decay in citrus fruit. Journal of Horticultural Science & Biotechnology 2005: 80:786–792.

171 Wilson CL and Wisniewski ME. Biological control of postharvest diseases of fruits and vegetables: an emerging technology. Annual Review of Phytopathology 1989: 27:425–441.

172 Droby S, Chalutz E and Wilson CL. Antagonistic microorganisms as biological control agents of postharvest diseases of fruits and vegetables. Postharvest News and Information 1991: 2:169–173.

173 Droby S, Cohen L, Weiss B, Daus A and Wisniewski M. Microbial control of postharvest diseases of fruits and vegetables - Current status and future outlook. Acta Horticulturae 2001: 553:371–376.

174 Wisniewski M, Wilson CL, El-Ghaouth A and Droby S. Non-chemical approaches to postharvest disease control. Acta Horticulturae 2001: 553: 407– 412.

175 *Wilson C L and Wisniewski ME. Biological control of postharvest diseases of fruits and vegetables - Theory and practice. Boca Raton, FL, USA: CRC Press; 1994.

176 *Droby S, Wilson CL, Wisniewski M and El-Ghaouth A. Biologically based technology for the control of postharvest diseases of fruits and vegetables. In: Microbial food contamination. Wilson CL, Droby S (editors). Boca Raton, FL, USA: CRC Press; 2000: pp. 187–205.

177 **El-Ghaouth A, Wilson CL, Wisniewski M, Droby S, Smilanick JL and Kortsten L. Biological control of postharvest diseases of citrus fruits. In: Biological control of crop diseases. Gnanamanickam SS (editor). New York, USA: Marcel Dekker Inc; 2002: pp. 289–312.

178 **Droby S, Cohen, L, Daus A, Weiss B, Horev E, Chalutz B, Katz H, Keren-Tzour, M and Shachnai A. Commercial testing of Aspire^{TM}: a biocontrol preparation for the control of postharvest decay of citrus. Biological Control 1998: 12:97–101.

179 Brown GE, Davis C and Chambers M. Control of citrus green mold with Aspire is impacted by the type of injury. Postharvest Biology and Technology 2000: 18:57–65.

180 Arras G, Fois M, Molinu MG, Venditti T and Agabbio M. Biological and integrated control by the yeast *Candida oleophila* of postharvest decay of Tangelo mapo. In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

181 Chalutz E and Wilson CL. Postharvest biocontrol of green and blue mold and sour rot of citrus fruit by *Debaromyces hansenii*. Plant Disease 1990: 74:134–137.

182 Droby S, Hofstein R, Wilson CL, Wisniewski M, Fridlender B, Cohen L, Weiss B, Daus A, Timar D and Chalutz E. Pilot testing of *Pichia guilliermondii*: a biocontrol agent of postharvest diseases of citrus fruit. Biological Control 1993: 3:47–52.

183 Droby S, Lischinski S, Cohen L, Weiss B, Daus A, Chand-Goyal T, Eckert JW and Manulis S. Characterization of an epiphytic yeast population of grapefruit capable of suppression of green mold decay caused by *Penicillium digitatum*. Biological Control 1999: 16:27–34.

184 De Corato U, Trupo M, Carboni MA, Palazzo S, Albdergo R and Nobili S. Biological control of the postharvest diseases of citrus fruits using lyophilized antagonistic yeasts. In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

185 **McGuire RG. Application of *Candida guilliermondii* in commercial citrus coatings for biocontrol of *Penicillium digitatum* on grapefruits. Biological Control 1994: 4:1–7.

186 *El-Ghaouth A, Smilanick J, Wisniewski M and Wilson CL. Improved control of apple and citrus fruit decay with a combination of *Candida saitoana* with 2-deoxy-D-glucose. Plant Disease 2000: 84:249–253.

187 *El-Ghaouth A, Smilanick JL, Brown GE, Ippolito A, Wisniewski M and Wilson CL. Application of *Candida saitoana* and glycolchitosan for the control of postharvest diseases of apple and citrus fruit under semi-commercial conditions. Plant Disease 2000: 84:243–248.

188 *Arras G. Mode of action of an isolate of *Candida famata* in biological control of *Penicillium digitatum* in orange fruits. Postharvest Biology and Technology 1996: 8:191–198.

189 D'hallewin G, Arras G, Dessi R, Dettori A and Schirra M. Citrus green mould control in stored 'Star Ruby' grapefruits by the use of a biocontrol yeast under curing conditions. Acta Horticulturae 1999: 485:111–115.

190 *Kutrzman CP and Droby S. *Metschnikowia fructicola*, a new ascosporic yeast effective for biocontrol of postharvest fruit rots. Systematic and Applied Microbiology 2001: 24:395–399.

191 Lanza G, di Martino Aleppo E, Strano MC, Aloisi V and Privitera D. Effectiveness of peracetic acid in integrated control strategies of *Penicillium* decay in Torocco orange fruit. In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

192 *Yildiz F, Kinay P, Yildiz M, Sen F and Karacali I. Effects of preharvest applications of $CaCl_2$, 2,4-D and benomyl and postharvest hot water, yeast and fungicide treatments on development of decay on Satsuma mandarins. Journal of Phytopathology 2005: 153:94–98.

193 Zheng XD, Zhang, HY and Sun P. Biological control of postharvest green mold decay of oranges by *Rhodotorula glutinis*. European Food Research and Technology 2005: 220:353–357.

194 *Zhang HY, Fu CX, Zheng XD, He D, Shan LJ and Zhan X. Effects of *Cryptococcus laurentii* (Kufferath) Skinner in combination with sodium bicarbonate on biocontrol of postharvest green mold decay of citrus fruit. Botanical Bulletin of Academia Sinica 2004: 45:159–164.

195 Long CA, Wu Z and Deng BX. Biological control of *Penicillium italicum* of citrus and *Botrytis cinerea* of grape by strain 34-9 of *Kloeckera apiculata*. European Food Research and Technology 2005: 221:197–201.

196 *Long CA, Deng BX and Deng XX. Pilot testing of *Kloeckera apiculata* for the biological control of postharvest diseases of citrus. Annals of Microbiology 2006: 56:13–17.

197 Jijakli MH, Friel D and Bajji M. In vivo application of glucanase-mutated strains of Pichia anomala against fungal pathogens on postharvest apple and citrus fruit. In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

198 **Bull CT, Stack JP and Smilanick JL. *Pseudomonas syringae* strains ESC-10 and ESC-11 survive in wounds on citrus and control green and blue molds of citrus. Biological Control 1997: 8:81–88.

199 Smilanick JL, Gouin-Behe CC, Margosan DA, Bull CT and Mackey BE. Virulence on citrus of *Pseudomonas syringae* strains that control postharvest green mold of citrus fruit. Plant Disease 1996: 80:1123–1128.

200 Cirvilleri G, Bonaccorsi A, Scuderi G and Scortichini M. Potential biological control activity and genetic diversity of *Pseudomonas syringae* pv. *syringae* strains. Journal of Phytopathology 2005: 153:654–666.

201 Stockwell VO and Stack JP. Using *Pseudomonas* spp. for integrated biological control. Phytopathology 2007: 97:244–249.

202 Smilanick JL and Denis-Arrue R. Control of green mold of lemons with *Pseudomonas species***.** Plant Disease 1992: 76:481–485.

203 Huang Y, Deverall BJ and Morris SC. Promotion of infection of orange fruit by *Penicillium digitatum* with a strain of *Pseudomonas cepacia*. Phytopathology 1991: 81:615–618.

204 Huang Y, Deverall BJ, Morris SC and Wild BL. Biocontrol of postharvest orange diseases by a strain of *Pseudomonas cepacia* under semi-commercial conditions. Postharvest Biology and Technology 1993: 3:293–304.

205 *Huang Y, Deverall BJ and Morris SC. Postharvest control of green mould on oranges by a strain of *Pseudomonas glathei* and enhancement of its biocontrol by heat treatment. Postharvest Biology and Technology 1995: 5:129–137.

206 Usall J, Teixidó N, Viñas I and Smilanick JL. Biological control of *Penicillium digitatum* on citrus fruits with the antagonistic bacterium *Pantoea agglomerans*. Acta Horticulturae 2001: 553:377–381.

207 Costa E, Teixidó N, Usall J, Atares E and Viñas I. Production of the biocontrol agent *Pantoea agglomerans* strain CPA-2 using commercial products and by-products. Applied Microbiology and Biotechnology 2001: 56:367–371.

208 Nunes C, Bajji M, Stepien V, Manso T, Torres R, Usall J and Jijakli MH. Development and application of a SCAR marker to monitor and quantify populations of the postharvest biocontrol agent *Pantoea agglomerans*

CPA-2. Postharvest Biology and Technology 2008: 47:422–428.

209 *Usall J, Smilanick JL, Palou L, Denis-Arrue N, Teixidó N, Torres R and Viñas I. Preventive and curative activity of combined treatments of sodium carbonates and *Pantoea agglomerans* CPA-2 to control postharvest green mold of citrus fruit. Postharvest Biology and Technology 2008: in press.

210 Arras G. Inhibition of postharvest fungal pathogens by *Bacillus subtilis* strains isolated from citrus fruit. Advances in Horticultural Science 1993: 7:123–127.

211 Arras G and D'hallewin G. In vitro and in vivo control of *Penicillium digitatum* and *Botrytis cinerea* in citrus fruit by *Bacillus subtilis* strains. Agricoltura Mediterranea 1994: 124:56–61.

212 Fan Q, Tian SP, Li YX, Wang Y, Xu Y and Li JD. Postharvest biological control of green mold and blue mold of citrus fruits by *Bacillus subtilis*. Acta Phytopathologica Sinica 2000: 30:343–348.

213 Zhang J and Dou H. Evaluation of *Bacillus subtilis* as potential biocontrol agent for postharvest green mold control on "Valencia" orange. Proceedings of the Florida State Horticultural Society 2002: 115:60–64.

214 *Obagwu J and Korsten L. Integrated control of citrus green and blue molds using *Bacillus subtilis* in combination with sodium bicarbonate or hot water. Postharvest Biology and Technology 2003: 28:187–194.

215 *Leelasuphakul W, Hemmanee P and Chuenchitt S. Growth inhibitory properties of *Bacillus subtilis* strains and their metabolites against the green mold pathogen (*Penicillium digitatum* Sacc.) of citrus fruit. Postharvest Biology and Technology 2008: 48: 113–121.

216 Huang Y, Wild BL and Morris SC. Postharvest biological control of *Penicillium digitatum* decay on citrus fruit by *Bacillus pumilus*. Annals of Applied Biology 1992: 120:367–372.

217 Meziane H, Gavriel S, Ismailov Z, Chet I, Chernin L and Höfte M. Control of green and blue mould on orange fruit by *Serratia plymuthica* strains IC14 and IC1270 and putative modes of action. Postharvest Biology and Technology 2006: 39:125–133.

218 Díaz MA and Vila R. Biological control of *Penicillium digitatum* by *Trichoderma viride* on postharvest citrus fruits. International Journal of Food Microbiology 1990: 11:179–184.

219 Schena L, Ippolito A, Zahavi T, Cohen L, Nigro F and Droby S. Genetic diversity and biocontrol activity of *Aureobasidium pullulans* isolates against postharvest rots. Postharvest Biology and Technology 1999: 17:189–199.

220 Liu X, Wang J, Gou P, Mao C, Zhu ZR and Li H. In vitro inhibition of postharvest pathogens of fruit and control of gray mold of strawberry and green mold of citrus by aureobasidin A. International Journal of Food Microbiology 2007: 119:223–229.

221 El-Ghaouth A, Wilson CL and Wisniewski M. Evaluation of two biocontrol products, Bio-Coat and Biocure, for the control of postharvest decay of pome and citrus fruit. In: Biocontrol agents: mode of action and interaction with other means of control. Elad Y, Freeman S, Monte E (editors). IOBC/WPRS Bulletin 24; 2001: pp. 161–166.

222 Karabulut OA, Smilanick JL, Mlikota Gabler F, Mansour M and Droby S. Near-harvest applications of *Metschnikowia fructicola*, ethanol, and sodium bicarbonate to control postharvest diseases of grape in central California. Plant Disease 2003: 87:1384–1389.

223 Karabulut OA, Tezcan H, Daus A, Cohen L, Weiss B and Droby S. Biological control of preharvest and postharvest rots in strawberries by *Metschnikowia fructicola*. Biocontrol Science and Technology 2004: 14:513–521.

224 Blachinsky D, Antonov J, Bercovitz A, El-ad B, Feldman K, Husid A, Lazare M, Marcov N, Shamai I, Droby S and Keren-Zur M. Commercial applications of Shemer for the control of pre- and post-harvest diseases. In: Fundamental and practical approaches to increase biocontrol efficacy. Edited by: Yigal E, Ongena M, Höfte M, Jijakli H (editors). IOBC/WPRS Bulletin 30; 2007: pp. 75–78.

225 Droby S, Chalutz E, Wilson CL and Wisniewski M. Biological control of postharvest diseases: a promising alternative to the use of synthetic fungicides. Phytoparasitica 1992: 20:1495–1535.

226 *Fajardo JE, McCollum TG, McDonald RE and Mayer RT. Differential induction of proteins in orange flavedo by biologically based elicitors and challenged by *Penicillium digitatum* Sacc. Biological Control 1998: 13:143–151.

227 **Droby S, Wisniewski M, Cohen L, Weiss B, Touitou D, Eilam Y and Chalutz E. Influence of $CaCl_2$ on *Penicillium digitatum*, grapefruit tissue and biocontrol activity of *Pichia guilliermondii*. Phytopathology 1997:87: 310–315.

228 Potjewijd R, Nisperos MO, Burns JK, Parish M and Baldwin EA. Cellulose-based coatings as carriers for *Candida guillermondii* and *Debaryomyces* sp. in reducing decay of oranges. HortScience 1995: 30:1417–1421.

229 McGuire RG and Hagenmaier RD. Shellac coatings for grapefruits that favor biological control of *Penicillium digitatum* by *Candida oleophila*. Biological Control 1996: 7:100–106.

230 McGuire RG and Dimitroglou DA. Evaluation of shellac and sucrose ester fruit coating formulations that support biological control of postharvest grapefruit decay. Biocontrol Science and Technology 1999: 9:53–65.

231 **Mercier J and Smilanick JL. Control of green mold and sour rot of stored lemon by biofumigation with *Muscodor albus*. Biological Control 2005: 32:401–407.

232 El-Ghaouth A, Droby S, Wilson CL, Wisniewski M, Smilanick JL and Korsten L. Biological control of postharvest diseases of fruits and vegetables. In: Applied mycology and biotechnology: agriculture and food production. Arora DK, Khachatourians GG (editors). Amsterdam, The Netherlands: Elsevier Science BV; 2004: pp. 11–27.

233 Alabouvette C, Olivain C and Steinberg C. Biological control of plant diseases: the European situation. European Journal of Plant Pathology 2006: 114:329–341.

234 Janisiewicz WJ and Korsten L. Biological control of postharvest diseases of fruits. Annual Review of Phytopathology 2002: 40:411–441.

235 Spadaro D and Gullino ML. State of the art and future prospects of the biological control of postharvest fruit diseases. International Journal of Food Microbiology 2004: 91:185–194.

236 *Arras G and Maltoni SL. Postharvest biological and integrated control of fungal pathogens on fruit. In: Crop management and postharvest handling of horticultural products, vol 4, Diseases and disorders of fruits and vegetables. Dris R, Niskanen R, Mohan Jain S (editors). Enfield, NH, USA: Science Publishers Inc; 2004: pp. 115–183.

237 *Segal E, Yehuda H, Droby S, Wisniewski M and Goldway M. Cloning and analysis of CoEXG1, a secreted 1,3-β-glucanase gene of the yeast biocontrol agent *Candida oleophila*. Yeast 2002: 19:1171–1182.

238 *Bar-Shimon M, Yehuda H, Cohen L, Weiss B, Kobeshnikov A, Daus A, Goldway M, Wisniewski M and Droby S. Characterization of extracellular lytic enzymes produced by the yeast biocontrol agent *Candida oleophila*. Current Genetics 2004: 45:140–148.

239 Costa E, Teixidó N, Usall J, Atares E, Viñas I. The effect of nitrogen and carbon sources on growth of the biocontrol agent *Pantoea agglomerans* strain CPA-2. Letters in Applied Microbiology 2002: 35:117–120.

240 Costa E, Usall J, Teixidó N, Torres R and Viñas I. Effect of package and storage conditions on viability and efficacy of the freeze-dried biocontrol agent *Pantoea agglomerans* strain CPA-2. Journal of Applied Microbiology 2002: 92:873–878.

241 Barkai-Golan R and Kahan RS. Combined action of diphenyl and gamma radiation on the in vitro development of fungi pathogenic to citrus fruit. Phytopathology 1967: 7:696–698.

242 Kahan RS and Barkai-Golan R. Combined action of sodium orthophenilphenate and gamma radiation on the in vitro development of fungi pathogenic to citrus fruit. Phytopathology 1968: 58:700–701.

243 Smilanick JL, Mansour MF, Margosan DA, Mlikota Gabler F and Goodwine WR. Influence of pH and $NaHCO_3$ on effectiveness of imazalil to inhibit germination of *Penicillium digitatum* and to control postharvest green mold on citrus fruit. Plant Disease 2005: 89:640–648.

244 Smilanick JL, Mansour MF and Sorenson D. Pre- and postharvest treat-

ments to control green mold of citrus fruit during ethylene degreening. Plant Disease 2006: 90:89–96.

245 *Cunningham NM and Taverner PD. Efficacy of integrated postharvest treatments against mixed inoculations of *Penicillium digitatum* and *Geotrichum citri-aurantii* in 'Leng' navel oranges (*Citrus sinensis*). New Zealand Journal of Crop and Horticultural Science 2007: 35:187–192.

246 Bower JP, Dennison MT and Schutte GC. An integrated approach to postharvest disease management in citrus. Acta Horticulturae 2003: 628:715–720.

247 Ritenour MA, Pelosi RR, Burton MS, Stover EW, Dou HT and McCollum TG. Assesing the efficacy of preharvest fungicide applications to control postharvest diseases of Florida citrus. HortTechnology 2004: 14:58–62.

248 Ligorio A, Schena L, Pentomone I, Quinto G, Mennone C, Nigro F, Ippolito A and Salerno M. Pre- and postharvest application of salts for controlling green and blue mold of Clementine. In: Proceedings of COST Action 924 International Congress, Novel approaches for the control of postharvest diseases and disorders. Bologna, Italy: CRIOF, University of Bologna, 2008. In press.

249 *Zhang J and Timmer LW. Preharvest application of fungicides for postharvest disease control on early season tangerine hybrids in Florida. Crop Protection 2007: 26:886–893.

250 *Barkai-Golan R, Kahan RS and Padova R. Synergistic effects of gamma radiation and heat on the development of *Penicillium digitatum* in vitro and in stored citrus fruit. Phytopathology 1969: 59:922–924.

251 D'hallewin G, Arras G, Castia T and Piga A. Reducing decay of 'Avena' mandarin fruit by the use of UV, heat and thiabendazole treatments. Acta Horticulturae 1994: 368:387–394.

252 Ben-Yehoshua S, Rodov V, D'hallewin G and Dore A. Elicitation of resistance against pathogens in citrus fruits by combined UV illumination and heat treatments. Acta Horticulturae 2005: 682:2013–2019.

253 *Palou L, Montesinos-Herrero C and del Río MA. Short-term CO_2 exposure at curing temperature to control postharvest green mold of mandarins. In: Proceedings of the XXVII International Horticultural Congress IHC 2006, Acta Horticulturae 2008: in press.

254 Barkai-Golan R and Apelbaum A. Synergistic effects of heat and sodium o-phenyl phenate treatments to inactivate *Penicillium* spores and suppress decay in citrus fruits. Tropical Science 1991: 31:229–233.

255 Schirra M and Mulas M. Improving storability of "Tarocco" oranges by postharvest hot-dip fungicide treatments. Postharvest Biology and Technology 1995: 6:129–138.

256 Schirra M, Cabras P, Angioni A, D'hallewin G, Ruggiu R and Minelli EV. Effect of heated solutions on decay control and residues of imazalil in lemons. Journal of Agricultural and Food Chemistry 1997: 45:4127–4130.

257 Smilanick JL, Michael IF, Mansour MF, Mackey BE, Margosan DA, Flores D and Weist CF. Improved control of green mold of citrus with imazalil in warm water compared with its use in wax. Plant Disease 1997: 81:1299–1304.

258 **Porat R, Daus A, Weiss B, Cohen L and Droby S. Effects of combining hot water, sodium bicarbonate and biocontrol on postharvest decay of citrus fruit. Journal of Horticultural Science & Biotechnology 2002: 77:441–445.

259 Brown GE and Baraka MA. Effect of washing sequence and heated solutions to degreened Hamlin oranges on Diplodia stem-end rot, fruit colour and phytotoxicity. Proceedings of the International Society of Citriculture 1996: 2:1164–1170.

260 Brown GE and Dezman DJ. Uptake of imazalil by citrus fruit after postharvest application and the effect of residue distribution on sporulation of *Penicillium digitatum*. Plant Disease 1990: 74:927–930.

261 *Plaza P, Usall J, Torres R, Abadias M, Smilanick JL and Viñas I. The use of sodium carbonate to improve curing treatments against green and blue moulds on citrus fruits. Pest Management Science 2004: 60:815–821.

262 *Plaza P, Usall J, Smilanick JL, Lamarca N and Viñas I. Combining *Pantoea agglomerans* (CPA-2) and curing treatments to control established infections of *Penicillium digitatum* on lemons. Journal of Food Protection 2004: 67:781–786.

263 *Stevens C, Khan VA, Lu JY, Wilson CL, Pusey PL, Igwegbe ECK, Kabwe K, Mafolo Y, Liu J, Chalutz E and Droby S. Integration of ultraviolet (UV-C) light with yeast treatment for control of postharvest storage rots of fruits and vegetables. Biological Control 1997: 10:98–103.

264 D'hallewin G, Arras G, Venditti T, Rodov V and Ben-Yehoshua S. Combination of ultraviolet-C irradiation and biocontrol treatments to control decay caused by *Penicillium digitatum* in 'Washington navel' orange fruit. Acta Horticulturae 2005: 682:2007–2012.

265 Brown CE and Chambers M. Evaluation of biological products for the control of postharvest diseases of Florida citrus. Proceedings of the Florida State Horticultural Society 1996: 109:278–282.

266 Arras G and Arru S. Inhibitory activity of antagonist yeasts against citrus pathogens in packinghouse trials. Agricoltura Mediterranea 1999: 129:249–255.

267 Kinay P, Yildiz M, Yildiz F, Delen N and Tosun N. Control of postharvest *Penicillium* decay of citrus fruits with antagonist yeasts and chemical fungicides. Acta Horticulturae 2001: 553:383–387.

268 *Arras G, Scherm B and Migheli Q. Improving biocontrol activity of *Pichia guillermondii* against post-harvest decay of oranges in commercial packing-houses by reduced concentrations of fungicides. Biocontrol Science and Technology 2002: 12:547–553.

269 **Teixidó N, Usall J, Palou L, Asensio A, Nunes C and Viñas I. Improving control of green and blue molds of oranges by combining *Pantoea agglomerans* (CPA-2) and sodium bicarbonate. European Journal of Plant Pathology 2001: 107:658–694.

270 Torres R, Nunes C, García JM, Abadias M, Viñas I, Manso T, Olmo M and Usall J. Application of *Pantoea agglomerans* CPA-2 in combination with heated sodium bicarbonate solutions to control the major postharvest diseases affecting citrus at several mediterranean locations. European Journal of Plant Pathology 2007: 118:73–83.

271 **Droby S, Vinokur V, Weiss B, Cohen L, Daus A, Goldschmidt EE and Porat R. Induction of resistance to *Penicillium digitatum* in grapefruit by the yeast biocontrol agent *Candida oleophila*. Phytopathology 2002: 92:393–399.