Agriculture and Food

http://www.aimspress.com/journal/agriculture

AIMS Agriculture and Food, 5(3): 337–364.
DOI: 10.3934/agrfood.2020.3.337
Received: 25 February 2020
Accepted: 08 July 2020
Published: 14 July 2020

Review

A review of the postharvest characteristics and pre-packaging treatments of citrus fruit

Alaika Kassim[1],*, Tilahun S. Workneh[1] and Mark D. Laing[2]

[1] Bioresources Engineering, School of Engineering, College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Private Bag X01, Pietermaritzburg, Scottsville, 3209, South Africa
[2] Discipline of Plant Pathology, School of Agricultural, Earth and Environmental Science, University of KwaZulu-Natal, Private Bag X01, Pietermaritzburg, Scottsville, 3209, South Africa

* **Correspondence:** Email: kassima@ukzn.ac.za; Tel: +27332605703.

Abstract: Once harvested, fruit continue to respire, which is further exacerbated by elevated temperatures in the field and during transport to packhouses. This favors the proliferation of pathogens, which is detrimental to the postharvest fruit quality and, consequently, results in a decrease in the fruit shelf life. The aim of this review is to highlight the common citrus postharvest disorders and the various pre-packaging treatments that can be used to alleviate such disorders and promote fruit quality. Hot water, surface coatings, ultra-violet irradiation, chlorine (hypochlorous), salt treatments and microbial antagonists have been beneficial in maintaining the citrus quality and reducing the prevalence of postharvest decay. Environmentally friendly anolyte water has also proven to be a favourable postharvest treatment. Integrated treatments, such as hot water treatments and chlorine disinfection, have been successfully used in the global citrus industry. The use of integrated pre-packaging treatments improved the quality and shelf life of citrus, compared to individual treatments. An effective combination of pre-packaging treatments should include: (1) disinfectant; (2) curative and (3) preventive treatments to control pre- and postharvest pathogens.

Keywords: citrus; pre-packaging treatments; quality; postharvest disorders

1. Introduction

The aesthetics of citrus fruit has a significant effect on the consumer's decision to purchase [1]. However, the aesthetics and nutritional characteristics of citrus are negatively affected by pathogenic disorders and postharvest handling. Unsuitable fruit handling leads to hastened physiological deterioration, which can manifest in the proliferation of microbiological activity, and accelerated ripening and decay. This can have further market related consequences, resulting in reduced income generation by farmers and a negative importer perception toward exporting countries. Many studies have identified *Penicillium digitatum* and *Penicillium italicum* to be the most severe postharvest fungal pathogens affecting citrus [2–4]. Fungicides have commonly been used to address these problems. However, more environmentally friendly treatments are being sought due to the development of fungal resistance to fungicides, and the growing public demand for safer foods [5,6]. Exposure of citrus fruit to field heat and ambient conditions during transport from the orchard to the packhouse exacerbates the deterioration process by further increasing fruit temperature, promoting microbial proliferation [7,8]. The use of pre-packaging treatments, such as hot water, surface coatings, ultra-violet irradiation, chlorinated water, biocontrol agents, and carbonate and bicarbonate salts were found to be beneficial in maintaining the postharvest quality of citrus fruit [4,9,10]. Heat treatments have been found to induce fruit tolerance against cold injury and pathogens due to the development of heat shock proteins [5]. The application of surface coatings or waxes promotes the aesthetic appeal of the fruit and reduces the loss of moisture, thereby extending the fruit shelf life [11]. Ultra-violet irradiation reduces decay in citrus fruit due to its germicidal effect and its ability to induce the fruit’s tolerance to decay [5]. Treatment of citrus with carbonate and bicarbonate salts can delay postharvest decay by activating the fruit’s defense mechanism [4]. Similarly, the use of chlorine (hypochlorite) as a disinfectant has also extended the citrus fruit shelf life and is widely used in the fruit industry [12,13]. Biocontrol agents have been used as an alternative to synthetic fungicides to alleviate postharvest decay [14,15]. Anolyte water has demonstrated strong germicidal and disinfecting characteristics when applied to tangerine [16]. These pre-packaging treatments have been used with success as individual treatments but more so, the combined effect of a number of these pre-packaging treatments have been beneficial in extending the shelf life of citrus [5,17,18,19–21]. The aim of this review was to determine the most prevalent form of pre-packaging treatments to reduce the onset and proliferation of common diseases affecting citrus fruit.

2. Disorders affecting citrus quality

2.1. Impact of harvesting techniques

Citrus fruit can be classified as being non-climacteric, with low rates of respiration and ethylene evolution during the ripening stage [22–24]. This allows for extended storage periods of six to eight weeks (variety dependent) [22,24]. Li et al. [24] observed that after harvest, under ambient conditions, citrus fruit can lose excessive moisture and become wrinkly. Grierson and Ben-Yehoshua [25] identified harvesting as being the single most critical factor influencing fruit quality during storage and transportation. Citrus fruit are unable to ripen once harvested unripe and, therefore, they should be picked when fully ripe [23,26]. The onset of postharvest decay in citrus fruit is largely dependent on cultural practices, such as the method and time of harvest, and pre- and postharvest factors [13,27]. Once harvested, the fruit become more susceptible to microbiological infections as it is detached from the plant [27]. McGuire and Reeder [28] found that late and early season grapefruit succumbed to greater damage (scalding) when exposed to air heated to 46 ℃, 48 ℃, and 50 ℃ for three, five or seven hours, compared to mid-season fruit after harvest. This could be attributed to early season fruit having immature skins and late season fruit already beginning to senesce. Dessert lemons and blood oranges are most susceptible to chilling injury when harvested early in the season [29,30].

Currently citrus harvesting is done manually by hand as this method results in the least damage to the fruit, which minimises the risk of early decay and inferior postharvest quality [31,32]. Mechanical harvesting in the citrus industry has not been a prominent feature because it lacks the flexibility and fruit selection ability of manual harvesting [32]. However, more automated systems employing the desired selection criteria for individual citrus fruit have been developed by Jimenez et al. [33]. Kumquat fruit stems are clipped rather than snapped because the latter may induce fruit injury. Fruit that are yellow to orange are ready to be picked [34]. A small portion of the pedicel is still attached to the kumquat because it cannot easily be removed without injuring the fruit. However, it is this portion of the stem that regularly causes injury to adjacent fruit in containers, which hastens fruit deterioration [13]. This problem requires research to be conducted to optimise kumquat harvesting. The pickers also play a pivotal role by practicing hygienic methods of harvesting to prevent *Escherichia coli* contamination of fruit [35]. This can be addressed by providing pickers with portable toilets, a suitable disinfectant and water. Pickers should also avoid picking fruit from the ground to minimise infection as the fruit may have been damaged when it fell to the ground.

2.1.1. Pathological and physiological disorders

Harvested commodities need to be cleaned of any dirt, debris, insects and synthetic chemicals prior to packaging to extend the shelf life and for greater aesthetic appeal to consumer [36]. Porat et al. [22] identified two factors that limit the postharvest shelf life of citrus: (1) pathological breakdown and (2) physiological breakdown. Physiological disorders are as a result of a malfunction of the fruit physiological processes due to abiotic stresses such as temperature, relative humidity and chemicals [23]. Pathological decay is caused by fungi or bacteria, which weaken the fruit and affect its ability to ripen properly [23,37]. Droby et al. [38], Ladaniya [23], Schirra et al. [39], Gomez-Sanchis et al. [40], Altieri et al. [3], and Youssef et al. [4] have all identified *Penicillium digitatum* and *Penicillium italicum* as the most severe postharvest pathological infections affecting citrus fruit. Similarly, Chalutz et al. [41]; cited by Schirra et al. [39], noted that citrus fruit are susceptible to rapid decay due to infection caused by *Penicillium* pathogens. Citrus fruit under ambient conditions are mainly susceptible to green mould caused by *P. digitatum* Sacc., which may result in 60–80% fruit decay while blue mould is a result of *P. italicum* Wehmer exhibited by fruit stored under cold storage (Figure 1 (a)). Citrus black spot (CBS), *Guignardia citricarpa*, has, in the past, contaminated South African citrus exports to the European Union (EU) after the disease was detected in some of the shipments, as explained by Mokomele [42]. As of 29 November 2013, the Standing Committee on Plant Health stated that only citrus from areas free of CBS in South Africa could be exported to the EU for that particular season (Mokomele, 2013). However, according to Yonowa et al. [43] the CLIMEX model, which simulates an organism’s response to a particular climate worldwide, showed that CBS poses an exceedingly low risk to the citrus producing regions in Europe. Figure 1 (b) illustrates freckle spot caused by CBS.

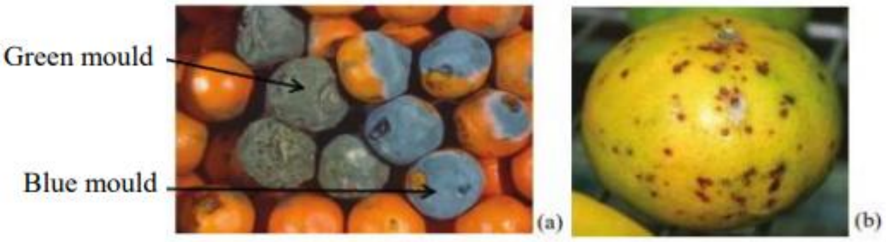

Figure 1. (a) Green mould caused by *Penicillium digitatutm* and blue mould caused by *Penicillium italicum* and (b) freckle spot caused by citrus black spot [44].

Sour rot (*Geotrichum candidum*) has also been described as a postharvest disease resulting in significant losses in citrus fruit [45,46]. Losses are particularly greater during the wet season and fruit degreening [46]. Sour rot requires open wounds on the citrus fruit for entry and proliferation [23,46]. Stem-end rind breakdown is classified as a physiological disorder, which can be attributed to an imbalance in potassium and nitrogen. However, its development is dependent on the handling procedures between picking and packaging [47]. This disorder results in the collapse and darkening of the epidermal tissue around the stem-end of the fruit. The loss in fruit moisture promotes stem-end rot [47–49]. Grierson [47] recommends that fruit be transported immediately after harvest to the packhouse and maintained at high relative humidity (>90%). Furthermore, during pre-treatment, brush applicator speeds should not exceed 100 rpm [47]. Table 1 lists some of the pathological and physiological diseases and disorders common to citrus fruit.

3. Postharvest quality of citrus

3.1. Physical quality parameters

3.1.1. Skin colour

The colour perception of citrus fruit is an important factor in determining a customer’s willingness to purchase [68,69]. Colour measurement can be carried out either subjectively or objectively, as in the case of firmness (Section 3.1.3). Subjective colour measurement is determined visually by eye. Ladaniya [23] describes a colour scale system, which divides samples into different colour categories of deep green, light green, yellowish-green, greenish-yellow, yellowish-orange, orange, and deep orange. This scale may vary depending on the citrus cultivar. Objective colour measurements make use of calibrated equipment such as colour meters [70]. The parameters associated with colour include L (lightness or brightness), a* (redness or greenness), b* (yellowness or blueness), hue and chroma [70]. The colour change in citrus fruit can be attributed to the conversion of chloroplasts to chromoplasts, resulting in a loss of chlorophyll and the synthesis of carotenoids [68,69,71,72]. Ortiz [71] attributed the yellow colour in citrus to carotenes and xanthophylls, and the reddish colour to anthocyanin. The application of exogenous ethylene during the process of degreening has been found to accelerate the development of carotenoids in citrus fruit and to improve colour development [73,74]. Rodov et al. [75] found that hot water brushing of citrus fruit at 60 °C delayed the colour change from green to yellow by two weeks. This could be due to the production of heat shock proteins, which inhibit senescence. Smilanick et al. [76] found that the postharvest application of sodium bicarbonate, either alone or in combination with thiabendazole fungicide, resulted in a detectable but minor delay in the colour change during the process of degreening.

3.1.2. Weight loss

Weight loss is an important factor in citrus fruit deterioration and is often accompanied by a decrease in firmness [77]. Citrus fruit have a high moisture content in both the pulp and peel [78,79]. The loss of moisture via transpiration and respiration occur rapidly after harvest, promoting fruit decay [41,80]. Much of the moisture is lost from the peel tissue, leading to shrivelling, shrinkage, softening and deformation, affecting the fruit appearance. The weight loss in heat-treated mandarins was significantly lower than in ultra-violet (UV) irradiated fruit [81]. The use of waxes reduces the loss in moisture in many horticultural crops [78,82,83]. However, over-waxing can lead to off-flavours and odours [80,82]. Cohen et al. [84] found that the use of water-based polyethylene waxes on Murcott tangerines reduced the weight loss but also led to an inferior taste, compared to un-waxed fruit. According to Ben-Yehoshua et al. [85], waxes block the stomatal pores, hindering gas exchange to a greater extent than moisture. It was further observed that individually wrapping oranges and grapefruit in high density polyethylene films reduced moisture loss by 90% without detrimentally restricting gas exchange, compared to waxing. Kumquat fruit dipped in hot water (53 °C for 120 seconds) displayed a lower weight loss, compared to control samples [86]. Heat treatments have a profound effect in reducing weight loss of citrus fruit. Fruit moisture loss, due to the vapour pressure deficit at the time between harvest and packing, leads to an increase in the incidence of pitting [87].

3.1.3. Firmness

Fruit firmness is a mechanical property which can be defined as the resistance to puncture and/or deformation. Fruit firmness is often used as a criterion to determine the effects of storage and shelf life [69]. Firmness tests include puncture resistance, compression, creep, impact and sonic tests [88]. Instruments commonly used to measure citrus firmness include texture analysers, and handheld penetrometers, which constitutes objective methods. Subjective techniques include hand-feel and acoustic response measurements [23,88,89]. The peel of the citrus fruit is composed of the flavedo (exterior coloured portion) and the albedo (white inner portion), which resists exerted forces. Beneath the peel are segments composed of juice sacs or juice vesicles, which offer minimal resistance to applied forces. With an increasing moisture loss, the peel becomes tough and leathery. Heat-treated mandarins resulted in superior fruit firmness, compared to UV treated samples [81]. Similar results were obtained by Rodov et al. [75], where hot water dipping (52 °C for 120 seconds) and hot water brushing (60 °C) resulted in firmer fruit than non-treated samples. Citrus fruit coated with chitosan wax and those treated with thiabendazole fungicide were firmer, compared to control samples, after 56 days of storage at 15 °C [78].

Citrus fruit firmness primarily depends on cell turgidity, which is associated with the moisture content. Rodov et al. [75,86] observed that heat treatments assist in redistributing the natural epicuticular wax, which seals microscopic cracks, preventing the escape of moisture, promoting cell turgidity and firmer fruit. Heat treatments may also improve fruit firmness by inhibiting enzyme activity involved in fruit softening or by cell wall strengthening (lignification).

Table 1. Summary of diseases and physiological disorders of citrus fruit.

Disease classification	Citrus cultivar	Disease/physiological disorder	Symptoms	Additional information	Prevention/remedy/control	Reference
Pre-harvest						
Bacterial disease	All citrus cultivars but may differ in the degree of susceptibility	Asiatic citrus canker caused by *Xanthomonas axonopodis* pv.*citri* (Xac A)	Raised lesion appearing on leaves, corky/ scab-like lesions on the fruit, premature fruit drop and poor fruit quality	Affects citrus trees. Areas that are susceptible experience high rainfall and humidity	Plants own defense mechanism, cultural practices, such as wind breaks, copper sprays	Stall (1988); Khalaf *et al*. (2007)
Fungal disease in nursery and orchards (affecting the fruit)	All citrus, mainly affecting orange, mandarin, lemon, and grapefruit	Black spot caused by *Guignardia citricarpa* (Kiely)	Premature fruit abscission. The four catagories of symptoms are (1) hard spot, (2) freckle spot, (3) virulent or spreading, and (4) false melanose or speckled blotch	Symptoms may appear during late stages fruit development or after harvest. Symptoms vary among cultivars	Removal of infected trees and fruit from orchards, copper fungicides, spore trapping, fruit maintained at below 20 °C after harvest	Kotze (1988); Korf *et al*. (2001); Bonants *et al*. (2003); Yonowa *et al*. (2013)
Postharvest						
Postharvest fungal disease	All citrus	Blue mould caused by *Penicillium italicum* Wehmer	Diseased tissue appears to be soft, watery and discoloured. Formation of a white powdery growth forms on lesions and develops into a mass of blue spores	Healthy fruit can be infected due to the movement of spores	Application of synthetic fungicides, hot water treatment, sodium carbonate, and sodium bicarbonate	Brown and Eckert (1988a); Palou *et al*. (2002); Venditti *et al*. (2005)
Postharvest fungal disease	All citrus	Green mould caused by *Penicillium digitatum* (Pers.:Fr.) Sacc.	The initial symptoms are similar to that of blue mould. The fruit becomes enveloped in a mass of olive green spores	Wounding during harvesting and postharvest handling initiates the action of this pathogen. Healthy fruit can be infected due to the movement of spores	Application of synthetic fungicides, hot water treatment, sodium carbonate, and sodium bicarbonate	Brown and Eckert (1988b); Smilanick *et al*. (1997); Smilanick *et al*. (1999); Pavoncello *et al*. (2001); Palou *et al*. (2002); Venditti *et al*., 2005, Youssef *et al*. (2014)

Continued on next page

Disease classification	Citrus cultivar	Disease/physiological disorder	Symptoms	Additional information	Prevention/remedy/control	Reference
Postharvest fungal disease	All citrus, particularly	*Geotrichum candidum*	Light to dark yellow water-soaked, raised lesions. White or cream mycelium may appear	Sour rot is stimulated by the presence of green mould	Preventing fruit contact with the soil during harvest. Delayed harvesting till later in the day. Minimizing fruit storage temperatures	Mercier and Smilanick, 2005; Smilanick *et al*., 2005; Ladaniya, 2008; Talibi *et al*., 2012
Postharvest fungal disease	All citrus	Stem-end rot caused by *Diplodia natalensis* P. Evans	The fungus starts at the stem and penetrates the rind and core. Decay is uneven and resembles finger-like projections of brown tissue. Mycelium form at the advanced stage of infection	Citrus that have been degreened using ethylene (5–10 μl.L^{-1}) are particularly susceptible. Temperatures in excess of 21 ℃ promote fungal growth	The use of fungicides before and after degreening. Immediate cooling after packing	Brown (1986); Brown and Eckert (1988c); Brown and Lee (1993); Zhang and Swingle (2005)
Rind disorders	All cultivars, but mainly grapefruit, lemons and lime	Rind disorder caused by chilling injury	Browning of the flavedo, albedo and dark, sunken tissue	Chilling injury is a result of exposing the fruit to too low temperatures before and/or after harvest	Heat treatments, intermittent warming, temperature conditioning, application of a wax, modified atmosphere packaging	Wardowski (1988a); Porat *et al*. (2004); Sapitnitskaya *et al*. (2006)
Stem-end rind breakdown	All cultivars but mainly in oranges	Rind disorder caused by aging.	Darkening and collapsing of the rind around the stem-end	Can result from an imbalance in potassium and nitrogen. Stem-end breakdown is associated with moisture loss and occurs mainly in thin-skinned small fruit. Symptoms usually occur two to seven days after packing	Maintaining high humidity environments, harvested fruit should be protected against heat and water loss, which can be achieved by use of a wax	Grierson (1986); Wardowski (1988b); Ritenour *et al*. (2004)

3.2. Chemical quality parameters

3.2.1. Total titratable acid

Organic acids play a major role in the organoleptic characteristics of citrus fruit. Citric acid accounts for approximately 80–95% of the total titratable acids (TTA) in citrus fruit [23]. Generally, there is a decrease in the TTA of citrus fruit during ripening, depending on the cultivar [23,68,71,90,91]. This can be attributed to the catabolism of citric acid as well as an increase in the total sugars, resulting in mature fruit having lower acidity [72]. Sadka et al. [90] found that a high acid content in mature citrus fruit can reduce the quality and delay harvest. The method commonly used to measure TTA is titration [23,92,93]. Other advanced methods make use of magnetic resonance [88]. Purvis [80] found that the acid content in grapefruit and oranges decreased during storage. Similarly, Baldwin et al. [94] observed a decrease in the citric acid of oranges after four weeks of storage. The TTA in fresh cut oranges stored at 4 °C was found to decrease from 0.46% to 0.29% over a 13-day storage period [95]. Hong et al. [93] found that heat-treated mandarins did not display a significant change in the TTA.

3.2.2. Total soluble solids

The total soluble solids (TSS) of citrus fruit contribute approximately 10–20% of the fresh weight. About 70–80% of the TSS are carbohydrates [72]. Other minor constituents of TSS include organic acids, proteins, lipids and minerals [23,68,72]. TSS determination is based on the refractive index of the fruit juice using a refractometer. Rodov et al. [75] found a gradual increase in the TSS of citrus fruit during storage. This is due to the loss in moisture resulting in an increase in the solute concentration. D’hallewin et al. [81] found that the TSS in heat-treated (36 °C for 72 hours) and UV-treated (24 nm) Avana mandarins were lower than control samples at 7.85, 7.63 and 8.02 °Brix, respectively. Baldwin et al. [94] found that coated oranges had a slightly lower TSS, compared to uncoated fruit stored at 16 °C or 21 °C; however, this was not significant. Purvis [80] did not find any significant change in the TSS of waxed oranges and grapefruit. Contrary to these observations, Hong et al. [93] found a decrease in the TSS, which was attributed to consumption of sugars and organic acids for plant metabolism in mandarins during storage.

3.2.3. Maturity index

Commercial maturity indices are essential in determining the best time for harvest. However, this is dependent on the citrus species and varieties and on external factors such as growing regions and destination [96]. The maturity index can be determined by the ratio of TSS:TTA [68,71,72,81]. This serves as an indication of the commercial maturity of oranges, mandarins, grapefruit, pummelos and their hybrids [23]. The maturity index is also used to determine the relative sweetness or sourness of citrus fruit. The maturity index tends to increase due to the increase in the soluble solids and the decrease in the organic acids [68]. Higher ratios generally imply a decrease in the acidity; however, this is dependent on the contributions of both TSS and TTA. The highest maturity index of Avana mandarins was observed for heat treatments at 36 °C for 72 hours (16.77), compared to UV treatment (15.48) [81]. The maturity index for an acceptable flavour quality in grapefruit, mandarin and orange were found to be approximately 6+, 8+ and 8+, respectively [26]. The juice content can also be used as a maturity indicator [96]. As the fruit ripens and matures, the juiciness increases to reach a maximum value at full maturity, thereafter decreasing. Lado et al. [96] has mentioned that it is important to differentiate between commercial maturity and physiological maturity with regard to the market. Bearing this in mind it was also mentioned to perhaps introduce ‘nutritional’ and ‘sensorial’ harvest indices to cater for the flavor and health attributes for marketability.

3.3. Microbiological quality parameters

3.3.1. Penicillium digitatum and *Penicillium italicum*

Citrus fruit treated by hot water dipping at 52 °C for 120 seconds, or thiabendazole wax, or curing at 36 °C for 72 hours, all controlled the development of *Penicillium* moulds [75]. The incidence of citrus decay was also reduced by hot drench brushing treatments at 56 or 60 °C. Similar results were obtained for kumquats in which fruit were dipped in water at 52 °C for 120 seconds. This effectively reduced decay during four weeks of storage [75]. Hot water brushing for 20 seconds at 56 °C reduced decay development due to *P. digitatum* by 80% [9]. The optimum curing temperature inhibiting *P. digitatum* growth in oranges was found to be 35 °C for 48 hours. However, this resulted in an increase in the occurrence of stem-end rot after two weeks [65]. The application of 500–2000 mg.L^{-1} of fludioxonil fungicide reduced the presence of green mould [6]. Ultra-violet-C (UV-C) irradiation has also shown to significantly reduce the incidence of blue and green mould. However, the risk of over dosage may lead to the development of phytotoxicity [97].

3.3.2. Citrus black spot

Citrus black spot (CBS) caused by *Guignardia citricarpa* (Kiely), attacks the citrus fruit and foliage, resulting in unsuitable fruit for the fresh market [43,53]. Infection occurs via both pycnidia and ascospores, which may be present on infected leaves on the orchard floor [17]. CBS has usually been controlled with copper fungicides. However, this leads to darkening of citrus blemishes and an undesirable accumulation of copper in the soil [98]. Agostini et al. [99] found that postharvest fungicide treatments alone had minimal effects in reducing CBS symptoms. However, the application of fungicides during fruit growth and storage of harvested fruit at 8 °C immediately after harvest was effective in reducing CBS symptoms. More environmentally friendly methods, such as heat treatments and waxing, have been used with success to alleviate CBS. The application of skin coatings to oranges was found to reduce the onset of CBS, which could be associated with reduced respiration rates [100]. Seberry et al. [100] recommended that postharvest treatments complement orchard control methods to control CBS. Korf et al. [17] found that conidial germination on CBS-infected fruit was reduced to zero with postharvest treatments of hypochlorite, heat treatments, a chemical mixture, polyethylene wax or all treatments combined. This demonstrated the beneficial application of combined pre-packaging treatments in reducing CBS. Further research is required to determine the feasibility of other combined pre-packaging treatments on citrus.

3.4. Pre-packaging treatments

3.4.1. Heat treatments

Heat treatments have been used to control decay in various fruit, such as avocados [101,102,], peppers [36,103,104] and citrus [105,106]. Heat treatments have the ability to inactivate surface or below surface pathogens, by inducing the fruits' resistance to inhibit pathogen development [108,39]. Heat treatments can be said to provide a 'curative' treatment [21,107,108]. Contrastingly, Palou et al. [55] described hot water treatments to be non-curative whose effects are only temporary. However, studies by Kim et al. [109], Ben-Yehoshua et al. [110] and Obagwu and Korsten [18] demonstrate the curative ability of heat treatments. The two main protein groups activated by hot water treatments are: (1) heat shock proteins (HSP) and (2) pathogenesis-related proteins (PRP) [60]. HSPs are responsible for inhibiting protein aggregation during high temperatures, thus promoting the fruit's ability to withstand these temperatures. PRPs are thought to contribute to the fruit's defense against a variety of pathogens. Water is the preferred heating medium due to it being more efficient in the heat transfer, compared to air [36]. The benefits associated with heat treatments include reduced chilling injury, increased gloss on the fruit peel and reduced weight loss, resulting in an increased fruit shelf life [39,86,108]. However, excessive heat exposure can result in phytotoxic damage to the fruit [105,108]. This can be avoided by applying higher water temperatures with shorter exposure durations [36]. Contrary to this, McGuire and Reeder [28] suggested that higher temperatures or extended exposure times should be avoided to prevent early decay. Table 2 summarises the effects of different heat treatments on citrus fruit.

3.4.2. Surface wax and coatings

Harvested horticultural commodities exhibit excessive weight loss as a result of moisture loss via transpiration and to a lesser degree the loss of carbon via respiration, reducing the shelf life and fruit quality [11,80,113]. The application of surface waxes and coatings have been found to address this problem, encompassing both physiological and aesthetic effects. Surface coatings or waxes impart a gloss to the fruit peel, thereby contributing to their aesthetic appeal [114,115]. However waxes have been found to restrict the movement of gas through the peel, which could lead to anaerobic conditions [116]. Research has been undertaken to create edible and natural coatings instead of the commercial synthetic waxes. Polysaccharide-based coatings have been found to be biodegradable, low cost and water soluble [116]. Chitosan and carboxymethyl cellulose combined with moringa leaf extract to create an edible coating improved the quality and shelf life of avocado fruit [117]. Chitosan, a cationic polysaccharide, coatings are a form of active packaging in which deposits from the film are transferred to the fruit surface, aiding in the inhibition of fungal growth [78,118]. Chitosan creates a semi-permeable layer allowing for gas exchange, leading to transpiration and ultimately reduced ripening. Chitosan-based coated tangerines exhibited better physicochemical characteristics, compared to control fruit during storage [118]. Nisperos-Carriedo et al. [114] found that coated oranges exhibited increased concentrations of volatile compounds (acetaldehyde, ethyl acetate, and methyl butyrate), contributing to enhanced orange juice flavour, compared to uncoated fruit. Similar findings were noted by Nisperos-Carriedo et al. [119]. Purvis [80] observed that waxed orange and grapefruit displayed greater loss in moisture and a reduction in the acidity, compared to individually sealed fruit. However, Hagenmaier and Baker [83] found that natural carnauba wax was more effective in reducing weight loss in citrus, compared to shellac or polyethylene waxes. At present, shellac, carnauba and polyethylene waxes are commonly used for citrus [120]. Hagenmaier and Shaw [121] recommended that a suitable citrus wax have high oxygen, carbon dioxide and ethylene permeabilities, while having low water vapour permeability. This will allow for a reduced transpiration rate without excessively restricting the respiration rate. However, some of the disadvantages of wax coatings are off-flavours and odours associated with impaired oxygen and carbon dioxide exchange. This leads to anaerobic respiration, resulting in the release of malodorous organic acids and increased ethanol and acetaldehyde concentrations [10,84,113,121,122]. In addition, kumquat fruit are consumed with the skin. As a result, consumers may not be willing to purchase kumquat fruit with waxes or chemical residues on the surface. Table 3 lists some of the surface coatings applied to citrus fruit.

3.4.3. Ultra-violet irradiation

Ultra-violet (UV) radiation from the sun can be divided into three groups, UV-C (below 280 nm), UV-B (280–320 nm) and UV-A (320–390 nm) as described by Stapleton [123]. Studies by Kim et al. [109], Rodov et al. [124], Rodov et al. [125] and D’hallewin et al. [126] have found that the release of two phytoalexins, (1) scoparone and (2) scopoletin, were elicited by UV light. These compounds contribute to the fruits’ resistance against pathogens. Effective UV-C dosage of fruit ranges from 0.25 $kJ.m^{-2}$ to 8.0 $kJ.m^{-2}$ [97,127]. Stevens et al. [128] reduced the onset of green mould in grapefruit and tangerines, and stem-end rot and sour rot in tangerines, by hormetic exposure of the fruit to 0.84 $kJ.m^{-2}$ to 3.6 $kJ.m^{-2}$ of UV-C. Similarly, D’hallewin et al. [126] found that grapefruit exposed to 0.5 $kJ.m^{-2}$ of UV-C irradiation developed less decay than untreated control fruit. Stevens et al. [128] found the effectiveness of UV-C irradiation in reducing postharvest decay was due to its germicidal effect on the fruit surface and its ability to induce fruit resistance (Stevens et al., 1996). However, Rodov et al. [125] attributed the fruit decay inhibition of UV irradiation to induced fruit resistance rather than to any germicidal effect because the sample citrus fruit were inoculated with the pathogens after exposure to UV light. In addition to a pathological defense, UV-irradiated fruit were shinier and firmer, possibly due to tissue lignification [110]. However, excessive amounts of UV irradiation can result in damage in kumquat that appears as peel damage and excessive shrivelling of the peel as observed by Rodov et al. [124,125]. Similar observations were made by Ben-Yehoshua et al. [110] on lemons. Canale et al. [129] found that UV irradiation was not able to satisfactorily control CBS in Valencia oranges. However, CBS lesions were lower on those fruit treated with UV irradiation. Table 4 lists some of the effects of UV-C irradiation on different citrus cultivars.

Table 2. The effects of different heat treatments applied to citrus fruit.

Type of Treatment	Exposure Time	Exposure Temperature	Fruit	Effect	Reference
Thermal curing	3 days	36 ℃	Eureka lemons	Prevention of *Penicillium* decay for > 2 months at 17 ℃ Production of scoparone	Kim *et al*. (1991)
Hot air	3 hours 2 hours	48 ℃ 49 ℃	Marsh grapefruit	Maintained fruit market quality	McGuire and Reeder (1992)
Hot Water	-	53 ℃	Kumquat	Improved fruit appearance, reduced weight loss and rot development	Schirra *et al.* (1995)
Hot water	120 seconds or 30 seconds	53 ℃ or 56 ℃	Kumquat	Reduction in blue and green mould	Ben-Yehoshua *et al*. (2000)
Hot water (dipping)	120 seconds	52 ℃	Oroblanco	Reduced fruit softening and button abscission. Inhibited yellow colour formation in combination with individual polyethylene packaging	Rodov *et al.* (2000)
Hot drench brushing	10 seconds	60 ℃	Oroblanco	Reduced fruit softening and button abscission. Delayed colour change	Rodov *et al.* (2000)
Hot water (dipping)	120 seconds	53 ℃	Kumquat	Reduced decay Reduced weight loss	Rodov *et al.* (2000)
Hot water (rinsing)	20 seconds	62 ℃	Star Ruby Grapefruit	Reduced chilling injury by 85% after 8 weeks	Sapitnitskaya *et al*. (2006)
Hot water dipping	120 seconds	50 ℃	Kumquat	Maintained 'fresh' appearance, reduced decay, reduced weight loss, maintained quality traits	Schirra *et al.* (2011)
Hot air	30 hours	37 ℃	Kumquat	Loss of peel gloss, excessive weight loss, diminished fruit quality	Schirra *et al.* (2011)
Hot water dipping	20 seconds	56 ℃	Tarocco oranges	Reduced weight loss, inhibition of green mould spore germination, maintained internal and external quality traits	Strano *et al.* (2014)
Hot water dipping	180 seconds	52 ℃	Tarocco oranges	Increased levels of alcohols, esters and aliphatic aldehydes	Strano *et al.* (2014)

Note: '-', information not provided in the source.

Table 3. The effects of different surface coatings applied to citrus fruit.

Description of Coating	Fruit	Effect	Reference
Beeswax emulsion and TAL Pro-long	Pineapple orange	Improved fresh orange juice volatiles and flavour	Nisperos-Carriedo *et al.* (1990)
Patented edible composite coating	Mature oranges	Improved volatiles and flavour	Nisperos-Carriedo *et al.* (1991)
Citral (120 second dipping time)	Mature light green lemons	Significantly reduced decay Fruit dipped in 1% citral resulted in phytotoxic damage	Ben-Yehoshua *et al.* (1992)
Low molecular weight chitosan (0.1% and 0.2%)	Murcott tangor	Improved firmness, TTA, TSS, ascorbic acid, reduced water loss Reduced postharvest decay (blue and green mould)	Chien *et al.* (2007)
Chitosan and $CaCl_2$ complex	Kumquats	Delay in ripening and senescence	Li *et al.* (2008)
Imazalil (3000 $mg.L^{-1}$) supplemented polyethylene wax	Navel oranges	Shiny fruit but resulted in off-flavours, compared to uncoated fruit Higher weight loss and less firm fruit, compared to carnauba wax supplemented with imazalil	Njombolwana *et al.* (2013)
Carboxymethyl cellulose (1.5% w/v)	Rishon and Michal mandarins	Improved firmness, reduced weight loss and a glossy peel	Arnon *et al.* (2015)

Table 4. The effects of different UV irradiation intensities on citrus fruit.

UV Irradiation Intensity	Fruit	Effect	Reference
5.0 $kJ.m^{-2}$	Lemon	Increased production of scoparone Reduced green mould	Ben-Yehoshua *et al.* (1992)
1.5 $kJ.m^{-2}$	Kumquat	Increased production of scoparone Reduced green mould	Rodov *et al.* (1992)
2.2 $kJ.m^{-2}$	Marsh grapefruit	Reduced the incidence of green mould to 14%	Stevens *et al.* (1996)
1.3 $kJ.m^{-2}$	Dancy tangerines	10-fold reduction in the onset of green mould	
3.2 $kJ.m^{-2}$	Mature grapefruit	Reduced decay from 72% to 16%	Lers *et al.* (1998)
3.0 $kJ.m^{-2}$	Washington Navel orange	Significant decay reduction in late harvested fruit	D'hallewin *et al.* (1999)
	Biondo Comune orange	Significant decay reduction in late harvested fruit	
0.5 $kJ.m^{-2}$ of UV-C	Star Ruby Grapefruit	Reduced decay caused by green mould to 2–3%	D'hallewin *et al.* (2000)

Continued on next page

UV Irradiation Intensity	Fruit	Effect	Reference
>0.5 kJ.m^{-2} of UV-C		Higher doses resulted in tissue necrosis and peel browning Fruit harvested earlier (less mature) exhibited more severe damage	
7.28 and 15.66 kJ.m^{-2} of UV-C	Valencia oranges	Did not effectively control citrus black spot. However, the appearance of quiescent black spot lesions were reduced	Canale *et al.* (2011)

3.4.4. Chlorinated water

Hypochlorite has been used widely as a disinfectant for controlling postharvest pathogens in fruit and vegetables [12,131,132]. Hypochlorite in chlorinated water is available as chlorine gas, calcium hypochlorite, or sodium hypochlorite [37]. A hypochlorite concentration ranging from 55–70 mg.L^{-1} at a temperature of 40 °C and pH of 7.0 is generally recommended for treating fruit and vegetables [37]. Kitinoja and Kader [133] recommend a pH of 6.5 to 7.5. Chlorination is a dynamic process and requires constant monitoring of factors, such as pH, hypochlorite concentration, temperature, organic matter, time, and the growth stage of the pathogen as explained by Boyette et al. [37]. Mango dipped in 100 µg.mL^{-1} chlorinated water for 600 seconds (10 minutes) resulted in a higher marketability after storage, which could be attributed to the disinfectant property of hypochlorite [134]. Delaquis et al. [131] found that warm chlorinated water (47 °C for 180 seconds) was more effective in retarding both the development of spoilage microorganisms and the onset of the brown discolouration in iceberg lettuce, compared to cold water. A 10-second wash using 200–250 mg.L^{-1} free chlorine of lettuce reduced the Listeria monocytogenes population by a factor of 10 [135]. However, chlorine can possess phytotoxic properties (bleaching or burning) due to high concentrations of either calcium or sodium with sodium hypochlorite being slightly more phytotoxic than calcium hypochlorite [136,137]. Workneh et al. [12] observed slight bleaching of carrots dipped in chlorinated water (100 µg.mL^{-1}). In addition, the disadvantage of chlorine is the instability of the chlorinated compounds, resulting in a loss and change in concentration [138]. Korf et al. [17] found that chlorine dioxide (10 µg.mL^{-1}) was more effective in reducing conidial germination in citrus fruit, compared to calcium hypochlorite (100 µg.mL^{-1}). Gil et al. [139] stated that a washing time exceeding 60 or 120 seconds had no significant effect in reducing the bacterial count. However, Boyette et al. [37] found that long dips were more effective than quick dips. A spray of water containing 800–1000 mg.L^{-1} hypochlorite was used to disinfect Nagpur mandarins and Mosambi sweet oranges with the aid of nylon brushes (6–8 seconds) [23]. Smilanick and Sorenson [140] used chlorinated water (50 mg.L^{-1}) at 1350 kPa for 45 seconds and a delivery rate of 2400 L.min^{-1} for washing of lemons. Currently, the South African kumquat industry uses a 1% chlorine bath or chlorine dioxide (ClO_2) as a pre-treatment [141]. Presence of trihalomethanes in chlorine disinfected fruit could also pose a threat to consumers as potential carcinogens and mutagens [142,143]. Therefore stricter measures are required to limit levels of trihalomethanes for safe consumption of chlorine disinfected fruit [143]. Some of the hypochlorite treatments applied to citrus fruit are appended as Table 5.

Table 5. The effects of different hypochlorite concentrations applied to citrus fruit.

*Hypochlorite Concentration	Exposure Time	Fruit	Effect	Reference
200–250 ppm and pH 6.0–7.5 (10% strength sodium hypochorite)	120 seconds	Kumquat	Reduced decay	Hall (1986)
150 $mg.L^{-1}$ active chlorine, pH 8	60 seconds	Lemons	Hypochlorite treatment alone resulted in higher decay rates	Stange and Eckert (1994)
100 $\mu g.mL^{-1}$ free chlorine	120 seconds	Satsuma mandarin	Significant reduction in decay. Positive influence on the b* component colour	Sen *et al*. (2007)
1000 ppm	120 seconds	Nagpur mandarins	Reduced decay for 30 days at ambient conditions	Ladaniya (2008)

*Assume 1 ppm = 1 $mg.L^{-1}$ [174].

3.4.5. Anolyte water

Electrochemically activated water (ECA) or anolyte water is produced by the electrolysis of a salt and water solution [12,16,148–151]. During this process the molecular state of water is changed from stable to metastable where two types of ECA water are produced, (1) anolyte and (2) catholyte water. The anolyte water, which has an oxidation-reduction potential (ORP) of +1000 mV, is better suited for disinfecting due to its antimicrobial characteristics and the catholyte, which has an ORP of −800 mV, is preferred for its cleaning and detergent ability. The active compound of anolyte water is the hypochlorous acid. Guentzel et al. [152] found that a dip and daily spray of electrolyzed oxidizing water at a pH of 6.3–6.5 at 250 $mg.L^{-1}$ and an ORP of 800–900 mV reduced the onset of gray mould and brown rot of grapes and peaches, respectively. Unpublished studies by Lesar [153] found that Neutral Anolyte also known as ACTSOL (Radical Waters, Johannesburg, South Africa) was comparable to chlorine (200 $mg.L^{-1}$) in preventing green mould and sour rot spore germination. Dilutions of Neutral Anolyte at 1:5 and 1:10 and exposure times of 30, 60, 300 and 600 seconds appeared to be effective. The immersion of tangerines for 480 seconds in electrolyzed oxidizing water was the most effective in reducing infection caused by *P. digitatum* [16]. Buck et al. [150] recommend the use of anolyte water for disinfection due to it being environmentally safe and effective. Research regarding the effect of anolyte water on citrus fruit is limited.

3.4.6. Sodium carbonate and sodium bicarbonate

The application of sodium carbonate (SC) or sodium bicarbonate (SB) solutions to the citrus fruit peel acts as a disinfectant specifically to reduce the postharvest incidence of green mould [58]. The efficacy of SC and SB can be attributed to their high pH levels suppressing the action of these pathogens [56], as well as promoting the host defense response [4]. Smilanick et al. [58] found that oranges immersed in 4% or 6% (w/v) SC solutions heated to 40.6 ℃ or 43.3 ℃ for 120 seconds resulted in the most effective control of green mould. Clementine mandarins dipped for 150 seconds in a 3% SC solution at 50 °C displayed a significant inhibition in blue and green moulds with no visible injury to the fruit [55]. Mandarins dipped in 2% or 3% SC solutions at room temperature for 60 seconds or 150 seconds resulted in a 40–60% reduction in both blue and green mould. The disadvantage of SB is that heating of these solutions results in the release of carbon dioxide and a subsequent decrease in the pH [59]. In addition, Obagwu and Korsten [18] found that SB treatment (5%) of oranges resulted in salt burn on the peel. Table 6 lists some of the SC and BC treatments applied to citrus fruit.

Table 6. The effects of sodium carbonate and bicarbonate treatments in citrus fruit.

Description of SC or SB Solution	Exposure Time	Solution Temperature	Fruit	Effect	Reference
4% or 6% SC	120 seconds	40.6 °C or 43.3 °C	Oranges	Significant reduction in green mould	Smilanick *et al.* (1997)
3% SC	60 seconds	56 °C or 61 °C	Navel oranges	Rind injury	Smilanick *et al.* (1999)
3% SC	150 seconds	50 °C	Clementine mandarins	Significant reduction in blue and green mould, no visible injury to the fruit	Palou *et al.* (2002)
2% or 3% SB	60 or 150 seconds	Room temperature (20 ± 1 °C)		Reduced incidence of blue and green mould by 40–60%	
2% SB	-	-	Grapefruit	Reduced decay as a result of green mould by 61%	Porat *et al.* (2002)
5% SC	-	-	Fairchild mandarin	Resulted in accumulation of scoparone, associated with a reduction in decay	Venditti *et al.* (2005)
			Biondo comune oranges	Green mould decay reduced by 97.2% and blue mould decay reduced by 93.9%	

Note: '-' Information not provided in the research article. SB, sodium bicarbonate; SC, sodium carbonate.

3.4.7. Postharvest biocontrol treatments

Microbial biocontrol (microbial antagonists) has been used successfully to control the postharvest decay of many horticultural commodities as an alternative to chemical based synthetic treatments [14,155–157]. Wisniewski and Wilson [158] and Sharma et al. [159] described the two methods of using micro-organisms to control postharvest decay as to either (1) use and control the already existing favorable microflora on the fruit surface or (2) to introduce foreign antagonists to postharvest pathogens. The biocontrol mode of action of yeasts are based on competing for nutrients and space, inducing fruit resistance and the production of lytic enzymes [157,160,161], while bacterial antagonists rely on the production of antibiotics [158]. The combined use of biocontrol agents with other treatments has been found more beneficial to the fruit, compared to biocontrol as the only treatment, as seen in Table 7. Some of the biocontrol products that are commercially available include BioSave-110®, Boniprotect® and BioSave-111® [12,15,161,162]. A study by Abraham et al. [15] revealed the preventive action of yeast strains B13 and Grape in controlling green mould decay in oranges and lemons in South Africa. Similar positive results were obtained by Arras [160]. However, Droby et al. [38] found that biocontrol was not as effective as the only method of postharvest treatment in alleviating decay in citrus on a commercial scale. The limitation of applying biocontrol agents commercially is primarily the 'uncontrolled' postharvest environment, compared to laboratory applications [158]. Research is required to determine the suitability of biocontrol agents, such as yeast B13, for commercialization [15]. Furthermore, there is no research specifically on the effects of biocontrol agents on kumquat, which warrants research being undertaken in this area.

Table 7. The effects of different postharvest biocontrol agents used on citrus fruit.

Type of Biocontrol Agent	Fruit	Effect	Reference
Candida famata isolated from fig leaves	Orange	95–100% reduction in infected fruit in terms of green mould Promoted the production of scoparone	Arras (1996)
Candida fermentati isolated from tomato fruit surface	Grapefruit	Production of fungal cell wall degrading enzymes resulting in a reduction in green mould infected fruit Reduced infected wounds to 10% in yeast-treated wounds, compared to 100%	Bar-Shimon *et al.* (2004)
Yeast isolates (B13 and Grape)	Navel oranges and lemons	Prevented the onset of decay as a result of green mould Suitable as a preventive mode of action rather than curative	Abraham *et al.* (2010)
Pichia guilliermondii (Z1)	Valencia-late oranges	Significant reduction in blue mould by at least 85%, independent of temperature or relative humidity Well suited as a prophylactic mode of action	Lahlali *et al.* (2011)

3.4.8. Integrated pre-packaging treatments

The application of combined treatments, as opposed to individual treatments, have been found to be far more effective in maintaining citrus fruit quality and preventing decay [18,146]. Hot water treatment, hypochlorite and salt treatments do not offer a permanent solution to postharvest decay but rather their effects have a limited duration [93]. Therefore, other treatments need to be applied to provide prolonged fruit protection. The combination of hot water and chlorine was shown to be effective in reducing the onset of decay in citrus fruit. The addition of a biocontrol further improves the efficacy [17,146]. Similarly, the treatment of chlorine and hot water proved to be beneficial in mandarins [146]. Ben-Yehoshua et al. [5] found the treatment of oranges with hot water dipping (52 °C for 120 seconds) followed by UV irradiation resulted in reduced fruit decay. Table 8 in presents some of the effects of integrated pre-packaging treatments applied to citrus fruit. It is evident from the table that biocontrol agents are more effective when used in combination with other pre-packaging treatments in reducing fruit decay.

Table 8. The effects of combined pre-packaging treatments applied to citrus fruit.

Number	Description of Treatments	Additional Information of Treatments	Fruit	Effect	Reference
1	Hot water Chlorine High pressure spray Polyethylene wax	43 or 46 °C for 180 seconds 100 μm.mL^{-1} and 15 μg.mL^{-1} 20–35 kPa -	Valencia oranges	Significant reduction in citrus black spot lesions	Korf *et al.* (2001)
2	Biocontrol Hot water	*Bacillus* F1 45 °C for 120 seconds	Valencia and Shamouti oranges	Significant reduction in both blue and green mould.	Obagwu and Korsten (2003)
3	Biocontrol SB	*Bacillus* F1 1% Solution	Valencia and Shamouti oranges	Significant reduction in both blue and green mould.	Obagwu and Korsten (2003)
4	Thermal curing UV-C Irradiation	35–36 °C for 72 hours 0.5, 1.5, or 3.0 kJ^{-2}	Nagami kumquat	Reduction in fruit decay	Ben-Yehoshua *et al.* (2005)
5	Hot water dipping UV-C Irradiation	52 °C for 120 seconds 0.5, 1.5, or 3.0 kJ^{-2}	Washington Navel orange	Reduction in fruit decay	Ben-Yehoshua *et al.* (2005)
6	SB Imazalil	1% Solution 10 μg.mL^{-1}	Eureka lemons	Incidence of green mould reduced to 22%	Smilanick *et al.* (2005)
7	Free chlorine Hot water dipping	100 μg.mL^{-1} 53 °C for 180 seconds	Satsuma mandarin	Closing of stomatal cracks by melting epicuticilar wax, reduction in decay caused by blue and green mould, Reduced weight loss	Sen *et al.* (2007)
8	Biocontrol Hot water SB	*Bacillus amyloliquefaciens* HF-01 45 °C for 120 seconds 1% or 2% Solution	Wuzishatangju mandarin	Firmer fruit, high ascobic acid, reduced levels of TSS, weight loss and decay	Hong *et al.* (2014)

4. Discussion and conclusions

The use of synthetic fungicides to control pathogen infection has now been associated with pathogen resistance, posing a risk to human and environmental health and high costs [4]. In light of this, more emphasis is placed on seeking alternative safe control methods. Inducing a fruit's intrinsic defense mechanism is one such method. Resistance against *P. digitatum* can be accomplished with the aid of physical means (ultra-violet irradiation) or antagonistic microorganisms. Bi et al. [163] reports that such treatments are capable of eliciting the fruit's resistance to pathogenic infection, however, these treatments do not provide complete control of infection. In most cases these treatments should be applied prior to any infection so that sufficient time is available to induce the fruit's resistance. It is therefore necessary to implement not only a preventive method of fungal control but a curative method as well [20]. Kassim et al. [21] goes a step further to include an initial disinfection treatment using anolyte water, followed by a curative hot water treatment and then a preventive treatment of a biocontrol agent to kumquat fruit. Currently, the main pre-packaging treatments identified within the citrus industry are postharvest fungicides, hypochlorite disinfection and waxing [23]. However, the relative efficacy of other treatments, such as hot water, biocontrol agents and anolyte water on citrus fruit have not been fully explored. Hot water treatments have a significantly positive effect on the postharvest citrus quality in terms of reduced decay as a result of the *Penicillium* pathogens, reduced weight loss and firmer fruit, [9,36,67,75,105,111,112]. Schirra et al. [111], Ben-Yehoshua et al. [105] and Rodov et al. [75] found 53 ℃ for 120 or 30 seconds to be the optimum temperature and time combination for kumquat heat treatments. Hot water treatments do not contain any chemicals and are, therefore, recommended for kumquat fruit due to the fruit being consumed with the skin [39,86,105,111]. Waxes were found to reduce the moisture loss and create shiny fruit surfaces; however, excessive waxing can result in the development of off-flavours due to suppressed gas exchange [10]. The use of hypochlorite as a disinfectant is common practice in the postharvest fruit industry. The current hypochlorite treatment of kumquats at packhouses in South Africa uses a 1% chlorine solution or chlorine dioxide. Biocontrol agents have been presented as an environmentally friendly alternative to fungicides. The yeast strain B13 provided positive results in preventing *P. digitatum* decay in oranges and lemons in South Africa [15]. Excessive UV-C irradiation (>0.5 kJ.m^{-2}) or too high salt content (5%) can result in damage to the citrus fruit peel [18,126,129]. Combined pre-packaging treatments have been recommended, compared to individual treatments, due to their higher overall efficacy in reducing decay and maintaining fruit quality [18,146]. An effective pre-packaging treatment combination should include a disinfectant (hypochlorite or anolyte water), curative (hot water) and a preventive agent (biocontrol). Many studies have focused on combined pre-packaging treatments on citrus fruit, such as oranges and mandarins [17,146]. However, these treatments did not combine disinfection, curative and preventive modes of action [5,146]. It can be suggested that an effective combination of treatments makes use of (1) disinfection; (2) curative and (3) preventive modes of action [21]. Chlorine (hypochlorite) or anolyte water provides a disinfecting effect. Curative treatments include hot water, surface coatings or waxes, or SC or SB [21]. Preventive treatment methods include biocontrol agents, such as B13. Disinfection treatments have the ability to remove existing pathogenic microorganisms present on the fruit surface. Curative treatments are able to 'repair' and initiate fruit resistance. The preventive mode of action hinders potential infection. Few studies have dealt with the combined action of a disinfectant, plus a curative and preventive treatment on citrus fruit.

Acknowledgments

This research was funded by the University of KwaZulu-Natal, National Research Foundation (NRF) and Cannon Collins Educational Trust.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

References

1. Blasco J, Aleixos N, Gomez-Sanchi J, et al. (2009) Recognition and classification of external skin damage in citrus fruits using multispectral data and morphological features. *Biosyst Eng* 103: 137–145.
2. Holmes GJ, Eckert JW (1999) Sensitivity of *Penicillium digitatum* and *P. italicum* to postharvest citrus fungicides in California. *Phytopathology* 89: 716–721.
3. Altieri G, Di Renzo GC, Genovese F, et al. (2013) A new method for the postharvest application of imazalil fungicide to citrus fruit. *Biosyst Eng* 115: 434–443.
4. Youssef K, Sanzani SM, Ligorio A, et al. (2014) Sodium carbonate and bicarbonate treatments induce resistance to postharvest green mould on citrus fruit. *Postharvest Biol Tec* 87: 61–69.
5. Ben-Yehoshua S, Rodov V, D’hallewin G, et al. (2005) Elicitation of resistance against pathogens in citrus fruits by combined UV illumination and heat treatments; V International Postharvest Symposium, 2013–2020. *Acta Hortic*: 682.
6. Zhang J (2007) The potential of a new fungicide fludioxonil for stem-end rot and green mold control on Florida citrus fruit. *Postharvest Biol Tec* 46: 262–270.
7. Sullivan GH, Davenport LR, Julian JW (1996) Precooling: Key factor for assuring quality in new fresh market vegetable crops. In: Janick, J, *Progress in New Crops,* ASHS Press, Virginia, USA, 521–524.
8. Brosnan T, Sun DW (2001) Precooling techniques and applications for horticultural products-a review. *Int J Refrig* 24: 154–170.
9. Porat R, Daus A, Weiss B, et al. (2000) Reduction of postharvest decay in organic citrus fruit by a short hot water brushing treatment. *Postharvest Biol Tec* 18: 151–157.
10. Njombolwana NS, Erasmus A, van Zyl JG, et al. (2013) Effects of citrus wax coating and brush type on imazalil residue loading, green mould control and fruit quality retention of sweet oranges. *Postharvest Biol Tec* 86: 362–371.
11. Johnston JW, Banks NH (1998) Selection of a surface coating and optimization of its concentration for use on ‘Hass’ avocado (*Persea americana* Mill.) fruit. *New Zeal J Crop Hort* 26: 143–151.
12. Workneh TS, Osthoff G, Pretorius JC, et al. (2003) Comparison of anolyte and chlorinated water as a disinfecting dipping treatment for stored carrots. *J Food Quality* 26: 463–474.
13. Beghin S (2014a) Personal communication. Premier Fruit Exports (Pty) Ltd, Durban, Republic of South Africa, 1 April 2014.
14. Droby S, Wisniewski M, Macarisin D, et al. (2009) Twenty years of postharvest biocontrol research: Is it time for a new paradigm? *Postharvest Biol Tec* 52: 137–145.

15. Abraham AO, Laing MD, Bower JP (2010) Isolation and in vivo screening of yeast and Bacillus antagonists for the control of *Penicillium digitatum* of citrus fruit. *Biol Control* 53: 32–38.
16. Whangchai K, Saengnil K, Singkamanee C, et al. (2010) Effect of electrolyzed oxidizing water and continuous ozone exposure on the control of *Penicillium digitatum* on tangerine cv. ‘Sai Nam Pung’ during storage. *Crop Prot* 29: 386–389.
17. Korf HJG, Schutte GC, Kotze JM (2001) Effect of packhouse procedures on the viability of *Phyllosticta citricarpa*, anamorph of the citrus black spot pathogen. *African Plant Protection* 7: 103–109.
18. Obagwu J, Korsten L (2003) Integrated control of citrus green and blue molds using *Bacillus subtilis* in combination with sodium bicarbonate or hot water. *Postharvest Biol Tec* 28: 187–194.
19. Hong P, Hao W, Luo J, et al. (2014) Combination of hot water, *Bacillus amyloliquefaciens* HF-01 and sodium bicarbonate treatments to control postharvest decay of mandarin fruit. *Postharvest Biol Tec* 88: 96–102.
20. Moscoso-Ramirez PA, Palou L (2014) Preventive and curative activity of postharvest potassium silicate treatments to control green and blue molds on orange fruit. *Eur J Plant Pathol* 138: 721–732.
21. Kassim A, Workneh TS, Laing MD, et al. (2016) The effects of different pre-packaging treatments on the quality of kumquat fruit. *CyTA-J Food* 14: 639–648.
22. Porat R, Weiss B, Cohen L, et al. (2004) Reduction of postharvest rind disorders in citrus fruit by modified atmosphere packaging. *Postharvest Biol Tec* 33: 35–43.
23. Ladaniya MS (2008c) Citrus Fruit: Biology, Technology and Evaluation. Elsevier, London, United, Kingdom.
24. Li Z, Zhong H, Peng X, et al. (2008) Effect of chitosan and $CaCl_2$ on senescence and membrane lipid peroxidation of postharvest kumquat fruits. *Acta Hortic* 769_37: 259–264.
25. Grierson W, Ben-Yehoshua S (1986) Storage of citrus fruits. In: Wardowski WF, Nagy S, Grierson W, *Fresh Citrus Fruit,* AVI Publishing Co., Connecticut, USA, Ch. 20, 479–507.
26. Kader AA (1999) Fruit maturity, ripening and quality relationships. In: Michalczuk L, *Proceedings of the International Symposium Effect of Pre- and Postharvest factors in Fruit Storage*, *Acta Hortic*, 203–208.
27. D’hallewin G, Schirra M, Manueddu E, et al. (1999) Scoparone and scopoletin accumulation and ultraviolet-c induced resistance to postharvest decay in oranges as influenced by harvest date. *J Am Soc Hortic Sci* 124: 702–707.
28. McGuire RG, Reeder WF (1992) Predicting market quality of grapefruit after hot-air quarantine treatment. *J Am Soc Hortic Sci* 117: 90–95.
29. Houck LG, Jenner JF, Mackey BE (1990) Seasonal variability of the response of desert lemons to rind injury and decay caused by quarantine cold treatments. *J Hortic Sci* 65: 611–617.
30. Schirra M, Agabbio M, D’hallewin G, et al. (1997) Response of tarocco oranges to picking date, postharvest hot water dips, and chilling storage temperature. *J Agric Food Chem* 45: 3216–3220.
31. Schueller JK, Whitney JD, Wheaton TA, et al. (1999) Low-cost automatic yield mapping in hand-harvested citrus. *Comput Electron Agr* 23: 145–153.
32. Sanders KF (2005) Orange harvesting systems review. *Biosyst Eng* 90: 115–125.
33. Jimenez AR, Ceres R, Pons JL (2000) A survey of computer vision methods for locating fruit on trees. *Trans ASAE* 43: 1911–1920.

34. Beghin S (2014b) Personal communication. Premier Fruit Exports (Pty) Ltd, Durban, Republic of South Africa, 8 May 2014.
35. Berger CN, Sodha SV, Shaw RK, et al. (2010) Fresh fruit and vegetables as vehicles for the transmission of human pathogens. *Environ Microbiol* 12: 2385–2397.
36. Fallik E (2004) Prestorage hot water treatments (immersion, rinsing and brushing). *Postharvest Biol Tec* 32: 125–134.
37. Boyette MD, Ritchie DF, Carballo SJ, et al. (1993) Chlorination and postharvest disease control. *HortTechnology* 3: 395–400.
38. Droby S, Cohen L, Daus A, et al. (1998) Commercial testing of Aspire: a yeast preparation for the biological control of postharvest decay of citrus. *Biol Control* 12: 97–101.
39. Schirra M, Angioni A, Cabras P, et al. (2011) Effects of postharvest hot water and hot air treatments on storage decay and quality traits of kumquat (*Fortunella japonica* Lour. Swingle, cv. Ovale) fruit. *J Agric Sci Tech* 13: 89–94.
40. Gomez-Sanchis J, Martin-Guerrero JD, Soria-Olivas E, et al. (2012) Detecting rottenness caused by *Penicillium* genus fungi in citrus fruits using machine learning techniques. *Expert Syst Appl* 39: 780–785.
41. Chalutz E, Lomenic E, Waks J (1989) Physiological and pathological observations on the postharvest behavior of kumquat fruit. *Trop Sci* 29: 199–206.
42. Mokomele P (2013) Reports of a Ban of Exports of Fresh Citrus Fruit to the European Union due to Citrus Black Spot, Department of Agriculture, Forestry and Fisheries, Media Release, Republic of South Africa. Available from: http://www.gov.za/speeches/view.php?sid=42268.
43. Yonowa T, Hattingh V, de Villiers M (2013) CLIMEX modelling of the potential global distribution of the citrus black spot disease caused by *Guignardia citricarpa* and the risk posed to Europe. *Crop Prot* 44: 18–28.
44. Cooke T, Persley D, House S (2009) Diseases of Fruit Crops in Australia. CSIRO Publishing, Collingwood, Australia.
45. Mercier J, Smilanick JL (2005) Control of green mold and sour rot of stored lemon by biofumigation with *Muscodor albus*. *Biol Control* 32: 401–407.
46. Talibi I, Askarne L, Boubaker H, et al. (2012) Antifungal activity of some Moroccan plants against *Geotrichum candidum*, the causal agent of postharvest citrus sour rot. *Crop Prot* 35: 41–46.
47. Grierson W (1986) Physiological disorders. In: Wardowski WF, Nagy S, Grierson W, *Fresh Citrus Fruit*, AVI Publishing Co., Connecticut, USA, Ch. 14, 361–378.
48. Wardowski WF (1988b) Inherited abnormalities and weaknesses. In: Whiteside JO, Garnsey SM, Timmer LW, *Compendium of Citrus Diseases*, The American Phytopathological Society, Minnesota, USA, Part I, 64.
49. Ritenour MA, Dou H, Bowman KM, et al. (2004) Effect of rootstock on stem-end rind breakdown and decay of fresh citrus. *HortTechnology* 14: 315–319.
50. Stall RE (1988) Infectious (biotic) diseases. In: Whiteside JO, Garnsey SM, Timmer LW, *Compendium of Citrus Diseases*, The American Phytopathological Society, Minnesota, USA, Part I, 6.
51. Khalaf A, Moore GA, Jones JB, et al. (2007) New insights into the resistance of Nagami kumquat to canker disease. *Physiol Mol Plant P* 71: 240–250.
52. Kotze JM (1988) Fungal diseases in nurseries and orchards. In: Whiteside JO, Garnsey SM, Timmer LW, *Compendium of Citrus Diseases*, The American Phytopathological Society, Minnesota, USA, Part I, 6.

53. Bonants PJM, Carroll GC, de Weerdt M, et al. (2003) Development and validation of a fast PCR-based detection method for pathogenic isolates of the citrus black spot fungus, *Guignardia citricarpa*. *Eur J Plant Pathol* 109: 503–513.
54. Brown GE, Eckert JW (1988a) Postharvest fungal diseases. In: Whiteside JO, Garnsey SM, Timmer LW, *Compendium of Citrus Diseases,* The American Phytopathological Society, Minnesota, USA, Part I, 32.
55. Palou L, Usall J, Munoz JA, et al. (2002) Hot water, sodium carbonate, and sodium bicarbonate for the control of postharvest green and blue molds of clementine mandarins. *Postharvest Biol Tec* 24: 93–96.
56. Venditti T, Molinu MG, Dore A, et al. (2005) Sodium carbonate treatment induces scoparone accumulation, structural changes, and alkalinization in the albedo of wounded citrus fruits. *J Agric Food Chem* 53: 3510–3518.
57. Brown GE, Eckert JW (1988b) Postharvest fungal diseases. In: Whiteside JO, Garnsey SM, Timmer LW, *Compendium of Citrus Diseases,* The American Phytopathological Society, Minnesota, USA, Part I, 35–36.
58. Smilanick JL, Mackey BE, Reese R, et al. (1997) Influence of concentration of soda ash, temperature, and immersion period on the control of postharvest green mold of oranges. *Plant Dis* 81: 379–382.
59. Smilanick JL, Margosan DA, Mlikota F, et al. (1999) Control of citrus green mold by carbonate and bicarbonate salts and the influence of commercial postharvest practices on their efficacy. *Plant Dis* 83: 139–145.
60. Pavoncello D, Lurie S, Droby S, et al. (2001) A hot water treatment induces resistance to *Penicillium digitatum* and promotes the accumulation of heat shock and pathogenesis-related proteins in grapefruit flavedo. *Physiol Plantarum* 111: 17–22.
61. Smilanick JL, Mansour MF, Margosan DA, et al. (2005) 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 Dis* 89: 640–648.
62. Brown GE (1986) Diplodia stem-end rot, a decay of citrus fruit increased by ethylene degreening treatment and its control. *P Fl St Hortic Soc* 99: 105–108.
63. Brown GE, Eckert JW (1988c) Postharvest fungal diseases. In: Whiteside JO, Garnsey SM, Timmer LW, *Compendium of Citrus Diseases,* The American Phytopathological Society, Minnesota, USA, Part I, 33–34.
64. Brown GE, Lee HS (1993) Interactions of ethylene with citrus stem-end rot caused by *Diplodia natalensis*. *Phytopathology* 83: 1204–1208.
65. Zhang J, Swingle PP (2005) Effects of curing on green mold and stem-end rot of citrus fruit and its potential application under Florida packing system. *Plant Dis* 89: 834–840.
66. Wardowski WF (1988a) Inherited abnormalities and weaknesses. In: Whiteside JO, Garnsey SM, Timmer LW, *Compendium of Citrus Diseases,* The American Phytopathological Society, Minnesota, USA, Part I, 63–64.
67. Sapitnitskaya M, Maul P, McCollum GT, et al. (2006) Postharvest heat and conditioning treatments activate different molecular responses and reduce chilling injuries in grapefruit. *J Exp Bot* 57: 2943–2953.
68. Olmo M, Nadas A, Garc á JM (2000) Nondestructive methods to evaluate maturity level of oranges. *J Food Sci* 65: 365–369.

69. Singh KK, Reddy BS (2006) Post-harvest physico-mechanical properties of orange peel and fruit. *J Food Eng* 73: 112–120.
70. Pathare PB, Opara UL, Al-Said FA (2013) Colour measurement and analysis in fresh and processed foods: a review. *Food Bioprocess Tech* 6: 36–60.
71. Ortiz JM (c2002) Botony: Taxonomy, morphology and physiology of fruits, leaves and flowers. In: Dugo G, Di Giacomo A, *Citrus: The Genus Citrus*, Taylor and Francis, London, Ch. 2, 16–35.
72. Iglesias DJ, Cercos M, Colmenero-Flores JM, et al. (2007) Physiology of citrus fruiting. *Braz J Plant Physiol* 19: 333–362.
73. Stewart I, Wheaton TA (1971) Effects of ethylene and temperature on carotenoid pigmentation of citrus peel. *P Fl St Hortic Soc* 84: 264–266.
74. Rodrigo MJ, Zacarias L (2007) Effect of postharvest ethylene treatment on carotenoid accumulation and the expression of carotenoid biosynthetic genes in the flavedo of orange (*Citrus sinensis* L. Osbeck) fruit. *Postharvest Biol Tec* 43: 14–22.
75. Rodov V, Agar T, Peretz J, et al. (2000) Effect of combined application of heat treatments and plastic packaging on keeping quality of ‘Oroblanco’ fruit (*Citrus grandis* L.C. *paradisi* Macf.). *Postharvest Biol Tec* 20: 287–294.
76. Smilanick JL, Mansour MF, Sorenson D (2006) Pre-and postharvest treatments to control green mold of citrus fruit during ethylene degreening. *Plant Dis* 90: 89–96.
77. Porat R, Weiss B, Cohen L, et al. (1999) Effects of ethylene and 1-methylcyclopropene on the postharvest qualities of ‘Shamouti’oranges. *Postharvest Biol Tec* 15: 155–163.
78. Chien P, Sheu F, Lin H (2007) Coating citrus (Murcott tangor) fruit with low molecular weight chitosan increases postharvest quality and shelf life. *Food Chem* 100: 1160–1164.
79. Ghanema N, Mihoubib D, Kechaoua N, et al. (2012) Microwave dehydration of three citrus peel cultivars: effect on water and oil retention capacities, color, shrinkage and total phenols content. *Ind Crop Prod* 40: 167–177.
80. Purvis AC (1983) Moisture loss and juice quality from waxed and individually seal-packaged citrus fruits. *P Fl St Hortic Soc* 96: 327–329.
81. D’hallewin G, Arras G, Castia T, et al. (1994) Reducing decay of Avana mandarin fruit by the use of UV, heat and thiabendazole treatments. International Symposium on Postharvest Treatment of Horticultural Crops, *Acta Hortic* 368: 387–394.
82. Hall DJ (1981) Innovations in citrus waxing-an overview. *P Fl St Hortic Soc* 94: 258–263.
83. Hagenmaier RD, Baker RA (1994) Wax microemulsions and emulsions as citrus coatings. *J Agric Food Chem* 42: 899–902.
84. Cohen E, Shalom Y, Rosenberger I (1990) Postharvest ethanol buildup and off-flavor in ‘Murcott’ tangerine fruits. *J Am Soc Hortic Sci* 115: 775–778.
85. Ben-Yehoshua S, Burg SP, Young R (1985) Resistance of citrus fruit to mass transport of water vapor and other gases. *Plant Physiol* 79: 1048–1053.
86. Rodov V, Ben-Yehoshua S, Albagli R, et al. (1995) Reducing chilling injury and decay of stored citrus fruit by hot water dips. *Postharvest Biol Tec* 5: 119–127.
87. Citrus Growers’ Association (2013) Citrus Growers’ Association of South Africa Annual Report 2013. Citrus Growers’ Association of South Africa, Durban, Republic of South Africa.
88. Abbott JA (1999) Quality measurement of fruits and vegetables. *Postharvest Biol Tec* 15: 207–225.
89. Petrisor C, Lucian-Radu G, Balan V, et al. (2010) Rapid and non-destructive analytical techniques for measurement of apricot quality. *Rom Biotech Lett* 15: 5213–5216.

90. Sadka A, Artzi B, Cohen L, et al. (2000) Arsenite reduces acid content in citrus fruit, inhibits activity of citrate synthase but induces its gene expression. *J Am Soc Hortic Sci* 153: 288–293.
91. Albertini M, Carcouet E, Pailly O, et al. (2006) Changes in organic acids and sugars during early stages of development of acidic and acidless citrus fruit. *J Agric Food Chem* 54: 8335–8339.
92. Lobit P, Soing P, Genard M, et al. (2002) Theoretical analysis of relationships between composition, pH, and titratable acidity of peach fruit. *J Plant Nutr* 25: 2775–2792.
93. Hong SI, Lee HH, Kim D (2007) Effects of hot water treatment on the storage stability of Satsuma mandarin as a postharvest decay control. *Postharvest Biol Tec* 43: 271–279.
94. Baldwin EA, Nisperos-Carriedo M, Shaw PE, et al. (1995) Effect of coatings and prolonged storage conditions on fresh orange flavor volatiles, degrees brix, and ascorbic acid levels. *J Agric Food Chem* 43: 1321–1331.
95. Rocha AMCN, Brochado CM, Kirby R, et al. (1995) Shelf-life of chilled cut orange determined by sensory quality. *Food Control* 6: 317–322.
96. Lado J, Rodrigo MJ, Zacarías L (2014) Maturity indicators and citrus fruit quality. *Stewart Postharvest Review* 10: 1–6.
97. Palou L, Smilanick JL, Droby S (2008) Alternatives to conventional fungicides for the control of citrus postharvest green and blue moulds. *Stewart Postharvest Rev* 4: 1–16.
98. Schutte GC, Beeton KV, Kotze JM (1997) Rind stippling on Valencia oranges by copper fungicides used for control of citrus black spot in South Africa. *Plant Dis* 81: 851–854.
99. Agostini J, Peres NA, Mackenzie SJ, et al. (2006) Effect of fungicides and storage conditions on postharvest development of citrus black spot and survival of *Guignardia citricarpa* in fruit tissues. *Plant Dis* 90: 1419–1424.
100. Seberry JA, Leggom D, Kiely TB (1967) Effect of skin coatings on the development of black spot in stored Valencia oranges. *Anim Prod Sci* 7: 593–600.
101. Wu CT, Roan SF, Hsiung TC, et al. (2011) Effect of harvest maturity and heat pretreatment on the quality of low temperature storage avocados in Taiwan. *J Fac Agr Kyushu U* 56: 255–262.
102. Kassim A, Workneh TS, Bezuidenhout CN (2013) A review on postharvest handling of avocado fruit. *Afr J Agr Res* 8: 2385–2402.
103. Fallik E, Grinberg S, Alkalai S, et al. (1999) A unique rapid hot water treatment to improve storage quality of sweet pepper. *Postharvest Biol Tec* 15: 25–32.
104. Gonzalez-Aguilar GA, Gayosso L, Cruz R, et al. (2000) Polyamines induced by hot water treatments reduce chilling injury and decay in pepper fruit. *Postharvest Biol Tec* 18: 19–26.
105. Ben-Yehoshua S, Peretz J, Rodov V, et al. (2000) Postharvest application of hot water treatment in citrus fruits: The road from the laboratory to the packing-house; XXV International Horticultural Congress; Part 8: Quality of Horticultural Products. *Acta Hortic*, 19–28.
106. Schirra M, Palma A, Aquino S, et al. (2008) Influence of postharvest hot water treatment on nutritional and functional properties of kumquat (*Fortunella japonica* Lour. Swingle Cv. Ovale) fruit. *J Agric Food Chem* 56: 455–460.
107. Schirra M, D'hallewin G, Ben-Yehoshua S, et al. (2000) Host–pathogen interactions modulated by heat treatment. *Postharvest Biol Tec* 21: 71–85.
108. Irtwange S (2006) Hot water treatment: A non-chemical alternative in keeping quality during postharvest handling of citrus fruits. *Agric Eng Int* 8:1–10.
109. Kim JJ, Ben-Yehoshua S, Shapiro B, et al. (1991) Accumulation of scoparone in heat-treated lemon fruit inoculated with *Penicillium digitatum* Sacc. *Plant Physiol* 97: 880–885.

110. Ben-Yehoshua S, Rodov V, Kim JJ, et al. (1992) Preformed and induced antifungal materials of citrus fruits in relation to the enhancement of decay resistance by heat and ultraviolet treatments. *J Agric Food Chem* 40: 1217–1221.
111. Schirra M, D'Aquino S, Continella G, et al. (1995) Extension of kumquat fruit storage life by postharvest hot dip treatments in water and freshening agent. *Adv Hortic Sci* 9: 1000–1004.
112. Strano MC, Calandra M, Aloisi V, et al. (2014) Hot water dipping treatments on Tarocco orange fruit and their effects on peel essential oil. *Postharvest Biol Tec* 94: 26–34.
113. Mannheim CH, Soffer T (1996) Permeability of different wax coatings and their effect on citrus fruit quality. *J Agric Food Chem* 44: 919–923.
114. Nisperos-Carriedo MO, Shaw PE, Baldwin EA (1990) Changes in volatile flavor components of pineapple orange juice as influenced by the application of lipid and composite films. *J Agric Food Chem* 38: 1382–1387.
115. Maftoonazad N, Ramaswamy HS (2008) Effect of pectin-based coating on the kinetics of quality change associated with stored avocados. *J Food Process Pres* 32: 621–643.
116. Arnon H, Granit R, Porat R, et al. (2015) Development of polysaccharides-based edible coatings for citrus fruits: A layer-by-layer approach. *Food Chem* 166: 465–472.
117. Tesfay SZ, Magwaza LS (2017) Evaluating the efficacy of moringa leaf extract, chitosan and carboxymethyl cellulose as edible coatings for enhancing quality and extending postharvest life of avocado (*Persea americana* Mill.) fruit. *Food Packag Shelf Life* 11: 40–48.
118. Plácido GR, da Silva RM, Cagnin C, et al. (2016) Effect of chitosan-based coating on postharvest quality of tangerines (*Citrus deliciosa* Tenore): Identification of physical, chemical, and kinetic parameters during storage. *Afr J Agr Res* 11: 2185–2192.
119. Nisperos-Carriedo MO, Baldwin EA, Shaw PE (1991) Development of an edible coating for extending postharvest life of selected fruits and vegetables. *P Fl St Hortic Soc* 104: 122–125.
120. Dodd M, Cronje P, Taylor M, et al. (2008) A review of the postharvest handling of fruits in South Africa over the past twenty five years. *S Afr J Plant Soil* 27: 97–116.
121. Hagenmaier RD, Shaw PE (1992) Gas permeability of fruit coating waxes. *J Am Soc Hortic Sci* 117: 105–109.
122. Hagenmaier RD, Baker RA (1993) Reduction in gas exchange of citrus fruit by wax coatings. *J Agric Food Chem* 14: 283–287.
123. Stapleton AE (1992) Ultraviolet radiation and plants: burning questions. *Plant Cell* 4: 1353–1358.
124. Rodov V, Ben-Yehoshua S, Kim JJ, et al. (1992) Ultraviolet illumination induces scoparone production in kumquat and orange fruit and improves decay resistance. *J Am Soc Hortic Sci* 117: 788–792.
125. Rodov V, Ben-Yehoshua S, Fang D, et al. (1994) Accumulation of phytoalexins scoparone and scopoletin in citrus fruits subjected to various postharvest treatments. International Symposium on Natural Phenols in Plant Resistance. *Acta Hortic*, 517–525.
126. D'hallewin G, Schirra M, Pala M, et al. (2000) 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.). *J Agric Food Chem* 48: 4571–4575.
127. Terry LA, Joyce DC (2004) Elicitors of induced disease resistance in postharvest horticultural crops: a brief review. *Postharvest Biol Tec* 32: 1–13.
128. Stevens C, Wilson CL, Lu JY, et al. (1996) Plant hormesis induced by ultraviolet light-C for controlling postharvest diseases of tree fruits. *Crop Prot* 15: 129–134.

129. Canale MC, Benato EA, Cia P, et al. (2011) In vitro effect of UV-C irradiation on *Guignardia citricarpa* and on postharvest control of citrus black spot. *Trop Plant Pathol* 36: 356–361.
130. Lers A, Burd S, Lomaniec E, et al. (1998) The expression of a grapefruit gene encoding an isoflavone reductase-like protein is induced in response to UV irradiation. *Plant Mol Biol* 36: 847–856.
131. Delaquis PJ, Stewart S, Toivonen PMA, et al. (1999) Effect of warm, chlorinated water on the microbial flora of shredded iceberg lettuce. *Food Res Int* 32: 7–14.
132. Prusky D, Eshel D, Kobiler I, et al. (2001) Postharvest chlorine treatments for the control of the persimmon black spot disease caused by *Alternaria alternata*. *Postharvest Biol Tec* 22: 271–277.
133. Kitinoja L, Kader AA (1994) Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops. Report No. 8E. Department of Pomology, University of California, California, USA.
134. Tefera, A, Seyoum T, Woldetsadik K (2007) Effect of disinfection, packaging, and storage environment on the shelf life of mango. *Biosyst Eng* 96: 201–212.
135. Simons LK, Sanguansri P (1997) Advances in the washing of minimally processed vegetables. *Food Aust* 49: 75–80.
136. Suslow T (1997) Chlorination in the production and postharvest handling of fresh fruits and vegetables. University of California-Davis, 1997. Available from: http://extension.psu.edu.
137. Jowkar MM (2006) Water relations and microbial proliferation in vase solutions of *Narcissus tazetta* L. cv. 'Shahla-e-Shiraz' as affected by biocide compounds. *J Hortic Sc Biotech* 81: 656–660.
138. Premuzic Z, Palmucci HE, Tamborenea J, et al. (2007) Chlorination: Phytotoxicity and effects on the production and quality of *Lactuca sativa* var. Mantecosa grown in a closed, soil-less system. *Phyton-Int J Exp Bot* 76: 103–117.
139. Gil MI, Selma MV, Lopez-Galvez F, et al. (2009) Fresh-cut product sanitation and wash water disinfection: Problems and solutions. *Int J Food Microbiol* 134: 37–45.
140. Smilanick JL, Sorenson D (2001) Control of postharvest decay of citrus fruit with calcium polysulfide. *Postharvest Biol Tec* 21: 157–168.
141. Beghin S (2014c) Personal communication. Premier Fruit Exports (Pty) Ltd, Durban, Republic of South Africa, 3 June 2014.
142. Gil MI, Gómez-López VM, Hung YC, et al. (2015) Potential of electrolyzed water as an alternative disinfectant agent in the fresh-cut industry. *Food Bioprocess Tech* 8: 1336–1348.
143. Coroneo V, Carraro V, Marras B, et al. (2017) Presence of Trihalomethanes in ready-to-eat vegetables disinfected with chlorine. *Food Addit Contam A* 34: 2111–2117.
144. Hall DJ (1986) Use of postharvest treatments for reducing shipping decay in kumquats. *P Fl St Hortic Soc* 99: 108–112.
145. Stange RR, Eckert JW (1994) Influence of postharvest handling and surfactants on control of green mold of lemons by curing. *Phytopathology* 84: 612–616.
146. Sen F, Knay P, Karacal I, et al. (2007) Effects of the chlorine and heat applications after harvest on the quality and resistance capacity of Satsuma mandarins. Proceedings of the International Congress, CRIOF, University of Bologna, Bologna, Italy, 231–239.
147. Chiou CT, Freed VH, Schmedding DW, et al. (1977) Partition coefficient and bioaccumulation of selected organic chemicals. *Environ Sci Technol* 11: 475–478.
148. Bakhir VM (1997) Electrochemical activation of water: Past, present and future. Proceedings of the 1st International Symposium on Electrochemical Activation, Moscow, 38–45.

149. Leonov BI (1997) Electrochemical activation of water: Theory and practice. Proceedings of the First International Symposium on Electrochemical Activation, Moscow, 11–27.
150. Buck JW, Van Iersel MW, Oetting RD, et al. (2002) In vitro fungicidal activity of acidic electrolyzed oxidizing water. *Plant Dis* 86: 278–281.
151. Workneh TS, Osthoff G (2010) A review on integrated agro-technology of vegetables. *Afr J Biotechnol* 9: 9307–9327.
152. Guentzel JL, Lam KL, Callan MA, et al. (2010) Postharvest management of gray mold and brown rot on surfaces of peaches and grapes using electrolyzed oxidizing water. *Int J Food Microbiol* 143: 54–60.
153. Lesar K (2002) The screening of neutral anolyte against post-harvest fungal spores causing disease of citrus fruit. Unpublished report, Citrus Research International, Nelspruit, South Africa.
154. Porat R, Daus A, Weiss B, et al. (2002) Effects of combining hot water, sodium bicarbonate and biocontrol on postharvest decay of citrus fruit. *J Hortic Sci Biotech* 77: 441–445.
155. Huanga Y, Deverall BJ, Morris SC (1995) Postharvest control of green mould on oranges by a strain of *Pseudomonas glathei* and enhancement of its biocontrol by heat treatment. *Postharvest Biol Tec* 5: 129–137.
156. El-Ghaouth A, Smilanick JL, Wilson CL (2000) Enhancement of the performance of *Candida saitoana* by the addition of glycolchitosan for the control of postharvest decay of apple and citrus fruit. *Postharvest Biol Tec* 19: 103–110.
157. Ippolito A, El Ghaouth A, Wilson CL, et al. (2000) Control of postharvest decay of apple fruit by *Aureobasidium pullulans* and induction of defense responses. *Postharvest Biol Tec* 19: 265–272.
158. Wisniewski ME, Wilson CL (1992) Biological control of postharvest diseases of fruits and vegetables: Recent advances. *HortScience* 27: 94–98.
159. Sharma RR, Singh D, Singh R (2009) Biological control of postharvest diseases of fruits and vegetables by microbial antagonists: A review. *Biol Control* 50: 205–221.
160. Arras G (1996) Mode of action of an isolate of *Candida famata* in biological control of *Penicillium digitatum* in orange fruits. *Postharvest Biol Tec* 8: 191–198.
161. Bar-Shimon M, Yehuda H, Cohen L, et al. (2004) Characterization of extracellular lytic enzymes produced by the yeast biocontrol agent *Candida oleophila*. *Curr Genet* 45: 140–148.
162. Lahlali R, Hamadi Y, Jijakli MH (2011) Efficacy assessment of *Pichia guilliermondi* strain Z1, a new biocontrol agent, against citrus blue mould in Morocco under the influence of temperature and relative humidity. *Biol Control* 56: 217–224.
163. Bi Y, Li Y, Ge Y (2007) Induced resistance in postharvest fruits and vegetables by chemicals and its mechanism. *Stewart Postharvest Rev* 3: 1–7.