GENERAL DISCUSSION

Efficacy of any management strategy to reduce the incidence of postharvest diseases depends on several key elements, viz. isolation of spore-generating areas, careful handling of fruit, proper sanitation procedures for decontamination of fruit handling equipment, weekly assays to monitor pathogen spore populations, judicious use of fungicides and modification of existing packhouse operations to prevent dispersal of pathogen inoculum (Gardner *et al.*, 1986).

It is well documented that careless harvesting and handling practices, along with high inoculum of postharvest pathogens in the packhouse environment, are the main factors involved in postharvest disease development (Sommer, 1982; Di Martino Aleppo & Lanza, 1996). Spores of pathogenic fungi are produced on decayed fruit and transferred by air currents, water dip tanks and fruit handling equipment to sound fruit (Barmore & Brown, 1982; Gardner *et al.*, 1986; Spotts & Cervantes, 1986, 1993). *Aspergillus niger* Thiegh, *Penicillium digitatum* (Pers.: Fr.) Sacc., *P. italicum* Wehmer and *Rhizopus stolonifer* (Ehrenb.: Fr.) Vuill. were present in each of the sampled packhouses, with *A. niger* and *P. digitatum* being the most dominant throughout. The main sources of accumulation of these fungal spores in packhouses were identified as crates/trailers and dip tank water, which corresponds with results from previous studies (Gardner *et al.*, 1986; Spotts & Cervantes, 1986; 1992; 1993; Van Dyk *et al.*, 1997). Strategies aimed at reducing the pathogen inoculum at critical locations in the packhouse are therefore of utmost importance (Gardner *et al.*, 1986).

Sanitation of packhouse equipment, floors and walls with surfactants/disinfectants (Gardner *et al.*, 1986; Beuchat, 1995) has recently been explored as a preventative control measure in the fruit packing industry. Surfactants/disinfectants are routinely used in food and dairy industries to reduce inoculum of spoilage organisms (Park *et al.*, 1991). The usefulness of this technique in other food handling industries warrants further investigation for its use in citrus packhouses. Of the surfactants/disinfectants evaluated in this study to inhibit *in vitro* germination and growth of *P. digitatum*, only Tronic was effective against both 10^3 and 10^5

conidia ml^{-1} of this pathogen. Besides ethanol and chlorine dioxide that have been reported to sanitise bins, control decay and sanitise water (Bancroft *et al.*, 1984; Smilanick *et al.*, 1995; Lesar, 1997), this is the first report of the disinfecting abilities of non-selective chemicals in citrus packhouses. Tronic should be further evaluated in future studies under packhouse conditions for disinfection of both fruit and packing equipment. The usefulness of surfactants/disinfectants in a citrus packhouse cannot be over estimated, and should be part of the total disease management strategy.

To promote the judicious use of fungicides, it is necessary to investigate various alternatives to establish their suitability and usefulness. Such alternatives include biological control and warm water treatments. It is evident from this study that, although antagonists could suppress postharvest diseases *in vitro*, control *in vivo* and in the packhouse is highly dependent on the inoculum levels of the pathogen. While *Bacillus subtilus* was the most effective antagonist *in vitro*, high concentrations (10^9 cells ml^{-1}) of the bacterium were needed to control *P. digitatum* levels of 10^4 conidia ml^{-1} *in vivo*. Packhouse experiments with *B. subtilis* also resulted in no control when the pathogen inoculum was high. Similar results were obtained by various researchers (Janisiewicz & Roitman, 1988; Droby *et al.*, 1989; Huang *et al.*, 1992; Smilanick & Dennis-Arrue, 1992), which emphasises the fact that enhanced control is associated with increasing antagonist concentration, or a decrease in the level of pathogen challenge (Pusey & Wilson, 1984; Janisiewicz & Roitman, 1988; Korsten *et al.*, 1995).

Integration of antagonists with warm water treatment and reduced concentrations of commercially used chemicals, reduced fruit decay. However, control was not as consistent or effective as commercial chemical treatments. This contradicts findings of several studies (Huang *et al.*, 1995; Arras, 1996; Schachnai *et al.*, 1996) which indicated the viability of both these management strategies. The main difference between the conflicting reports is the time of pathogen application. In the present study, pathogen inoculum was applied prior to antagonist treatment to simulate field conditions where infection occurs during harvesting through wound and natural openings (Sommer, 1982; Brown & Eckert, 1989; Eckert & Brown, 1989). In the other studies pathogen inoculum was applied after the antagonist had already been introduced. Effectiveness of antagonist treatments depends on the successful establishment of the antagonist at wound sites prior to pathogen challenge (Janisiewicz &

Roitman, 1988; Huang *et al.*, 1992). Antagonists in this study did not have the advantage of colonising natural openings and wounds before arrival of the pathogen and hence fulfilled a curative rather than preventative function. In formulating an effective postharvest disease management strategy, factors such as timing of antagonist application, reduction of inoculum, prevention or eradication of field infection, suppression of disease development and inactivation of wound infection (Eckert & Ogawa, 1985), should be considered. Preharvest antagonist treatments may therefore provide a feasible alternative to antagonist application in the packhouse for disease management (Jeffries & Jeger, 1990; Korsten, 1993).

Postharvest warm water treatment of artificially inoculated citrus fruit resulted in a significant reduction in fruit decay caused by *P. digitatum* notwithstanding the high inoculum levels of 10^5 and 10^6 conidia ml^{-1}. Control of citrus postharvest pathogens may be attributed to host responses such as production of scoparone (Kim *et al.*, 1991). Packhouse experiments confirmed *in vivo* results, indicating that the most effective warm water treatment is 36 °C for 1 min. Although inhibition of *P. digitatum* by scoparone was also observed when fruit were treated at 36 °C for 2.5 and 5 min, and 40 °C for 1, 2.5 and 5 min, maintaining water temperature at 36 °C and dipping fruit for 1 min is the most cost-effective and less time-consuming treatment. Ben-Yehoshua *et al.* (1992), however, found *Citrus* species to vary considerably in their ability to produce scoparone in response to *Penicillium* and hot air treatments, with consequent variance in decay control. Optimisation of warm water treatment for different citrus cultivars packed in South Africa is therefore needed. Integration of surfactants/disinfectants with biological control and warm water treatments could be proposed, considering the success of these procedures on mango (De Villiers & Korsten, 1996) and citrus (Smilanick *et al.*, 1995), respectively.

Several environmentally friendly approaches are available for managing postharvest diseases, including biological control, surfactants and disinfectants, induced resistance and harvesting and careful handling practices to minimise injury and infection (Wisniewski & Wilson, 1992). This study proved that several of these approaches were viable alternatives to the use of fungicides for control of citrus postharvest diseases. Some aspects require further investigation, but it is nevertheless obvious that integration of the various procedures could provide a management strategy, which is economically viable, readily implemented and

environmentally sound.

REFERENCES

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

Bancroft, M.N., Gardner, P.D., Eckert, J.W. & Baritelle, J.L. 1984. Comparison of decay control strategies in California lemon packinghouses. *Plant Disease* 68: 24-28.

Barmore, C.R. & Brown, G.E. 1982. Spread of *Penicillium digitatum* and *Penicillium italicum* during contact between citrus fruit. *Phytopathology* 72:116-120.

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

Beuchat, R.L. 1995. Pathogenic microorganism associated with fresh produce. *Journal of Food Protection* 59: 204-216.

Brown, G.E. & Eckert, J.W. 1989. Postharvest fungal diseases. Pages 30-38 in: J.O. Whiteside, S.M. Garnsey & L.W. Timmer (eds). Compendium of citrus diseases. APS Press, St. Paul, Minnesota.

De Villiers, E.E. & Korsten, L. 1996. Alternative strategies to control mango fruit diseases. *South African Mango Growers' Association Yearbook* 16: 61-64.

Di Martino Aleppo, E. & Lanza, G. 1996. Effect of injury and inoculum density on the infection of Italian oranges by *Penicillium digitatum*. *Proceedings of the 8th Congress of the International Society of Citriculture* 2: 1171-1173.

Droby, S., Chalutz, E., Wilson, C.L. & Wisniewski, M.E. 1989. Characterization of the

biocontrol activity of *Debaromyces hansenii* in the control of *Penicillium digitatum* on grapefruit. *Canadian Journal of Microbiology* 35: 794-800.

Gardner, P.D., Eckert, J.W., Baritelle, J.L. & Bancroft, M.N. 1986. Management strategies for control of *Penicillium* decay in lemon packhouses: economic benefits. *Crop Protection* 5: 26-32.

Eckert, J.W. & Brown, G.E. 1989. Postharvest fungal diseases. Pages 30-38 in: J.O. Whiteside, S.M. Garnsey & L.W. Timmer (eds). Compendium of citrus diseases. APS Press, St. Paul, Minnesota.

Eckert, J.W. & Ogawa, J.M. 1985. The chemical control of postharvest diseases: subtropical and tropical fruit. *Annual Review of Phytopathology* 23: 421-454.

Huang, Y., Deverall, B.J. & Morris, S.C. 1995. 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* 5: 129-137.

Huang, Y., Wild, B.L. & Morris, S.C. 1992. Postharvest biological control of *Penicillium digitatum* decay on citrus fruit by *Bacillus pumilus*. *Annals of Applied Biology* 120: 367-372.

Janiesiewics, W.J. & Roitman, J. 1988. Biolgogical control of blue mold and grey mold on apple and pear with *Pseudomonas capacia*. *Phytopathology* 78: 1697-1700.

Jeffries, P. & Jeger, M.J. 1990. The biological control of postharvest diseases of fruit. *Postharvest News and Information* 1: 365-368.

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

Korsten, L. 1993. Biological control of avocado fruit diseases. Ph.D. thesis, University of Pretoria, Pretoria, SA.

Korsten, L., De Jager, E.S., De Villiers, E.E., Lourens, A., Kotzé, J.M. & Wehner, F.C. 1995. Evaluation of bacterial epiphytes isolated from avocado leaf and fruit surfaces for biocontrol of avocado postharvest diseases. *Plant Disease* 79: 1149-1156.

Lesar, K. 1997. *In vitro* evaluation of oxine (chlorine dioxide) as an alternative to calcium hypochlorite for packhouse water sanitation. *Citrus Journal* 7: 26-28.

Park, D.L., Rua, S.M. & Accker, R.F. 1991. Direct application of a new hypochlorite sanitizer for reducing bacterial contamination on foods. *Journal of Food Protection* 54: 960-965.

Pusey, P.L. & Wilson, C.L. 1984. Postharvest biological control of stone fruit brown rot by *Bacillus subtilis*. *Plant Disease* 68: 753-756.

Shachnai, A., Chalutz, E., Droby, S., Cohen, L., Weiss, B., Daus, A., Katz, H., Bercovitz, A., Keren-Tzur, M. & Binyamini, Y. 1996. Commercial use of Aspire™ for the control of postharvest decay of citrus fruit in the packhouse. *Proceedings of the 8th International Congress of the Society for Citriculture* 2: 1174-1177.

Smilanick, J.L. & Denis-Arrue, R. 1992. Control of green mold of lemons with *Pseudomonas* species. *Plant Disease* 76: 481-485.

Smilanick, J.L., Margosan, D.A. & Henson, D.J. 1995. Evaluation of heated solutions of sulfur dioxide, ethanol and hydrogen peroxide to control postharvest green mold of lemons. *Plant Disease* 79: 742-747.

Sommer, N.F. 1982. Postharvest handling practices and postharvest diseases of fruit. *Plant Disease* 66: 357-364.

Spotts, R.A. & Cervantes, L.A. 1986. Populations, pathogenicity, and benomyl resistance of *Botrytis* spp., *Penicillium* spp., and *Mucor piriformis* in packinghouses. *Plant Disease* 70: 106-108.

Spotts, R.A. & Cervantes, L.A. 1992. Effect of ozonated water on postharvest pathogens of pear in laboratory and packhouse tests. *Plant Disease* 76: 256-259.

Spotts, R.A. & Cervantes, L.A. 1993. Use of filtration for removal of conidia of *Penicillium expansum* from water in pome fruit packinghouses. *Plant Disease* 77: 328-330.

Van Dyk, K., De Villiers, E.E. & Korsten, L. 1997. Determination of possible infection and alternative control application sites in avocado packhouses. *South African Avocado Growers' Association Yearbook* 20: 106-108.

Wisniewski, M.E. & Wilson, C.L. 1992. Biological control of postharvest diseases of fruit and vegetables: Recent advances. *Horticultural Science* 27: 94-97.