

# POSTHARVEST DECAY ON STONE FRUIT - WHAT, WHEN and HOW TO REDUCE

## Part 2: Pre- and postharvest control measures to reduce decay development

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### Introduction

An integrated approach to disease management, encompassing pre- and postharvest activities, including effective use of postharvest technologies, is required to restrict fruit deterioration between harvest and end use (Wills, McGlasson, Graham, & Joyce, 2007). All decay management programmes must start with good pre-harvest practices. Practices to reduce the impact of environments favourable for the development of pathogens and to minimize the inoculum potential, should be followed meticulously, after which postharvest decay control should be applied. Postharvest decay control practices do not only entail chemical application. This communication focuses on control measures across pathogens, based on the premise that the infection process of the potential causal organisms, the physiology of the fruit and effect of environmental conditions are understood, as elaborated previously in Part 1 of the series.

### Pre-harvest management of decay

#### *Inherent condition of the crop*

Practices such as planting of disease resistant cultivars, canopy management, minimizing wetness duration and application of appropriate insect and weed control measures, are important pre-harvest aspects to be managed in order to reduce postharvest decay. Inherent condition of the crop, as influenced by fertilization and soil factors, affects the susceptibility of stone fruit to disease (Sholberg & Conway, 2004). Excessive fertilization, especially nitrogen, is known to predispose stone fruit to decay development. Fruit decay before harvest is generally less severe in a semi-arid climate, unless rain occurs at harvest time. Incorrect irrigation practices can create favourable environments for disease development (Adaskaveg *et al*, 2005).

#### *Physical control measures*

Most physical control practices focus on the reduction of the infection potential by eradicating the spores or infectious material, and hence, creating a less suitable environment for infections to manifest. Handling and treatment strategies must be based on sound knowledge of the

interrelationships between the host and the pathogen. The critical points are: the type of pathogen responsible for losses, where in the supply chain the pathogen is present, when and where infections occur, maturity of the fruit, environmental conditions, harvesting practices and storage conditions.

#### *Harvest, handling and fruit maturity*

Generally, immature fruit maintain a high degree of resistance to infection and decay development (Boyette, Ritchie, Carballo, Blankenship & Sanders, 1993). Fruit become more susceptible to infection and decay as ripening progresses, and this escalates rapidly as the fruit enters senescence. Harvesting of overripe fruit should thus be avoided. Damaged cells lead to increased respiration and ethylene production, stimulating further senescence, increasing susceptibility to fungal infection. Careful handling during harvesting will minimise mechanical damage and reduce subsequent wastage.

#### *Harvesting after rain*

Harvesting and packing stone fruit after rain increases the likelihood of decay development during storage. After rain, it is wise to ascertain the levels of the different decay types in the orchard, in order to make informed decisions regarding whether to continue packing or not. Every bout of rain should be treated as a separate event, with decisions made for each, according to circumstances, such as: wetting period, cultivar type, marketing conditions and weather forecasts for the 3-day period following rain, and beyond.

#### *Sanitation*

A good sanitation programme should be applied in the orchard. This entails a process of cleaning by removal and eradication of inoculum, to minimise the background level of fungal spores to cause later infections and decay. Decayed fruit on the orchard floor, or in the tree, can be a source for infections, and hence, removal is recommended (Figure 1).



**Figure 1:** Decayed fruit occurring on the tree or orchard floor can be a source for infections; sanitation by removal of such fruit is recommended

### *Chemical and biological decay control*

Success of chemical treatment prior to harvest depends on several factors, such as the initial spore load, the stage of infection, the growth rate of the fungi under the specific weather conditions, as well as product deposition and retention on the fruit. Ineffectiveness of fungicides is often associated with sub-optimal residue deposition on fruit, especially the waxy stone fruit types, such as plums. Deposition and adherence on different cultivars may vary, depending on surface characteristics.

Control products can be fungistatic or fungicidal (Kirk, Cannon, Minter & Stalpers, 2008). Products with fungistatic properties will inhibit spore germination, or reduce the rate of germination and growth, rather than killing the organism. Suitable selection and application of control products can determine the success or failure of decay control programmes.

Pre-harvest application of chemical fungicides or biological control agents is aimed at reducing inoculum, eradicating the causal organisms and protecting the fruit against possible infections. Fungicides are generally specific in their control. Pre-harvest fungicide treatments are therefore essential to reduce the incidence of post-harvest decay. The efficacy of a fungicide does not only depend on the dosage, but also deposition and adherence to the fruit surface. Residues, in particular maximum residue limits (MRL's), need to be adhered to at all times. Resistance of pathogens to specific fungicides, which includes pathogens causing decay on stone fruit, is becoming a serious issue, affecting efficacy of products to control decay. Spray applications, particularly scheduling and frequency of use, should be strictly according to the label. New reduced-risk fungicides are evidently available for managing pre- and postharvest diseases of stone fruit crops in California. These include active ingredients such as fludioxinil, pyraclostrobin, boscalid, fenhexamid, pyrimethanil and cyprodinil (Adaskaveg *et al.*, 2005). The reduced-risk fungicides have a low impact on the environment, are highly specific to the target organism, and have reputedly low human health risks. Use of these products has not necessarily been registered in South Africa

Despite substantial progress with biological control agents (BCA's), these are not widely used or routinely applied (Mari, Neri & Bertolini, 2007). The main drawbacks are: insufficient and inconsistent performance, difficulty in achieving unfailing formulations, and difficulty in controlling decay from latent infections.

It is important to apply good fungicide stewardship to effectively use the available fungicides prior to harvest to confine decay on stone fruit, since not many registered products are available (Adaskaveg *et al.*, 2005). Consequently, strategies to prevent fungicide resistance are of critical importance. Practices such as mixtures and rotation of registered fungicides should be implemented to prevent resistance and to ensure the prolonged efficacy of the reduced-risk chemicals.

## Post-harvest decay management

### *Handling practices*

Post-harvest handling should focus on maintaining physiologically healthy fruit and minimizing losses from decay (Kader, 1992a). Fruit quality can only be maintained during storage and cannot be improved. Handling procedures must guard against injuries to fruit, which would enable infection by pathogens and result in decay.

### *Humidity control and packaging*

Water vapour constitutes an important part of the atmosphere surrounding stone fruit during cold storage. The amount of water vapour in the atmosphere is expressed as a percentage relative humidity (RH). The RH during storage is generally close to saturation, but not quite 100%, which would lead to the presence of free water. Free water frequently develops on the surface of fruit due to condensation, which occurs when temperature increases, for example on removal from refrigeration, or when temperature breaks occur in the cold chain. Saturated atmospheres, or water occurring on fruit, favours spore germination and infection by *Botrytis* and *Monilinia*, amongst other pathogens. For this reason, while RH in the storage environment should be maintained at a level high enough to prevent moisture loss and shrivel, care must be taken to avoid free water. Perforated bags or wrappers can be used to lower the risk of free water, as opposed to non-perforated bags, in instances where moisture loss control from fruit, by using liners, is a necessity.

### *Cold storage*

Preservation of stone fruit after harvest, as with other fresh fruit, is mainly dependant on cold storage (Kader, 1992a). Storage at low temperature is important to slow microbial activity and the physiological processes, in order to maintain fruit quality. Fruit should be kept at a temperature which confines infection and growth of the prevalent fungi, without causing internal disorders, such as chilling and freezing injury. Cold storage reduces the respiration rate of the fruit and hence ripening, senescence and decay development. Stone fruit should be cooled without delay after harvest, to minimise exposure to high temperatures, during which infection and decay could manifest. Good temperature management throughout the handling chain is critical to control decay development. Cooling of stone fruit to temperatures higher than the norm of  $-0.5^{\circ}\text{C}$  may address issues of energy saving and in some cases may assist with management of internal disorders. However, decay development by specific pathogens may increase under such conditions and must therefore be taken into consideration when setting handling protocols.

### *CA storage and MAP*

The atmosphere surrounding the fruit during storage can be changed by adjusting the level of oxygen and carbon dioxide, by using controlled atmosphere (CA) storage or modified atmosphere packaging (MAP) (Kader, 1992b). Growth and development of several decay causing organisms can be reduced by atmosphere manipulation to levels of 10% carbon dioxide ( $\text{CO}_2$ ) or higher, provided that the commodity can tolerate such high  $\text{CO}_2$  levels, without developing physiological disorders. In some

instances, the modification of the atmosphere can also enable extended storage by suppressing the rate of respiration. In MAP, the reduction of O<sub>2</sub> and increase in CO<sub>2</sub> is achieved by application of semi-permeable barriers. To date, MAP has not been used very successfully on plums in South Africa, mainly due to over modification, which typically occurs under dual-temperature storage conditions. Over modification results in off-taste and internal damage.

#### *Pack-house management and sanitation*

Pack-house hygiene, involving actions such as cleaning and sanitising of equipment, as well as management of handling and packing procedures to minimise damage to stone fruit and spread of fungal spores, are important. Regular washing and sterilisation of the pack-house equipment, at least once a day, requires that pack-houses need to be designed to accommodate such actions. Organic waste (culls, plant parts and soil) in the pack-house can act as substrate for decay causing pathogens, and should therefore be removed immediately from pack lines and other surfaces (Figure 2).



**Figure 2:** Decayed fruit occurring in the pack-house can act as source for infections and decay development during storage, hence removal of such fruit is essential

#### *Chemical control*

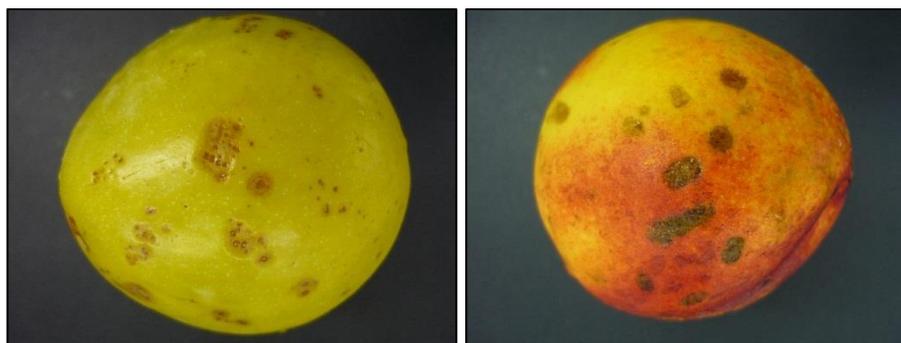
Chemicals for post-harvest use are typically applied as complimentary treatments in combination with appropriate pre-harvest treatments. Post harvest chemical application is aimed at preventing the spread of infections which may have been field-induced, established in wounds, or those induced at time of harvesting and packing (Figure 3).



**Figure 3:** Control of *Botrytis* decay can be achieved by post-harvest atomizer treatment of peaches (left), compared to untreated (right)

Chemicals are typically applied by atomizer, drench, or dip treatment, of which the atomizer application is the most commonly used for stone fruit in South Africa. Compared to pre-harvest disease control on other crops, the number of fungicides registered for postharvest use on stone fruit is very low. Iprodione is the only active ingredient currently registered for post-harvest use on plums, nectarines and apricots, but not peaches. In the case of atomizers, treatment of plums is done on rollers, with the fruit rotating below the applicators. Peaches and nectarines are treated statically after packing, with the packed box conveyed below the applicators, to avoid injuries to the fruit, especially to the soft-tipped cultivars. Calibration of all fungicide application equipment is essential to avoid over or under dosage. Residue analysis is required to optimise treatment and subsequent decay control, and also to ensure MRL's are not exceeded.

Fungicide application efficacy is related to the quantity of the product deposited on the fruit, but also the quality of deposition, which varies between fruit kinds, as well as cultivars (Förster, Driever, Thompson & Adaskaveg, 2007). It is important that chemicals applied should not be phytotoxic (Figure 4) and are permitted for use according to local and export regulations. There is an urgent need for new postharvest fungicides to supplement pre-harvest control measures in South Africa.



**Figure 4:** Symptoms of phytotoxicity on plums and nectarines; care should be taken that fungicide or sanitizer treatments do not damage the fruit surface

The use of endogenous plant metabolites and extracts to control microbial growth, is often perceived by the consumer as being more acceptable than standard chemicals, since these products are 'generally regarded as safe' (GRAS). Organic volatiles and essential oils are examples of such GRAS products. To be commercially viable, alternatives must be effective in controlling decay, without causing phytotoxicity. Phytotoxicity is often a function of temperature during treatment. To be effective, many of the alternative products need to be applied at higher concentrations than the levels at which they occur naturally, which can cause damage to the fruit. Furthermore, such products are likely to have been manufactured through chemical synthesis, rather than extraction from plants, as was originally intended. This can also impact on performance, as well as increase manufacturing costs.

Chlorine effectively kills most pathogenic fungi associated with deciduous fruit decay, when applied at a level of 50-150 ppm of active chlorine (Meheriuk, & McPhee, 1984; Spotts & Peters, 1980). However, chlorine will not protect wounded tissue against subsequent infection, nor kill infections that have already established prior to treatment (Sholberg & Conway, 2004). Chlorine is very sensitive to pH (Boyette *et al*, 1993). At a high pH, chlorine will be more stable, but less fungicidal, with the converse applicable at low pH. Organic matter in water used for treatment will inactivate chlorine. Therefore, for best effect, chlorine levels need to be monitored constantly during treatment of fruit.

Post-harvest treatment of fruit with permissible sanitizers, is sometimes used to reduce the spore load. Generally, sanitizers are not able to control infections that have already manifested within the fruit tissue. Furthermore, most sanitizers do not have a residual action and fruit are therefore not protected against infections during storage. Phytotoxicity of products on different fruit types must be tested before commercial use is considered.

#### *Biological control*

Biological control agents (BCA's) are often considered as alternatives to synthetic chemicals for post-harvest treatment for decay control (Sholberg & Conway, 2004). Safety issues, as well as limited success, often restrict the use of these products. Variability in the products and lack of understanding on how to adapt biological control systems for commercial application, remain a problem (Wisniewski & Wilson, 1992). For a BCA to be effective in the postharvest environment, storage conditions must allow the organism to remain active. BCA's suppress pathogens by a number of mechanisms. Direct attack, competition for space or nutrients, eliciting of defence mechanisms, and synthesising of antibiotics, are the most common modes of action. Production of antibiotics, although a very effective mechanism, is often not acceptable on food crops. Antagonism between organisms is seen as the most promising mechanism of biological control. While the organisms often occur naturally in the environment, they may cause human toxicity or allergic reactions, as do certain synthetic fungicides. Consequently, rigorous testing is required before postharvest commercial use of BCA's. A combination of BCA's with other treatments, as part of an integrated control approach, is a likely direction for stone fruit in future (Roberts, 1994).

#### *Ethylene reduction*

Commencement of ripening and senescence in climacteric fruit is accompanied by an increase in ethylene production (Wills, McGlasson, Graham, & Joyce, 2007). Delaying ripening is essential for quality maintenance of stone fruit, particularly for the inhibition of decay development. Various methods are available to reduce ethylene levels in packed produce. Avoidance of ethylene accumulation by good ventilation is an effective method, albeit not always the most suitable. Ethylene in the atmosphere can be reduced by oxidation, using different chemicals and processes, such as potassium permanganate and ozone. SmartFresh<sup>SM</sup> can also be used to block ethylene production on plums, and thereby delay ripening. The different stone fruit types and cultivars react differently to

these treatments. Therefore, careful management and operational experience is required before commercial application.

#### *Ozone treatment*

Ozone gas treatment is of growing interest in the fruit industry, especially for cold stored fruit (Palou, Crisosto & Smilanick, 2007). Aerial mycelial growth and sporulation of the most important fungi can be inhibited effectively by ozone on peaches. However, even continuous exposure to ozone cannot control infections already established in or under the fruit skin. Following wound or latent infections, the development of most pathogens occurs at a sub-epidermal level, where the oxidizing effect of ozone is limited. Direct and continuous contact with ozone gas is required for effective control. When treatment is terminated, normal aerial growth and sporulation resumes. Ozone treatment is often seen as a supplementary treatment rather than a substitute for fungicides. Important facts not to be ignored are that ozone can be harmful to humans, phototoxic to fruit, and corrosive to numerous materials if not used at the correct concentration.

#### *Fungicide and sanitising alternatives*

Non-residual fungicide and sanitizing alternatives have been developed, unfortunately often with limited success as stand-alone treatments. Product registration remains a prerequisite. New advances in the field of alternative low-risk chemicals, including essential oils, as secondary plant metabolites, are currently being made in many countries (Wilson, Wisniewski, Biles, McLaughlin, Chalutz & Droby, 1991). However, commercial use has not materialised. Other concepts include: plant defence enhancers, fruit coatings, genetic engineering, novel fungicides and residue-free products. The search continues for effective and economical sanitisers and alternatives to chemical fungicides with undesirable residues.

#### **12-Point decay control plan for fresh cold stored stone fruit**

- Analyse quality reports to ascertain the reason for rejection or downgrading of fruit.
- Identify the causal pathogen and become acquainted with the disease cycle on stone fruit.
- Be on the lookout for survival structures or infectious material and eradicate them if present.
- Know the susceptibility status of the fruit kind and cultivar, and be aware of the sensitivity to infection at specific growth stages, and react accordingly.
- Apply pre-harvest chemicals, in accordance with market requirements and specifications (MRL's) to protect fruit from infections or eradicate infectious material.
- Monitor weather conditions and ascertain the possible impact on decay.
- Apply sanitation practices, by removal of infectious material, to reduce the inoculum load and potential for infections.
- Handle fruit carefully to avoid injuries, especially during harvest and packing.
- Schedule harvesting according to maturity, weather conditions and market demand, and pack and sell without unnecessary delays.
- Apply applicable post-harvest treatment for protection of fruit during storage.

- Use the correct packaging material for quality maintenance throughout the post-harvest handling chain.
- Store stone fruit at the lowest temperature possible to inhibit disease development, but high enough not to compromise fruit quality.

### Summary

It is apparent from Part 1 '**Postharvest decay on stone fruit - what, when and how to reduce**', and Part 2 above, that control of post-harvest decay on stone fruit can be best achieved by incorporating pre-harvest, as well as post-harvest measures into control strategies.

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