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Harvesting and handling effects on postharvest decay

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Abstract

Purpose of review: The aims of this review are: (1) to highlight the most significant results over the last few years in harvesting methods and pre- and postharvest handling of horticultural products; and (2) to provide insights in terms of technological aspects, with special reference to the control of postharvest decay. New system approaches that should be considered as components of an integrated decay control strategy and overall good agricultural practices are also described.

Main findings: Harvest and handling practices have major effects on postharvest decay. Mechanical harvesting systems and time of harvest have a prominent effect on postharvest decay and mycotoxin contamination. Fruit maturity at harvest, which directly affects bruising, is a major factor affecting infection by postharvest pathogens. Harvest of fruits from the ground and contact of harvest containers with soil contaminate fruits with postharvest propagules and result in increased decay. Climatic conditions affect sources of contamination and infection of fruits: under dry, hot subtropical climates latent and quiescent infections preharvest play a significant role while under warm, humid tropical climates contamination of fruit wounds during harvest can be of great importance, affecting levels of postharvest decay. Packing directly in the field reduces production costs but increases chances for postharvest decay. Electronic noses have been constructed that can "smell" and separate decayed fruits in packinghouses and predict mycotoxin contamination. Regression models have been developed to detect the impact of mechanical damage on postharvest decay. In addition, new packaging systems have been created to minimise mechanical injuries and decrease susceptibility to decay and bruising. Postharvest treatments, such as application of reduced-risk fungicide, biological agents and natural products, heat treatment and edible coating formulations, alone or in combination, can be successfully applied in a range of commodities in order to prevent decay.

Directions for future research: The mode of action of antagonistic yeast in postharvest fruit disease control may be an important tool in postharvest biocontrol strategies, thus providing important guidance for their future application. In addition, mixtures of low-risk fungicides with biological agents should be carried out to identify the best postharvest treatments with the lowest environmental impact and the greatest consumer safety. Comparative studies for a range of fleshy products harvested from organic, integrated and conventional production systems should be also carried out.

Keywords: mechanical harvest; maturity stage; biological agents; edible coating; heat treatment; fungal pathogens

Abbreviations

GAP	Good Agricultural Practices
GPP	Good Postharvest Practices
GRAS	Generally Regarded as Safe
MAP	Modified Atmosphere Packaging

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Introduction

Postharvest decay may occur because of both pre- and postharvest factors and can be the result of preharvest latent infection or contamination and infection during harvest. These infections can develop into disease symptoms during postharvest storage, transport or marketing of fleshy products. The postharvest life of fruits and the severity of postharvest decay of fleshy agricultural products depend partly on preharvest effects and harvest systems, and partly on handling of these products during postharvest storage, transport and marketing. Efficient harvest methods have been developed that are low cost and offer ways to prevent postharvest decay. In general, harvesting is an important issue in the postharvest life of a commodity. Postharvest handling and treatment of agricultural products have also evolved to reduce postharvest decay and simultaneously increase the nutritional value of these products.

Although postharvest technology has evolved over the last two decades, there isn't enough emphasis on preharvest factors and the influence of these factors on postharvest decay. A fact that is sometimes overlooked by growers and packers is that postharvest decay problems are related to specific field problems. Therefore, the initial step in reducing postharvest decay is necessary before fruits are harvested or during harvest. Reduction of propagules, which contaminate crops in the field or cause high levels of incipient or latent infections, plays a tremendous role in the management of postharvest decay. Realising the importance of these processes, the majority of the agricultural industries that deal with horticultural products have developed a series of guidelines called "good agricultural practices (GAP)". GAP can start as soon as crops are at bloom and finish with the harvest of each commodity. With the same thinking, "good postharvest practices" (GPP) could also be developed and followed during the postharvest life of agricultural products.

Factors during harvest that affect postharvest decay

To ensure the best quality for the consumer, crops are harvested at various maturities by different ways that involve the method of harvest, type of container used to collect the product, type of container used for hauling to packing sheds, and the condition of the roads that will be used to transport fruits. The aim of agricultural industries is to offer horticultural products that are less prone to postharvest decay and of high quality. The maturity stage of fruits is of critical importance to their potential for postharvest decay. Any deviation from the optimum harvesting stage may cause considerable loss in terms of quality, quantity and monetary inputs [1]. The maturity stage of fleshy fruits is usually determined by fruit colour, shape, size, soluble solids, sugars and acid contents [1]; however, over the last decade new non-destructive methods (eg, near infra red spectroscopy) have been developed to evaluate the maturity stage of horticultural products [2*].
Harvesting of fleshy fruits is usually done by hand, particularly for highly-perishable commodities. However, hand harvesting has a high cost, particularly for small crops, and is time consuming; therefore, mechanical harvesting is an important alternative method. Mechanical harvest systems include trunk shake-and-catch and continuous canopy shake-and-catch systems. For nut crops, trunk shake and catch is used for pistachios while trunk shake and sweeping from the ground after some sun-drying are used for almond and walnuts. Furthermore, for figs, branches are shaken with large blowers or beaten with mallets, and then the figs are swept in windrows and collected into large containers (harvest bins). Other methods may involve laying on the ground a special type of paper and shaking vines, catching and evenly laying the berries on the paper to dry (raisin production in California), or cutting the canes and allowing them to dry on the vines (dried-on-the-vine [DOV] procedure), or cutting the bunches and laying them on special paper on the south side of the vines to sun-dry, then rolling the paper and letting them cure in the field for some days, and subsequently collecting the raisins from the field for further storage and processing. Fresh fruits destined for processing may also be mechanically harvested.

Mechanical harvesting has also been proposed for commodities where hand harvesting is a time-consuming task and the harvesting period is relatively short, eg, in apricots [3]. Mechanical harvesting is also aided by the use of abscission agents, eg, in oranges [4] and processed table olives [5], resulting in increased harvesting capacity. Mechanical harvesting of apples can predispose the stem cavity to blue mould decay (*Penicillium expansum*); however, this problem can be alleviated using a biological control (antagonist *Pseudomonas syringae* (used in BioSave 110)) without the need for synthetic pesticides [6]. Despite the above-mentioned examples of successful mechanical harvesting of deciduous tree fruit crops destined for the fresh market, attempts to mechanically harvest fleshy fruits by mass removal techniques have not been successful due to excessive fruit damage caused during detachment, fall through the canopy, and collection [7]. An innovation of a sorting/sizing system that eliminates culls in the field and delivers only fresh market quality fruits to the packers can make mechanical harvesting a viable harvesting system, even for commodities destined for the fresh market [7].

A good example where the direct effects of harvest method were evaluated on postharvest decay is an old study done with prunes cv. 'French' in California. Three methods were used: 1) prunes were hand-harvested from the ground after trees were mechanically shaken; 2) prunes were harvested by a mechanical shaker with a catching canvas laid on the ground; and 3) prunes were harvested either mechanically onto elevated frames or by hand directly from the trees into boxes. In all cases fruits harvested directly from the ground developed significantly more postharvest decay at 4, 20 and 28°C after 20, 4 and 4 days, respectively. Fruits harvested mechanically on elevated frames had the lowest incidence of postharvest decay, while fruits that were harvested mechanically on canvas laid on the ground in some cases had an intermediate incidence of postharvest decay between those harvested from the ground and those harvested mechanically on elevated frames [8]. However, to date, few or no studies have been conducted on the effect of mechanical harvesting on postharvest performance of horticultural crops with reference to their susceptibility to postharvest decay.

Another example where practices during harvest affect postharvest decay is *Mucor* and *Penicillium* rots of pears. To reduce the amount of spores of these fungi going into the packinghouse, growers can put a layer of gravel or wood chips on the soil surface to insulate the bottom of the harvest bins in the loading area. This practice not only prevents direct contact of the bottom of the bin with the soil, but also, once the bins are filled, the bins are ready to be transported to the packinghouse from an easy access area. In recent years, harvest of more mature fruits (to obtain higher quality and better colour) is done in plastic buckets or totes that are filled in the field and transported directly to the packinghouse. Usually during harvest (mechanical or hand harvest) some fruits drop onto the orchard floor. It is recommended that these fruits are not collected from the ground and comingled with fruits harvested from trees as such fruits can be a source of contamination and spread of decay organisms in postharvest storage. Propagules of *Mucor piriformis* increased after harvest in apple orchards in California, and the practice of flail-mowing the orchard floor after harvest may increase population levels of *M. piriformis*, therefore growers should not flail-mow fruits on the orchard floor [9]. In orchards with prunes (and in other stone fruit orchards), similar to thinned fruits that provide a significant spore inoculum source for latent infections of fruits by the brown rot fungi (*Monilinia* spp.) [10], sporulation of these fungi on fruits that fall onto the ground during harvest also contributes to increased amounts of spore inoculum load during and after harvest on varieties that mature on different dates [11].

There is also an influence of climate and harvest on postharvest diseases. A good example is grey mould of kiwifruit (*Actinidia deliciosa*) caused by *Botrytis cinerea* for California- and New Zealand-grown kiwifruit. A study by Michailides and Morgan [12] showed that colonisation of sepals and receptacles by *B. cinerea* starts as early as 30 days after fruit set for California kiwifruit, and this colonisation correlates significantly (r = 0.90) with postharvest decay after 3 and 5 months cold storage. The authors found that harvest infections along with infections through wounds could explain only 10% of the postharvest decay. In contrast, colonisation of sepals of kiwifruit in New Zealand plays a minor role (if any) in postharvest grey mould decay; instead the fresh stem scar gets infected during harvest in the vineyards [13]. Elmer and co-workers [13] compared areas with low and high *B. cinerea* population size in the kiwifruit canopy and the number of viable propagules were all correlated with low and high grey mould after 16 weeks in cold storage [14**]. These studies suggest that the amounts of inoculum load on kiwifruit at harvest is the most important factor affecting postharvest decay in New Zealand, and not the latently colonised sepals and stem ends, as is the case in California. Overall, such comparisons showed that the climatic differences (eg, hot, dry sub-tropical versus warm, humid tropical) between locations where a crop is grown affect the incidence of latent infections or inoculum load potential during harvest.

Handling at harvest

Harvest and packing of table grapes is now done directly at the site of vineyard mainly to reduce costs, but unfortunately no studies exist to determine if this practice affects postharvest grey mould incidence. It is thought that by clipping and removing the foci of infection, postharvest decay could be reduced since *B. cinerea* will not have the opportunity to nest from infected to healthy berries. In Australia, researchers modified an old technique developed in California in which berries are incubated (18–22°C for 7–10 days) and the levels of infection by *Botrytis* are recorded and correlated with grey mould incidence. This approach is now used to predict postharvest decay and make decisions on fruit marketing.

Discussions about the superiority of vineyard versus shed packing have never reached a conclusion. Although vineyard packing predominates now, there is currently a move to go back to shed packing. Shed packing is easier to attract and manage workers and the packs are of better quality than packing in the field. Most of the problems with shed packed grapes are related to rachis drying, and some cultivars are very susceptible to this problem (J. Smilanick, pers. com.). We are not aware of any studies that have compared the two methods of harvest and packing directly in terms of grey mould control. However, it is well established that delays in precooling and initial fumigation, and higher than optimal postharvest handling temperatures are correlated with increased decay during storage [15].

Other factors that perhaps have more weight in a decision about what method should be used to harvest grapes are the limitation in space, availability of workers and grape market prices. Although cost may be low, the loss of quality control is the main disadvantage in field packing. In contrast, house packing generally occurs to accommodate a buyer's requests. Often times, it might be a special pack type (clamshells), or multiple pack types where it would be just too complicated to have that many different packaging materials out in the field. Furthermore, a significant advantage of the house pack is superior quality control and much of this is monitored by high-tech automated equipment on the packing line. The advantage of packing in the packinghouse is that fruits are transported more quickly to the cold storage facility and is kept at lower temperatures during the packing process, as fruits are placed in the cold room and brought out to the line as needed (J. Hashim, pers. com.).

Harvest and handling of nut crops also play a major role in postharvest decay and contamination with aflatoxins. Delaying harvest of pistachio and almond increases damage with navel orangeworm, which results in increased contamination of these tree nuts with aflatoxins [16]. When nuts are dried to a specified water content (6% for pistachios and almonds and < 9% for walnuts), stored properly, marketed within a reasonable time period, and maintained in the retail store dry, no aflatoxin contamination develops after harvest. Aflatoxin contamination of these commodities then would entirely depend on preharvest and harvest factors. For years, it was a common practice that labourers collected in buckets pistachio nuts that fell on the ground after mechanical shaking of the trees. However, after the strict regulations of various governments and mainly the European Union market on aflatoxin thresholds, this practice has been abandoned entirely. It is unfortunate that this is commonly used in harvesting pistachios and other nuts in other counties where mechanical harvesting is not an option.

In California, when almonds are ready for harvest, they are shaken to the ground, allowed to dry on the orchard floor for about 7–10 days (depending on the temperatures of the season), mechanically swept in windrows, and transported and placed in stockpiles and sealed with a plastic. A recent study by Lampinen [17] determined that conditions in the stockpile favour aflatoxin contamination, especially when hulls are still wet and provide conditions for condensation; temperature does not seem to be a limiting factor because temperatures are still hot at the end of summer and early fall when stockpiles are built.

An obvious practice that can reduce decay is the culling of damaged or decayed products during harvest and on the sorting table in packinghouses. Mechanical and electronic sorters are used for nuts, and currently electronic noses are under experimentation to “smell” and separate decayed fruits in packinghouses and predict mycotoxin production by detecting specific volatile metabolites [18, 19**].

The development and testing of procedures for new packaging systems is evolving. The aim should be to construct new packaging systems with better protective performance and improved quality parameters in order to minimise mechanical injuries and decrease susceptibility to decay and bruising. Packaging systems should be evaluated in terms of physical protection, heat transfer characteristics for rapid cooling (for optimum temperature and relative humidity) to avoid water loss during the postharvest period, as well as for quality maintenance and marketing issues. Mechanical damage is one of the major causes of quality loss in fruits; therefore, proper packaging is needed for better protection. Other criteria are also important for meeting consumer acceptance [20].

Modified atmosphere packaging (MAP) in combination with biological or antimicrobial compounds has been suggested as a direction for future research with a further aim to develop “smart-intelligent consumer units” [21]. The combined effect of MAP (bioriented polypropylene) and an antimicrobial agent (*Bacillus subtilis*), evaluated as an alternative method to commercial SO_2 fumigation, controlled postharvest decay and retained the overall quality of litchi cv. McLean's Red fruits [22].

Postharvest factors affecting decay

Fungicide treatments

New reduced-risk fungicides have replaced most previously registered materials because of their high efficacy in managing pre- and postharvest diseases of stone fruit crops [23**]. Fungicides such as boscalid + pyraclostrobin, fenhexamid, cyprodinil and pyrimethanil have been shown to be very effective against natural incidence of brown rot fungi causing fruit decay [23**]. Similarly, the reduced-risk fungicides boscalid plus pyraclostrobin (Pristine) and fludioxonil (Scholar) significantly reduced Rhizopus soft rot of sweet potatoes [24]. Thiabendazole, fludioxonil and pyrimethanil, applied to pear fruits, were effective in controlling decay in artificial wounds inoculated with *Penicillium expansum* up to 14 days after inoculation. Three yeast and one bacterial biological agents reduced decay in wounds inoculated with *P. expansum* up to 14 days after inoculation, but were ineffective when applied at 28 days after inoculation. Of possible sequential arrangements of fungicide and biological treatments, application of the most effective material promptly after harvest generally resulted in the highest level of decay control [25].

Biological agents and inorganic compounds

Microbial antagonists have a greater potential for success when applied postharvest than when applied in the field. However, such postharvest biological agents cannot control latent and quiescent infections [26]. The effect of the antagonistic yeast *Pichia membranaefaciens* on alleviating oxidative stress caused by *P. expansum* in sweet cherry fruits at two maturity stages showed no decay in yeast-treated fruits even 5 days after inoculation [27]. The authors highlighted the induction of antioxidant defence as an important mechanism of antagonistic yeast in mitigating pathogen-induced oxidative stress to postharvest fruits and controlling postharvest disease.

The use of biological products such as BioSave (a.i. non pathogenic *Pseudomonas syringae* strains ESC_{10} and ESC_{11}) gave variable results and the GRAS products (eg, calcium chloride, copper ionised water, potassium sorbate, hydrogen dioxide, etc) were ineffective in controlling soft rot in sweetpotato [24]. In contrast, another GRAS compound, acetic acid, the active ingredient of household vinegar was very effective in reducing postharvest decays of stone and pome fruits [28**].

Heat treatments

The effect of postharvest heat treatments on horticultural crops over the last years has been recently reviewed [29].

Heat treatment may be combined with other methods in order to prevent decay. The combination of heat treatment and an antagonistic yeast (*Cryptococcus laurentii*) was suggested as an alternative to chemicals for the control of postharvest decay on peach fruits caused by *P. expansum* and *Rhizopus stolonifer* [30]. The efficacy of thiabendazole for controlling postharvest decay caused by *Penicillium digitatum* of citrus fruits can be enhanced by co-application of sodium bicarbonate or heat treatment [31]. A limitation of heat treatments is that they are difficult to apply on a commercial scale since risk margins for safe application of postharvest heat are not fully understood and differ, based on the commodity and the pathogen considered [29].

Edible coatings and natural products

Edible coatings on fruits is an innovative and interesting means for commercial application and an alternative to the use of postharvest chemical treatments, particularly in high-perishable fruits [32**, 33]. They have been successfully used in a range of fleshy fruits, giving promising results in extending their shelf-life. These coatings act as barriers during processing, handling and storage, and do not solely retard food deterioration and enhance its quality, but are safe due to natural biocide activity, or to the incorporation of antimicrobial compounds [34]. Different compounds have been used mainly as edible coatings to prevent commodity weight loss, including wax, milk proteins, celluloses, lipids, starch, zein and alginate [35]. However, in order for such edible coatings to be used at a commercial level they must fulfil some basic requirements: acceptable sensorial characteristics, appropriate barrier properties, good mechanical strength and adhesion, reasonable microbial, biochemical and physicochemical stability, safety for health, low cost raw material and simple technology for production [36]. A novel edible coating based on *Aloe vera* gel has been successfully used as a means of preservation to maintain the quality and safety of cv. Crimson Seedless table grapes during cold storage and subsequent shelf-life. In addition, gels derived from *A. vera* were shown to exhibit antifungal activity against four common postharvest pathogens: *P. expansum*, *P. digitatum*, *B. cinerea* and *A. alternata* [37] and can be extended to other commodities as an innovative and interesting means for commercial application and an alternative to the use of postharvest chemical treatments [32**].

Combination of chitosan, a natural biopolymer with antifungal and eliciting properties, and ethanol, a common food additive with antifungal properties, was successfully applied on table grapes to control postharvest grey mould caused by *B. cinerea* [38]. Furthermore, when chitosan was dissolved in a range of acids to form 1% solutions of chitosan acetate the solutions proved effective in reducing grey mould without causing any injury to the grapes [39*]. Chitosan and grapefruit seed extract treatments, alone or combined significantly reduced postharvest fungal rot of table grapes (cv. Redglobe). Grapefruit seed extract had both antifungal and antioxidative activity and additional beneficial effects in terms of sensorial properties were also discovered [40].

Concluding remarks – future perspectives

A number of innovations have been developed in the last decade whose effects improved not only the general quality of agricultural products but at the same time reduced postharvest decay. The ultimate effect of these innovations was to provide the consumer with healthy and safe fruits with low chemical residues and higher returns to the growers. Practical implications from the studies mentioned in this review are that there is no doubt that harvesting and handling of agricultural products have major effects on postharvest decay. Generally, harvest has been adjusted and performed in ways to minimise production costs, but also taking into account issues that do not compromise the heath of the postharvest life of products in all, cold storage, transit to market and retailed store periods. Simple procedures and methods used during harvest in the field can reduce pathogen inoculum load on fruit surface, bruising and cut wounds, and infection of fruits during harvest. Postharvest treatments with low-risk fungicides alone or combined with effective biological agents, edible coatings and GRAS antimicrobial products, all provide opportunities for reducing postharvest decay and extending the shelf-life of products, making them more appealing to consumers.

One area that needs further study is the development of latent and quiescent infection of various types of fruit by pathogens which initiate infection in the field long before harvest. A proportion of these infections are expressed as disease at harvest, and fruits can be easily removed. However, another portion of these infections will be expressed as disease symptoms during the postharvest life of the fruits. It is this latter portion of infections that needs to be studied further and possibly develop procedures to quantify it. At least, in hot dry climates, the incidence of latent infection before harvest could be used as a biological predictor of the amount of decay at harvest and postharvest. This information will be very useful in helping growers and packinghouse operators in decision making for pre- and postharvest treatments, longevity of storage, and timing of marketing the fruit (a good example is the grey mould of kiwifruit system in California [12]).

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