The Return on Investment in Postharvest Technology for Assuring Quality and Safety of Horticultural Crops

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Summary

Reduction of postharvest losses can increase food availability to the growing world population, decrease the area needed for production, and conserve natural resources. Strategies for loss prevention include use of genotypes that have longer postharvest-life; use of integrated crop management systems and Good Agricultural Practices (GAP) that result in good keeping quality of the commodity; and use of proper postharvest handling practices in order to maintain quality and safety of the products. There are many postharvest technologies that extend the marketable life of fruits and vegetables. However, some of these technologies do not have a positive return on investment (ROI) due to the large capital investments needed for their implementation and/or the increasing competition related to globalization of produce marketing. Appropriate postharvest technologies when used effectively can greatly enhance profitability, but no single technology is a substitute for the many integrated steps involved in proper postharvest management. A few examples of the ROI in various postharvest technologies are presented. Similar site-specific and commodity-specific studies are needed as basis for selecting the most suitable postharvest handling technologies in each situation

Keywords: Horticultural crops; Postharvest technology; Quality and safety; Return on investment.

1. Introduction

1.1. Quality factors:

Quality, the degree of excellence or superiority, is a combination of attributes, properties, or characteristics that give each commodity value in terms of its intended use. The relative importance of each quality component depends upon the commodity or the product and how it is utilized and varies among producers, handlers, and consumers. To producers a given commodity must have high yield and good appearance, must be easy to harvest, and must withstand long-distance shipping to markets. Appearance quality, firmness, and shelf life are important from the point of view of wholesale and retail marketers. Consumers judge quality of fresh fruits, ornamentals, and vegetables on the basis of appearance (including freshness) at the time of initial purchase. Subsequent purchases depend upon the consumer's satisfaction in terms of flavor (eating) quality of the edible products (Kader, 2002 and Kader & Rolle, 2004).

Grade standards identify the degrees of quality in a commodity that are the basis of its usability and value. Such standards, if enforced properly, are essential tools of quality assurance during marketing and provide a common language for trade among growers, handlers, processors, and receivers at terminal markets. Some production areas enforce minimum standards concerning produce quality, maturity, container, marking, size and packing requirements. This provides orderly marketing and equity in the market-place and protects consumers from inedible and poor quality produce (Kader, 2002).

1.2. Safety factors:

Safety factors in fruits and vegetables include naturally-occurring toxicants, such as glycoalkalosids in potatoes; natural contaminants, such as fungal toxins (mycotoxins) and bacterial toxins and heavy metals (cadmium, lead, mercury); environmental pollutants; residues of pesticides; and microbial contamination. While health authorities and scientists regard microbial contamination as the number one safety concern, many consumers rank pesticide residues as the most important safety issue (Kader & Rolle, 2004).

Unless fertilized with animal and/or human waste or irrigated with water containing such waste, raw fruits and vegetables normally should be free of most human and animal enteric pathogens. Organic fertilizers, such as chicken manure, should be sterilized before use in fruits and vegetables to avoid the risk of contaminating fresh produce with Salmonella, Listeria and other pathogens. Commodities that touch the soil are more likely to be contaminated than those that do not come in contact with the soil. Strict adherence to Good Agricultural Practices (GAP) during production, Good Hygienic Practices (GHP) during postharvest handling and Good Manufacturing Practices (GMP) during processing are strongly recommended to minimize microbial contamination (Kader & Rolle, 2004). These practices have a positive ROI since lack of safety can have major negative consequences in terms of marketability.

1.3. Postharvest losses of horticultural perishables:

Both quantitative and qualitative losses occur in horticultural commodities between harvest and consumption (Shewfelt & Prussia, 1993; Kader, 2002 and Gross *et al.*, 2004). Qualitative losses, such as loss in edibility, nutritional quality, caloric value, and consumer acceptability of the products, are much more difficult to assess than quantitative losses. Standards of quality and consumer preferences and purchasing power vary greatly among countries and across cultures and these differences influence marketability and the magnitude of postharvest losses (Kader & Rolle, 2004).

Postharvest losses vary greatly among commodities and production areas and seasons. In developed countries, the losses of fresh fruits and vegetables are estimated to range from 2% for potatoes to 23% for strawberries, with an overall average of 12% losses between production and consumption sites. In contrast, the range of produce losses in devel-

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oping countries is estimated to vary from 5 to 50%, with an overall average of 22%. Losses at the retail, food-service, and consumer levels are estimated at approximately 20% in developed countries and about 10% in developing countries. Overall, about one third of horticultural crops produced are never consumed by humans (Kader, 2003 & 2005).

Reduction of postharvest losses can increase food availability to the growing world population, decrease the area needed for production and conserve natural resources. Strategies for loss prevention include: (1) use of genotypes that have longer postharvest-life; (2) use of integrated crop management systems and GAP that result in good keeping quality of the commodity; and (3) use of proper postharvest handling practices in order to maintain quality and safety of the products (Kitinoja & Kader, 2002 and Kader, 2005).

There are many postharvest technologies that extend the marketable life of fruits and vegetables. However, many of these technologies are inappropriate economically due to the large capital investments needed for their implementation and the increasing competition related to globalization of produce marketing. Appropriate postharvest technologies when used effectively can greatly enhance profitability, but one must keep in mind that no single technology is a substitute for the many integrated steps involved in proper postharvest management (Gorny & Kitinoja, 1999 and Kitinoja & Gorny, 1999). In this report, I will present a few examples of the ROI in various postharvest technologies. Similar site-specific and commodity-specific studies are needed as basis for selecting the most suitable postharvest handling technologies.

2. Postharvest Management Procedures that are Critical to Maintaining Quality and Safety of Horticultural Crops

2.1 Preparing fruits and vegetables for market:

Preparation of produce for market may be done in the field or in a packinghouse where the product is cleaned and sanitized, sorted by quality and size, waxed and treated with an approved fungicide for some commodities, then packed in shipping containers (Shewfelt & Prussia, 1993 and Kader, 2002). Packing protects the product against mechanical injuries and contamination during marketing. Corrugated fiberboard containers are the most commonly used for produce packing, but these are being replaced with reusable plastic containers, in some cases, at the request of some produce buyers. Packaging materials (such as trays, cups, wraps, liners and pads) may be used to help immobilize the produce. Mechanical packing systems based on the volume-fill or tight-fill method are more commonly used than hand packing procedures. Packing and packaging methods can influence airflow rate around the commodity, which is an important factor in management of temperature and relative humidity (Kader & Rolle, 2004). There are no published studies of the ROI in the various preparations for market procedures. However, many of these procedures are essential for successful marketing of horticultural perishables.

2.2 Temperature and relative humidity management:

Temperature is the most important environmental factor that influences the deterioration of harvested commodities. Most temperate, perishable horticultural commodities last longest at temperatures near 0°C. At temperatures above the optimum, the rate of deterioration increases 2- to 3-fold for every 10°C rise in the temperature (Table 1). Temperature influences how other internal and external factors influence the commodity and has a dramatic effect on the spore germination and growth of pathogens. Temperatures outside the optimal range can cause rapid deterioration due to the freezing, chilling (of subtropical and tropical commodities), or heat disorders.

Table 1. Effect of temperature on deterioration rate of a non-chilling sensitive commodity (Kader, 2002)

Temperature (°C)	Assumed Q_{10}*	Relative velocity of deterioration	Relative postharvest-life	Loss per day (%)
0	—	1.0	100	1
10	3.0	3.0	33	3
20	2.5	7.5	13	8
30	20	15.0	7	14
40	1.5	22.5	4	25

$$^{*}Q_{10} = \frac{\text{Rate of deterioration at temperature T+10°C}}{\text{Rate of deterioration at T}}$$

Relative humidity (RH) can influence water loss, decay development, incidence of some physiological disorders, and uniformity of fruit ripening. Condensation of moisture on the commodity (sweating) over long periods of time is probably more important in enhancing decay than is the RH of ambient air. An appropriate RH range for storage of fruits is 85 to 95% while that for most vegetables varies from 90 to 98%. The optimal RH range for dry onions and pumpkins is 70 to 75%. Some root vegetables, such as carrot, parsnip and radish can best be held at 95 to 100% RH (Kader, 2002; Gross *et al.*, 2004 and Kader & Rolle, 2004).

RH can be controlled by one or more of the following procedures: (1) adding moisture (water mist or spray, steam) to air by humidifiers; (2) regulating air movement and ventilation in relation to the produce load in the cold storage room; (3) maintaining temperature of the refrigeration coils within about 1°C of the air temperature; (4) providing moisture barriers that insulate walls of storage rooms and transit vehicles; (5) adding polyethylene liners in containers and using perforated polymeric films for packaging; (6) wetting floors in storage rooms; (7) adding crushed ice in shipping containers or in retail displays for commodities that are not injured by the practice and (8) sprinkling produce with sanitized-clean water during retail marketing of commodities that benefit from misting, such as leafy vegetables, cool-season root vegetables and immature fruit vegetables (such as snap beans, peas, sweet corn and summer squash).

2.3 Cooling methods:

Temperature management, which is the most effective tool for extending the shelf life of fresh horticultural commodities, begins with the rapid removal of field heat by using one of the cooling methods listed in Table (2).

Table 2. Comparison among cooling methods (Thompson *et al.*, 1998)

Variable	Cooling method				
	Ice	Hydro	Vacuum	Forced-air	Room
Cooling times (h)	0.1-0.3	0.1-1.0	0.3-2.0	1.0-10.0	20-100
Water contact with the product	yes	yes	no	no	no
Product moisture loss (%)	0-0.5	0-0.5	2.0-4.0	0.1-2.0	0.1-2.0
Capital cost	high	high	medium	low	low
Energy efficiency	low	low	high	low	low

Packing a product with crushed or flaked ice can quickly cool it and can provide a source of cooling and high RH during subsequent handling. However, its use is limited to a few products that tolerate direct contact with ice and are packaged in moisture-resistant containers. Clean-sanitized water is used as the cooling medium in hydrocooling (shower or immersion systems) of some commodities that tolerate water contact and are packaged in moisture-resistant containers. Vacuum cooling is used for a few leafy vegetables that release water vapor quickly allowing them to be cooled rapidly. Water loss of about 1% causes 6°C product cooling. In forced-air cooling, refrigerated air is used as the cooling medium and is forced through produce packed in boxes or pallet bins. Most horticultural perishables can be cooled by forced-air cooling (Thompson *et al.*, 1998).

2.4. Refrigerated transport and storage:

Cold storage facilities should be appropriately designed and adequately equipped. They should be of good construction and be properly insulated. Their insulation should include a complete vapor barrier on the warm side of the insulation; strong floors; adequate and well-positioned doors for loading and unloading; effective distribution of refrigerated air; sensitive and properly located controls; refrigerated coil surfaces designed to adequately minimize the difference between the coil and air temperatures and adequate capacity for expected needs. Commodities should be stacked in the cold room with air spaces between pallets and room walls so as to ensure proper air circulation. Storage rooms should not be loaded beyond their limit for proper cooling. In monitoring temperatures, commodity temperature rather than air temperature should be measured.

Temperature management is critical during long distance transport. Loads must be stacked to enable proper air circulation to facilitate removal of heat from the produce as well as incoming heat from the atmosphere and off the road. Also, produce must be stacked in ways that minimize mechanical damage, braced and secured. Transit vehicles must be cooled before loading the commodity. Delays between cooling after harvest and loading into transit vehicles should be avoided. Proper temperature maintenance should be ensured throughout the handling system (Kader & Rolle, 2004).

There are continued improvements in attaining and maintaining the optimum environmental conditions (temperature; relative humidity; concentrations of oxygen, carbon dioxide and ethylene) in transport vehicles. Treating fruits with ethylene to initiate their ripening during transportation is feasible and is used commercially to a limited extent on mature-green bananas and tomatoes. Products are commonly cooled before loading and are loaded with an air space between the palletized product and the walls of the transport vehicles to improve temperature maintenance. In some cases, vehicle- and product- temperature data are transmitted by satellite to a control center allowing all shipments to be continuously monitored. Air-ride suspensions, in new truck models can also eliminate damage caused by vibration during transportation. Controlled-atmosphere and precision temperature management allow non-chemical insect control for markets which possess quarantine restrictions against pests endemic to exporting countries and for markets that do not want their produce exposed to chemical fumigants.

Mixing several produce items in one load is common and often compromises have to be made in selecting optimal temperatures and atmospheric composition when transporting chilling-sensitive with non-chilling sensitive commodities or ethylene-producing with ethylene-sensitive commodities. In the latter case, ethylene scrubbers can be used to remove ethylene from the circulating air within the vehicle. Several types of insulating pallet covers are available for protecting chilling-sensitive commodities when transported with non-chilling-sensitive commodities at temperatures below the threshold chilling temperature.

2.5 Return on investment in maintaining the cold chain:

Mitchell *et al* (1996) showed that a one-hour delay in cooling strawberries after harvest resulted in a 10% loss due to decay during marketing. The resulting economic loss was greater than the increased cost of expedited handling of the strawberries by more frequent deliveries of harvested fruits to the cooling facility and initiation of forced-air cooling.

Jordan *et al* (1987) showed that the average net revenue for lettuce kept below 5°C was $9.75 per carton, compared to $9.06 per carton for lettuce held at 5°C or higher. This loss of $0.69 per carton due to quality deterioration caused by poor temperature management resulted in a loss of $172.50 per truckload of 900 cartons.

2.6 Return on investment in reducing water loss:

Thompson *et al* (1998) found that table grapes handled near ideal conditions of prompt cooling after harvest and maintenance of proper temperature (0-2°C) and RH (90-95%) throughout handling from shipping point to the retail market lost about 2% of their weight at harvest. In contrast, grapes that were subjected to delays between harvest and cooling and were handled at temperatures above the optimal range (higher than 5°C) and relative humilities below 90% lost about 7% of their weight at harvest. The stems of these grapes turned brown, which reduced their quality. The combination of the additional 5% weight loss and lower appearance quality resulted in a 15% loss in value of the grapes and returns to the shipper and marketer. This economic loss is greater than the cost of improved management of temperature and RH by using perforated plastic liners in the boxes and by minimizing delays before cooling with humidified and forced air.

3. Postharvest Treatments Designed to Minimize Produce Contamination and Maximize Quality

3.1 Treatments to reduce microbial contamination:

Over the past few years, food safety has become and continues to be the number one concern of the fresh produce industry. The U.S. Food and Drug Administration published in October 1998 a Guide to Minimize Microbial food Safety Hazards for Fresh Fruits and Vegetables . This guide is based on the following principles: (1) Prevention of microbial contamination of fresh produce is favored over reliance on corrective actions once contamination has occurred; (2) In order to minimize microbial food safety hazards in fresh produce, growers, packers or shippers should use GAP and GMP in those areas over which they have control; (3) Fresh produce can become microbiologically contaminated at any point along the farm-to-table food chain. The major source of microbial contamination with fresh produce is associated with human or animal feces; (4) Whenever water comes in contact with produce; its quality dictates the potential for contamination. The potential of microbial contamination from water used with fresh fruits and vegetables must be minimized; (5) The use of animal manure or municipal biosolid wastes as fertilizers should be closely managed in order to minimize the potential for microbial contamination of fresh produce and (6) Worker hygiene and sanitation practices during production, harvest, sorting, packing and transport play a critical role in minimizing the potential for microbial contamination of fresh produce.

Clean-disinfected water is required in order to minimize the potential transmission of pathogens from water to produce, from healthy to infected produce within a single lot, and from one lot to another over time. Waterborne microorganism, including postharvest plant pathogens and agents of human illness, can be rapidly acquired and taken up on plant surfaces. Natural plant surface contours, natural openings, harvest and trimming wounds and scuffing can be points of entry as well as provide safe harbor for microbes. In these protected sites, microbes are largely unaffected by common or permitted doses of postharvest water sanitizing treatments (Table 3).

Maintaining the Cold Chain for Perishables

Harvest
- ¥ Protect the product from the sun
- ¥ Transport quickly to the packinghouse

Cooling
- ¥ Minimize delays before cooling
- ¥ Cool the product thoroughly as soon as possible

Temporary Storage
- ¥ Store the product at optimum temperature
- ¥ Practice first in first out rotation
- ¥ Ship to market as soon as possible

Transport to Market
- ¥ Use refrigerated loading area
- ¥ Cool truck before loading
- ¥ Load pallets towards the center of the truck
- ¥ Put insulating plastic strips inside door of reefer if truck makes multiple stops
- ¥ Avoid delays during transport
- ¥ Monitor product temperature during transport

Handling at Destination
- ¥ Use a refrigerated unloading area
- ¥ Measure product temperature
- ¥ Move product quickly to the proper storage area
- ¥ Transport to retail markets or foodservice operations in refrigerated trucks

Handling at home or food service oulet
- ¥ Display at proper temperature range
- ¥ Store product at proper temperature
- ¥ Use the product as soon as possible

It is essential, therefore, that an adequate concentration of sanitizer is maintained in water in order to kill microbes before they attach or become internalized in produce. This is important in some preharvest water uses (such as spraying pesticides or growth regulators) and in all postharvest

Table 3. Water sanitizing chemicals used in produce handling (Kader & Rolle, 2004)

Sanitizing chemicals	Advantages	Disadvantages
Chlorine compounds, Calcium hypochlorite, Sodium hypochlorite, Chlorine gas or Chlorine dioxide	Low cost	Corrosive, irritating, trihalomethanes are by-product
Iodine compounds	Low cost, non irritating	Slightly, corrosive, staining
Ozone	Faster action on micro-organisms, fewer disinfection by-products than chlorine	Higher cost than chlorine
Peroxy-acetic acid or Hydrogen peroxide	More effective in removing and controlling microbial biofilms	Higher cost than chlorine

procedures involving water, including washing, cooling, water-mediated transport (flumes) and postharvest drenching with calcium chloride or other chemicals.

3.2 Treatments to minimize water loss:

Transpiration, or evaporation of water from the plant tissues, is one of the major causes of deterioration in fresh horticultural crops after harvest. Water loss through transpiration not only results in direct quantitative losses (loss of saleable weight), but also causes losses in appearance (wilting and shriveling), textural quality (softening, flaccidity, limpness and loss of crispness and juiciness), and nutritional quality. Transpiration (water loss) is a physical process that can be controlled by various postharvest treatments which are applied to the commodity (surface coatings and other moisture barriers) or which involve manipulation of the environment (maintenance of high relative humidity).

Treatments that can be applied to the commodity to minimize water loss include the following:

a. Curing of certain root vegetables, such as garlic, onion, potato and sweet potato.
b. Waxing and other surface coatings used on some used on some commodities, such as apple, citrus fruits, nectarine, peach, plum, pomegranate and tomato.
c. Packaging in polymeric films that act as moisture barriers.
d. Careful handling to avoid physical injuries, which increase water loss from produce.
e. Addition of water to those commodities that tolerate misting with water, such as leafy vegetables.

3.3 Treatments to reduce ethylene damage:

The promotion of senescence in harvested horticultural crops by ethylene (0.1ppm or higher) results in acceleration of deterioration and reduced postharvest life. Ethylene accelerates chlorophyll degradation and induces yellowing of green tissues, thus reducing quality of leafy-, floral-, and immature fruit-vegetables and foliage ornamentals. Ethylene induces abscission of leaves and flowers, softening of fruits and several physiological disorders. Ethylene may increase decay development of some fruits by accelerating their senescence and softening and by inhibiting the formation of antifungal compounds in the host tissue.

The incidence and severity of ethylene induced deterioration symptoms depend upon temperature, exposure time, and ethylene concentration. For example, yellowing of cucumbers can result from exposure to 1 ppm ethylene for 2 days or to 5 ppm ethylene for 1/2 day at 10°C. Also, the effects of ethylene are cumulative throughout the postharvest life of the commodity (Kader, 2002).

Treating ornamental crops with 1-methylcyclopropene (1-MCP), which is an ethylene action inhibitor, provides protection against ethylene damage and is used commercially. In July 2002, 1-MCP at concentrations up to 1 ppm was approved by the US Environmental Protection Agency for use on apples, apricots, avocados, kiwifruit, mangoes, nectarines, papayas, peaches, pears, persimmons, plums, and tomatoes. The first commercial application was on apples to retard their softening and extend their postharvest-life. As more research is completed, the use of 1-MCP will no doubt be extended to several other fruits and vegetables.

3.4 Treatments for decay control:

A major cause of losses in perishable crops is the action of a range of microorganisms on the commodity. Fungi and bacteria may infect the plant organ at any time. In fruits, latent infections, in which the fungus invades the fruit tissue shortly after flowering, become apparent only when the fruit starts to ripen. Postharvest rots frequently occur as a result of rough handling during the marketing process and are caused by a wide array of microorganisms. The grey mold *Botrytis cineria* is a very important cause of loss in many commodities (such as grapes, kiwifruit, pomegranates, raspberries and strawberries) and is an aggressive pathogen, even at low temperatures. Virus infection frequently lowers the quality of perishable commodities, usually as a result of visual deterioration, although viruses may also affect flavor and composition.

Curing is a postharvest treatment that facilitates certain anatomical and physiological changes that can prolong the storage life of some root crops. It is one of the most effective and simple means of reducing water loss and decay during subsequent storage of root, tuber and bulb crops.

Sanitation practices include treatment to reduce populations of microorganisms on equipment, on the commodity, and in the wash water used to clean it. Water washes alone are effective in removing nutrients that allow microorganisms to grow on the surfaces of produce as well as in removing inoculum of postharvest pathogens. Sanitizers that reduce inoculum levels of decay organism from fruit surfaces include treatments added to water dumps and spray or dip washes. These treatments inactivate spores brought into solution from fruit or soil and prevent the secondary spread of inoculum in water. Sanitizing washes may consist of halogenated compounds (e.g., hypochlorous acid from chlorine gas or sodium hypochlorite and chlorine dioxide) or ozonated water.

Treatments for decay control include: (1) heat treatments, such as dipping mangoes for 5 minutes in 50°C water to reduce subsequent development of anthracnose; (2) use of postharvest fungicides, such as imazalil and/or thiabendazole on citrus fruits; (3) use of biological control agents, such as Bio-Save (*Pseudomonas syringae*) and Aspire (*Candida oleophila*) alone or in combination with fungicides at lower concentrations on citrus fruits; (4) use of growth regulators such as gibberellic acid or 2, 4-D to delay senescence of citrus fruits; (5) use of 15-20% CO_2 in air or 5% O_2 on strawberries, cane berries, figs and pomegranates; and (6) use of SO_2 fumigation (100 ppm for one hour) on grapes.

3.5 Treatments for insect control:

A large number of insects can be carried by fresh fruits, vegetables and flowers during postharvest handling. Many of these insect species, especially the fruit flies of the family Tephritidae (e.g. Mediterranean fruit fly, Oriental fruit fly, Mexican fruit fly and Caribbean fruit fly) can seriously disrupt trade among countries. Continuing globalization of marketing fresh produce will be facilitated by use of acceptable disinfestation treatments, including ionizing radiation. Selection of the best treatment for each commodity will depend upon the comparative cost and the efficacy of that treatment against the insects of concern with the least potential for damaging the host (produce).

Currently approved quarantine treatments include certification of insect-free areas, use of chemicals (e.g. methyl bromide, phosphine and hydrogen cyanide), irradiation, cold treatments, heat treatments and some combinations of these treatments. The potential for additional treatments, such as new fumigants (carboryl sulfide, methyl iodide, and sulfuryl fluoride), insecticidal atmospheres (below 0.5% oxygen and/or 40-60% carbon dioxide) alone or in combination with heat treatments and ultraviolet radiation, is being investigated. Each of these treatments is usable on a limited number of commodities because of phototoxic effects on others.

4. Postharvest Treatments Designed to Manipulate the Environment around Produce in order to Enhance Quality

4.1. Modified atmosphere storage:

When used as supplements to keeping fresh horticultural perishables within their optimum ranges of temperature and relative humidity, controlled atmospheres (CA) or modified atmospheres (MA) can serve to extend their postharvest-life (Table 4). Optimum concentrations of oxygen and carbon dioxide lower respiration and ethylene production rates, reduce ethylene action, delay ripening and senescence, retard growth of decay-causing pathogens, and control insects. On the other hand, CA conditions unfavorable to a given commodity can induce physiological disorders and enhance susceptibility to decay.

CA transport is used to continue the CA chain for some commodities (such as apples, pears and kiwi fruits) that had been stored in CA since harvest. CA transport of bananas permits their harvest at a more fully-mature stage (higher yield). CA transport of avocados facilitates use of a lower temperature (5°C) than if shipped in air because CA ameliorates chilling injury symptoms. CA combined with precision temperature management allow non-chemical insect control in some commodities for markets that have restrictions against pests endemic to exporting countries and for markets that prefer organic produce.

Table 4. Classification of horticultural crops according to their controlled atmosphere storage potential at optimum temperatures and relative humidities (Kader, 2002)

Range of storage duration (months)	Commodities
More than 12	Almond, Brazil nut, cashew, filbert, macadamia, pecan, pistachio, walnut, dried fruits and vegetables
6-12	Some cultivars of apples and European pears
3-6	Cabbage, Chinese cabbage, kiwifruit, persimmon, pomegranate, some cultivars of Asian pears
1-3	Avocado, banana, cherry, grape (no SO_2), mango, olive, onion (sweet cultivars), some cultivars of nectarine, peach and plum, tomato (mature-green)
<1	Asparagus, broccoli, cane berries, fig, lettuce, muskmelons, papaya, pineapple, strawberry, sweet corn, fresh-cut fruits and vegetables, some cut flowers

The use of polymeric films for packaging produce and their application in modified atmosphere packaging (MAP) systems at the pallet, shipping container (plastic liner), and consumer package levels continues to increase MAP (usually to maintain 2 to 5% O_2 and 8 to 12% CO_2) is widely used in extending the shelf-life of fresh-cut vegetable and fruit products. Use of absorbers of ethylene, carbon dioxide, oxygen and/or water vapor as part of MAP is increasing. Although much research has been done on use of surface coatings to modify the internal atmosphere within the commodity, commercial applications are still very limited due to the inherent biological variability of the commodity.

At the commercial level, CA is most widely applied during the storage and transport of apples and pears. It is also applied to a lesser extent on kiwifruits, avocados, persimmons, pomegranates, nuts and dried fruits. Atmospheric modification during long-distance transport is used on apples, avocados, bananas, blueberries, cherries, figs, kiwifruits, mangoes, nectarines, peaches, pears, plums, raspberries and strawberries. Continued technological developments in the future to provide CA during transport and storage at reasonable cost (positive benefit/cost ratio) are essential to expanding its application on fresh fruits and vegetables.

4.2. Return on investment in using modified and controlled atmospheres:

Although MA/CA have been shown to be effective in extending postharvest life of many commodities (Table 4), commercial applications have been limited due to their relatively high cost. However, there are a few cases where a positive ROI (cost/benefit ratio) can be demonstrated. In a comparison of losses due to decay during retail marketing of strawberries shipped in air and those shipped in 15% CO_2-enriched air (modified atmosphere within pallet cover), MacLeod (1999) observed that use of the modified atmosphere reduced losses by 50% (average of 20% losses in air vs 10% losses in MA). The economic loss of 10% value ($50-75 per pallet) was much greater than the cost of using MA ($15-25 per pallet).

Use of modified atmosphere (MA) during marine transportation can extend the postharvest-life of many fruits and vegetables with short postharvest-life potential and allow use of marine transportation instead of air transport. Savings realized with the use of marine transportation are much greater than is the added cost of MA service (Dohring, 1999).

4.3. Ethylene exclusion and removal:

Many green vegetables and most floral products are quite sensitive to ethylene damage. Ethylene must be kept away from these products. Ethylene contamination from ripening rooms can be minimized by 1) using ethylene levels of 100 ppm instead of the higher levels often used in commercial ripening operations, 2) venting ripening rooms to the outside after the exposure period is complete, 3) at least once per day ventilating the area around the ripening rooms or installing an ethylene scrubber, 4) use of battery-powered forklifts instead of engine driven units.

Ethylene-producing commodities should not be mixed with ethylene-sensitive commodities during storage and transport. Potassium permanganate, an effective oxidizer of ethylene, is used commercially as a scrubber. Scrubbing units based on the catalytic oxidation of ethylene are used to a limited extent in some commercial storage facilities.

Thompson *et al* (1989) estimated the capital costs of heated catalyst, catalytic converter, potassium permanganate scrubber and ventilation to be $11,800, 5,000, 1600, and 1000 respectively; annual operating costs were estimated to be $3'226, 979, 974, and 295, respectively. Thus, ventilation to keep ethylene concentration low in the storage room is the least expensive method followed by potassium permanganate-based ethylene scrubber.

4.4. Return on investment in reducing ethylene damage:

Ayoub *et al* (1987) evaluated the use of ethylene absorbers in extending shelf-life and Concluded that ethylene-absorbing blankets containing alumina coated with potassium permanganate should be used in all fruit and vegetable storage areas in order to ensure maximum shelf-life at an affordable cost. In a comparison of two mixed loads of fruits and vegetables in two marine containers with or without scrubbers shipped from California to South Korea, the total produce lost in the container without ethylene scrubbing was 2'645 lbs (out of 16'070 lbs) valued at $928, which is much higher than the $160 cost of the ethylene scrubbers (Ayoub *et al.*, 1987).

Jordan *et al* (1987) determined the economic effect of transportation management techniques to separate ethylene-generating commodities from ethylene-sensitive commodities to increase shelf-life. They estimated a shelf-life (time to loss of 50% of arrival quality) of 6.4, 5.6 and 5.1 days for lettuce exposed to low (<1ppm), medium (3-7ppm), and high (10-15ppm) ethylene concentrations, respectively. The net revenues of lettuce exposed to the low, medium, and high ethylene levels were $12'886, 10'164 and 8'165, respectively.

Thompson *et al* (1989) showed that adding an ethylene scrubber in storage facilities used for lettuce significantly reduced russet spotting, which is caused by exposure to ethylene (Morris *et al.*, 1978). The difference in value of lettuce that was protected from ethylene vs that which was exposed to ethylene was estimated to be 20 to 25%, which was greater than the cost of the ethylene scrubber. Similar results were found with kiwifruits, which soften very rapidly when exposed to as low as 50 ppb ethylene. Wills *et al* (2000) concluded that ethylene levels of 0.1ppm or higher result in 10-30% loss of potential Postharvest life of fruits and vegetables during marketing.

4.5. Treatments to enhance more uniform ripening of fruits:

Ethylene treatment is used commercially to enhance ripening rate and uniformity of some fruits, such as bananas, avocados, mangoes, pears, tomatoes, and kiwifruits. Optimal ripening conditions are as follows:

- Temperature: 18 to 25°C
- Relative humidity: 90 to 95 percent
- Ethylene concentration: 10 to 100 ppm
- Duration of treatment: 24 to 74 hours depending on fruit kind and maturity stage
- Air circulation: Sufficient to ensure distribution of ethylene within the ripening room
- Ventilation: Require adequate air exchanges to prevent accumulation of O_2 which reduces the effectiveness of C_2H_4

The potential for greater sales as a result of increased consumer satisfaction is likely to have higher value than the cost of fruit ripening. However, specific studies are needed to determine the ROI of fruit ripening procedures.

Concluding Remarks

The basic recommendations for maintaining postharvest quality and safety of produce are the same regardless of the distribution system (direct marketing, local marketing, export marketing). However, the type of appropriate technology needed to provide the recommended conditions depends upon the distance and time between production and consumption sites and intended use, such as fresh vs processing (Kader & Rolle, 2004):

The technology used elsewhere is not necessarily the best for use under conditions of a given developing country. Many of the recent modifications in postharvest technology in developed countries have been in response to the need to economize in labor, materials and energy use and to protect the environment. It is useful to study the currently used practices in other countries, but to select only those which are appropriate for local conditions based on their ROI. Expensive equipment and facilities without proper management are useless. People who operate such facilities are more important than their level of sophistication. Effective training and supervision of personnel must be an integral part of quality and safety assurance programs. Assuring food safety throughout the postharvest handling system is very critical to successful marketing of produce and should be given the highest priority. Much more research is needed to evaluate the ROI of all relevant postharvest technologies.

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عائد الاستثمار في مجال تقنية ما بعد الحصاد لضمان جودة وأمان الحاصلات البستانية

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الخلاصة

إنّ تقليل الفاقد في الحاصلات البستانية بعد حصادها يزيد من مقدرة العالم النامي على توفير الغذاء ويقلل من المساحات الزراعية اللازمة لإنتاج هذه المحاصيل مع الاقتصاد الكبير في استنزاف الموارد الطبيعية. وتشتمل استراتيجيات تقليل الفاقد بعد الحصاد لهذه المحاصيل على عدة نظم وتقانات منها استخدام الطرز الجينية المتسمة بطول فترة ما بعد الحصاد واستخدام نظم إدارة إنتاجية متكاملة بالإضافة إلى تطبيق العمليات الزراعية الجيدة (GAP) بهدف الحفاظ على عاملي الجودة والأمان للحاصلات البستانية بعد حصادها.

هناك العديد من التقانات التي يمكن تطبيقها بغرض تقليل الفاقد بعد الحصاد وكذلك إطالة العمر التسويقي لمحاصيل الفاكهة والخضر بعد حصادها، ولكن بعض هذه التقانات لا تتسم بعائد استثماري عند تطبيقها نظراً لارتفاع تكاليفها الاستثمارية من جهة، ولزيادة المنافسة التسويقية نتيجة العولمة من جهة أخرى.

يضمن استخدام تقانات ما بعد الحصاد تحقيق عائد استثماري كبير وذلك عند الاستخدام الأمثل للتقانات الملائمة والمناسبة التي تتسم بتأثيرها الإيجابي على المنتجات بعد الحصاد، ولكن لابد من استخدام التقانات في خطواتٍ متسلسلة تضمن التداول الأمثل للمحاصيل بعد حصادها حيث لايمكن لخطوةٍ واحدة أو تقانة منفردة أن تحل محل التسلسل المطلوب من الخطوات والتقانات الواجب تطبيقها في هذا المجال لضمان تقليل الفاقد والحفاظ على الجودة وزيادة عامل الأمان بما ينعكس إيجاباً على الاستثمار.

وتتناول المقالة بعض الأمثلة لبيان العائد الاستثماري الإيجابي من تطبيق بعض تقانات التداول بعد الحصاد، وكأساس لبيان مثل هذا العائد الاستثماري الإيجابي تمت الاستعانة بحالات تداول محددة لمحاصيلٍ محددة كامثلة استثمارية واضحة عن طريقها يمكن اختيار أفضل طرق التداول في كل حالة.

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