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ASSESSMENT OF POST-HARVEST PRACTICES FOR FRUITS AND VEGETABLES IN JORDAN

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1. Summary and Recommendations

At the request of The KAFA'A (Knowledge and Action Fostering Advances in Agriculture) Project (USAID Contract No. 273-C00-03-00222-00), I visited Jordan during the period between May 7 and 17, 2006 and had the opportunity to see examples of current postharvest practices and to talk with many individuals from both the public and private sectors. I greatly appreciate the support that I received from the KAFA'A Project team members, especially Lama Kilany, who was my counterpart and organizer of an excellent itinerary for my visit.

I saw both modern, well managed postharvest handling facilities (very good sanitation, temperature management, careful sorting by quality, and other quality and safety assurance procedures) and very poor handling examples (lack of sanitation, temperature management, uniformity of quality within containers, overfilling of containers). Although most of the individuals with whom I discussed the current situation realize the need for improving postharvest handling of horticultural perishables in Jordan, it is clear to me that there is no pressure from the buyers in the markets of the Arab Gulf countries and the local market to improve the current situation. On the other hand, the exporters to Western European countries have had to meet much higher standards of quality and safety that are demanded by the buyers in those countries. In addition to market forces, improvements in the current postharvest handling procedures can be encouraged and enforced by governmental regulations that specify at least minimum standards of quality and safety. This is a very appropriate and necessary role of government that should be implemented as soon as possible.

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. The Jordanian Government should enforce minimum standards for produce quality, maturity, container marking, and uniformity within packages . This provides orderly marketing and equity in the marketplace and protects consumers from inedible and poor quality produce.

Safety factors in fruits and vegetables include natural contaminants, such as fungal toxins (mycotoxins) and bacterial toxins, and heavy metals (cadmium, lead, mercury); environmental pollutants; residues of pesticides; and microbial contamination (the most important factor). 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" during production, "Good Hygienic Practices" during postharvest handling, and "Good Manufacturing Practices" during processing are strongly recommended to minimize microbial contamination. Careful handling and washing of all produce to be consumed raw and the strict observance of proper sanitary measures are strongly recommended to reduce microbial contamination at the foodservice, retail, and consumer levels. All these food safety assurance procedures should be enforced by the Jordanian Government.

The Jordanian Government should encourage improvements in postharvest handling facilities to assure quality and safety of produce by providing incentives to those who want to implement such facilities (such as proper preparation for market, cooling, cold storage, refrigerated transport, etc). Such incentives program can be targeted to: (1) existing modern facilities that are capable of exporting products to the EU markets and would like to expand and help market the products of small-scale producers who are willing to follow the quality and safety requirements; (2) Associations or companies to be formed by a large number of small-scale producers to jointly build a modern packinghouse with cooling and cold storage facilities that can be utilized for at least 8 months per year; and (3) improvement of postharvest handling facilities that serve the produce export sector, such as the cold storage facility at the Amman airport and modernization of the refrigerated transport trucks to improve their ability to maintain product temperature and to reach destination markets in the shortest time possible.

In Jordan, Styrofoam boxes are the predominant in local markets and in exports to the Gulf countries. The tendency to overpack these containers must be stopped because it results in damage to the produce and increases the potential for contamination. This can be achieved if prohibition of overpacking in any container is included in the grade standards and strictly enforced by the governmental inspectors. One-way plastic containers are used for export to Eastern European countries and fiberboard containers are used for export to EU countries. There is a growing trend towards the use of returnable plastic containers that can be rented from suppliers, used for shipping the products to the receiver, who would return the empty containers to the nearest company's center for cleaning and renting to the next user. These containers can be folded so that 7 folded containers can occupy the space taken by one full container to reduce the cost of transporting the empty containers. I highly recommend that JEPA take the lead in making returnable plastic containers available in Jordan in the near future.

I strongly recommend that NCARTT provide the leadership in forming the Jordanian Postharvest Working Group to include members of the recently formed Postharvest Taskforce at NCARTT, the Postharvest Technology Team of the World Bank-funded

Export Promotion Project, and postharvest specialists from the Ministry of Agriculture's Marketing Section and the University of Jordan. It is essential that these groups work together to achieve the goals of disseminating science-based information about postharvest technology to all those who can use it. The activities of this working group should include the following: (1) Gathering the relevant information and adapting it to the Jordanian conditions before disseminating it via a website, publications, posters, and other effective means of communication; (2) Conducting studies of the cost/benefit ratio (return on investment) of various postharvest technologies, such as proper maturity, shading the harvested product, quality sorting, packaging to reduce water loss, type of shipping container, cooling,and refrigerated transport; and (3) Training quality and safety assurance personnel , marketers of fresh produce, and workers who handle fresh produce on proper procedures for maintaining quality and safety of fresh produce.

The Jordan Exporters and Producers Association for Fruit and Vegetables (JEPA) should be encouraged to continue to expand its membership and to achieve sustainability in terms of funding to support its services. The following are possible additional services that can help with funding sustainability: (1) establishing a "service-for a fee" Information Center that will build and maintain a postharvest technology database and identify a group of resource persons who can help answer questions from members in a timely manner; (2) establishing a for-profit company that would sell postharvest equipment, tools, and supplies to provide a one-stop shopping for members (at a discount) and non-members. An example of a company that sells a broad range of postharvest tools and supplies is www.QAsupplies.com. The JEPA-associated company can also sell packaging materials and can represent within Jordan an international supplier of returnable plastic containers, such as IFCO Systems (www.ifcosystems.com) and www.ipl-mh.com ; and (3) continuing to develop a well-trained group of quality and safety assurance inspectors, who can provide"service-for a fee" assistance to members who want to meet the required quality and safety expectations of the countries to which they wish to export. Continued collaboration with similar organizations, such as the Horticultural Exports Improvement Association (HEIA) in Egypt is highly recommended.

The KAFA'A Project can continue to contribute to improvement of postharvest technology in Jordan by: (1) providing local training on quality and safety assurance procedures for agricultural extension workers and private sector personnel concerned with quality and safety assurance of fresh produce; (2) continuing development of the portable forced-air cooling unit in the context of the overall improvement in temperature management ; (3) completing the postharvest handling guides prepared by Lama Kilany and publishing them electronically via the websites of JEPA and NCARTT as well as printing enough copies of each commodity guide to distribute to every producer and marketer of this commodity in Jordan; and (4) providing funding to encourage research by NCARTT and other collaborators in the proposed Jordanian Postharvest Working Group on the cost-benefit ratio of postharvest technologies.

The information included in sections 2, 3 & 4 of this report should be translated into Arabic and disseminated widely to all those involved in handling horticultural crops in Jordan.

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

2.1 Packing and packaging of fruits and vegetables

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. 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 air flow rate around the commodity, which is an important factor in management of temperature and relative humidity.

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2.2 Temperature and relative humidity management

Temperature is the most important environmental factor that influences the deterioration of harvested commodities. Most 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.

Table 1. Effect of temperature on deterioration rate of a non-chilling sensitive commodity

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	2.0	15.0	7	14
40	1.5	22.5	4	25

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

Temperatures outside the optimal range can cause rapid deterioration due to the following disorders:

a. Freezing. In general, perishable commodities are high in water content, and possess large, highly vacuolate cells. The freezing point of their tissues is relatively high (ranging from –3°C to –0.5°C), and the disruption caused by freezing usually results in immediate collapse of the tissues and total loss of cellular integrity. Freezing is normally the result of inadequate refrigerator design, or failure of thermostats. In winter conditions, freezing can occur if produce is allowed to remain for even short periods of time on unprotected transportation docks.

b. Chilling injury. Some commodities (chiefly those native to the tropics and subtropics) respond unfavorably to storage at low temperatures well above their freezing points, but below a critical temperature termed the chilling threshold temperature or lowest safe temperature (Table 2). Chilling injury is manifested in a variety of symptoms including surface and internal discoloration, pitting, water soaking, failure to ripen, uneven ripening, development of off flavors and heightened susceptibility to pathogen attack.

Table 2. Classification of some chilling-sensitive fruits and vegetables according to their lowest safe temperature for transport and storage

Lowest safe temperature (°C)	Commodities
3	Asparagus
4	Cantaloupe, certain apple cultivars (such as McIntosh and Yellow Newton), potato
5	Guava, kumquat, mandarin, orange (Navel and Valencia)
7	Avocado, okra, olive, pepper, pomegranate, snap bean
10	Cucumber, eggplant, grapefruit, lime, mango (ripe), melons (casaba, crenshaw, honeydew, persian), squash (soft rind), tomato (ripe), watermelon
13	Banana, lemon, mango (mature-green), pumpkin and hard-rind squash, sweet potato, tomato (mature-green)

c. Heat injury. High temperatures are also very injurious to perishable products. In growing plants, transpiration is vital to maintaining optimal growth temperatures. Organs removed from the plant, however, lack the protective effects of transpiration, and direct sources of heat, for example full sunlight, can rapidly heat tissues to above the thermal death point of their cells, leading to localized bleaching or necrosis (sunburn or sunscald) or general collapse.

Relative humidity (RH) is the moisture content (as water vapor) of the atmosphere, expressed as a percentage of the amount of moisture that can be retained by the atmosphere (moisture holding capacity) at a given temperature and pressure without condensation. The moisture holding capacity of air increases with temperature. Water loss is directly proportional to the vapor pressure difference (VPD) between the commodity and its environment. VPD is inversely related to RH of the air surrounding the commodity.

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.

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 is the most effective tool for extending the shelf life of fresh horticultural commodities. It begins with the rapid removal of field heat by using one of the cooling methods listed in Table 3

Table 3. Comparison among cooling methods

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	low	medium	low	low
Energy efficiency	low	high	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.

The trend is towards increased precision in temperature and RH management to provide the optimum environment for fresh fruits and vegetables during cooling and storage. Operators can ensure that all produce shipments leave the cooling facility within about 0.5°C of their optimum storage temperatures. Precision temperature management (PTM) tools, including time-temperature monitors, are becoming more common in cooling and storage facilities. Several manufacturers have developed self-contained temperature monitors and recorders, which are small and can be packed in a box with the product. Data are read by connecting these units to a personal computer. Electronic thermometers (with very thin, strong probes for fast response) are used for measuring product temperature. Infrared thermometers can be used to measure surface temperature of products in various locations within storage facilities.

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 and 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 (see chart on maintaining the cold chain for perishables).

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.

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
- Display at proper temperature range

Handling at home or foodservice outlet

- Store product at proper temperature
- Use the product as soon as possible

2.5 Return on investment in maintaining the cold chain

In a University of California study, it was shown 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.

In a University of Georgia study, it was shown 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

In a University of California study, 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, 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 good agricultural and management practices 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."

These principles are very similar to those included in other food safety guidelines, such as EUREPGAP, established by various EU organizations.

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

Table 4. Water sanitizing chemicals used in produce handling

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

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, shriveling), textural quality (softening, flaccidity, limpness, 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 (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. In some cases, ethylene may stimulate growth of fungi, such as *Botrytis cineria* on strawberries and *Penicillium italicum* on oranges.

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.

Treating ornamental crops with 1-methylcylopropene (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 is its use on apples to retard their softening and extend their postharvest-life. As more research is completed, the use of 1-MCP (marketed as "Smartfresh" by Agrofresh ; www.agrofresh.com) 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 (Table 5) 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, such as those listed in Table 5.

Table 5. Conditions for curing root, tuber, and bulb crops

Crops	Temperature (°C)	Relative humidity %	Duration (days)
Onion and garlic bulbs	30-45	60-75	1-4
Potato tubers	15-20	85-90	5-10
Sweet Potato roots	30-32	85-90	4-7

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. Sanitiers 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, 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, other than irradiation, include certification of insect-free areas, use of chemicals (e.g. methyl bromide, phosphine, hydrogen cyanide), cold treatments, heat treatments, and some combinations of these treatments, such as methyl bromide fumigation + cold treatment. The potential for additional treatments, such as new fumigants (carboryl sulfide, methyl iodide, 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 phytotoxic effects on others.

Most insects are sterilized when subjected to irradiation doses ranging between 50 and 750 Gy. The actual dosage required varies in accordance with the species and its stage of development. An irradiation dose of 250 Gy has been approved for certain fresh commodities, such as lychees, mangoes, and papayas by U.S. quarantine authorities in light of its efficacy in preventing the reproduction of tropical fruit flies. Most fresh fruits and vegetables will tolerate irradiation dose of 250 Gy with minimal detrimental effects on quality. At doses above 250 Gy and up to 1000 Gy (the maximum allowed as of 2002), damage can be sustained by some commodities. Fruits, in general, are more tolerant to the expected dose range (250 to 500 Gy absorbed by fruits on the inside *vs*. those on the outside of the pallet) than non-fruit vegetables and cut flowers. Detrimental effects on fresh produce may include loss of green color (yellowing), abscission of leaves and petals, tissue discoloration, and uneven ripening. The potential for detrimental effects, which may not become visible until the commodity reaches the market, must be evaluated for each commodity on a commercial scale before large-scale commercialization of the irradiation treatment.

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 6). 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.

Table 6. Classification of horticultural crops according to their controlled atmosphere storage potential at optimum temperatures and relative humidities.

Range of storage duration (months)	Commodities
More than 12	Almond, filbert, pistachio, walnut, dried fruits and vegetables
6-12	Some cultivars of apples and European pears
3-6	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 or breaker)
<1	Asparagus, broccoli, fig, lettuce, muskmelons, strawberry, sweet corn; fresh-cut fruits and vegetables

Several refinements in CA storage technology have been made in recent years. These include the creation of nitrogen on demand by separation from compressed air using molecular sieve beds or membrane systems, use of low (0.7 to 1.5%) oxygen concentrations that can be accurately monitored and controlled, rapid establishment of CA, ethylene-free CA, programmed (or sequential) CA (such as storage in 1% O_2 for 2 to 6 weeks followed by storage in 2-3% O_2 for remainder of the storage period), and dynamic CA where levels of O_2 and CO_2 are modified as needed based on monitoring some attributes of produce quality, such as ethanol concentration and chlorophyll fluorescence.

The use of CA in refrigerated marine containers continues to benefit from technological and scientific developments. CA transport is used to continue the CA chain for some commodities (such as apples, pears, and kiwifruits) 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 nonchemical insect control in some commodities for markets that have restrictions against pests endemic to exporting countries and for markets that prefer organic produce.

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, and 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 6), commercial applications have been limited due to their relatively high cost. However, there are a few cases where a positive return on investment (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), it was 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 controlled atmosphere (CA) 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 CA service.

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.

4.4.Return on investment in reducing ethylene damage

In a University of California study, it was shown that adding an ethylene scrubber in storage facilities used for lettuce significantly reduced russet spotting, which is caused by exposure to ethylene. 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.

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, 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

5. Importance of Proper Logistics and Management in the Postharvest Sector

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 (fresh vs processing). The following facts should be considered when selecting the proper postharvest technology procedures:

A. 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.

B. 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.

C. Commodity requirements can be provided using simple and inexpensive methods in many cases. For example, proper temperature management procedures include: (1) Protection from exposure to the sun; (2) Harvesting during cooler parts of the day or even at night; (3) Adequate ventilation in containers and non-refrigerated transport vehicles; (4) Use of simple and inexpensive cooling procedures, such as evaporative cooling and use of cool-night ambient air; and (5) Expedited handling.

D. Mechanical injuries are major causes of losses in quality and quantity of fresh horticultural commodities in all handling systems. Their incidence and severity can be greatly minimized by reducing the number of steps involved in harvesting and handling and by informing all personnel involved about the need for careful handling.

E. Assuring food safety throughout the postharvest handling system is very critical to successful marketing of produce and should be given the highest priority.

F. Solving the postharvest technology problems in a given country will require cooperation and effective communication among all the research and extension personnel involved. Postharvest horticulturists need to coordinate their efforts and to cooperate with production horticulturist, agricultural marketing economists, engineers, food technologist, microbiologists, and others who may be involved in various aspects of the marketing systems. In most cases, solutions to existing problems in the postharvest handling system require use of available information rather than any new research. Following is a proposed program for research and extension activities aimed at improving the postharvest handling system :

(1) Surveying the magnitude and causes of losses in quality and quantity during harvesting and postharvest handling of major commodities.

(2) Surveying available tools and facilities for harvesting, packing, transport, storage, and marketing of each commodity in its important production seasons and areas.

(3) Evaluating the impact and return on investment of simple modifications in the handling system (such as picking stage and method, type of containers, and quality sorting) on quality and safety maintenance.

(4) Extending information about recommended harvesting and handling procedures to all those who can use it. All appropriate extension methods for the intended audiences should be used.

(5) Identifying problems which need further research, conducting the needed research and extending any new information when completed to those who can use it.

6. Future Oulook

Reduction of postharvest losses can increase food availability to the growing population in Jordan, 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 Good Agricultural Practices 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. Since minimizing postharvest losses of already produced food is more sustainable than increasing production to compensate for these losses, higher priority should be given to funding research and extension activities related to maintenance of produce quality and safety during postharvest handling.

Remarkable progress in postharvest biology and technology of horticultural crops has been achieved during the past 25 years through collaborative and interdisciplinary research and development efforts of the public and private sectors, especially in developed countries. Achieving similar progress in Jordan requires application of current knowledge to improve the handling systems of horticultural perishables and overcoming the socioeconomic constraints that have prevented such progress.

Devoting more attention to flavor and nutritional quality of fruits and vegetables is strongly recommended. This should include identification of the reasons for postharvest-life based on flavor being shorter than postharvest-life based on appearance , selection of cultivars with flavor-life that is close to appearance-life, and modification of current postharvest handling recommendations on the basis of maximizing flavor-life potential. New cultivars of fruits and vegetable with better flavor and nutritional quality will be developed using biotechnology and/or plant breeding methods. This will contribute to increased consumption and consequently healthier diets for consumers. Educational efforts to encourage increased consumption of fresh fruits and vegetables must be expanded to achieve their goals.

Innovative technologies for maintaining optimal temperature and relative humidity, delaying losses of flavor and nutritional quality by supplemental treatments, and assuring safety will continue to be developed through collaboration between public and private organizations.

Worldwide availability of both conventially- and organically- grown horticultural crops will continue to increase in terms of the number of species and cultivars as well as their expanded season of availability with production in northern and southern hemisphere countries. Continued consolidation and vertical integration among producers and marketers will characterize the global marketing systems for fresh produce. This will facilitate collaboration among producers and marketers from various production areas to limit the marketing period on the basis of availability of superior flavor quality products from each production area. Jordanian exporters must form alliances with exporters from other countries if they are to be able to meet the demand of the decreasing number and increasing size of the buying organizations.

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8. Internet Resources

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http://www.ba.ars.usda.gov/hb66/index.html : Adraft version of the forthcoming revision of USDA Handbook 66 (Commercial Storage of Fruits, Vegetables and Ornamentals)

http://www.fao.org/inpho/ : Postharvest information site of the Food and Agricultural Organization of the United Nations.

http://www.uckac.edu/postharv/ : University of California Kearney Agricultural Center.

http://www.postharvest.ifas.ufl.edu : University of Florida Postharvest Group.

http://www.fdocitrus.com : Florida Department of Citrus postharvest information.

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http://www.postharvest.com.au/ : Sydney Postharvest Laboratory postharvest information.

http://www.chainoflifenetwork.org: Postharvest handling of floral crops.

www.foodsafety.gov : Gateway to U.S. government information on food safety.

www.jifsan.umd.edu/gaps.html: U.S. Food and Drug Administration's Manual on "Improving the Safety and Quality of Fresh Fruits and Vegetables".

http://www.eurep.org/Languages/English/index_html: Global Partenership for Safe and Sustainable Agriculture, EUREP GAP.

http://ucgaps.ucdavis.edu: University of California at Davis site for produce safety.

www.mrldatabase.com : Database for maximum pesticides residue levels permitted on various crops in various countries.

http://www.ams.usda.gov/nop/: National Organic Program Standards in the USA.

www.nutrition.gov : Gateway to U.S. government information on human nutrition and nutritive value of foods.

http://www.ams.usda.gov : U.S. Department of Agriculture, Agricultural Marketing Service information on quality standards, transportation, and marketing.

http://www.aphis.usda.gov : U.S. Department of Agriculture, Animal and Plant Health Inspection Service information on phytosanitary and quarantine requirements.

http://www.postharvest.biz: Directory of European suppliers of postharvest equipment and supplies.

Produce Quality Assurance

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Quality control (QC) is the process of maintaining an acceptable quality level to the consumer. Quality assurance (QA) is the system whose purpose is to assure that the overall QC job is being done effectively . QA and QC are often used interchangeably to cover the planning, development, and implementation of inspection and testing techniques; they take time and a lot of training. A successful QA/QC system cannot be flexible, but it must be subject to constant review and improvement as conditions change. QA personnel should report directly to the manager of the company and should have the authority to take corrective action when needed to assure product quality.

An effective quality assurance system throughout the handling steps between harvest and retail display is required to provide a consistently good-quality supply of intact and fresh-cut fruits and vegetables to the consumers and to protect the reputation of a given marketing label. Quality assurance starts in the field with the selection of the proper time to harvest for maximum quality. Careful harvesting is essential to minimize physical injuries and maintain quality. Each subsequent step after harvest has the potential to either maintain or reduce quality; few postharvest procedures, such as ripening certain fruits, can improve the quality of individual units of the commodity.

Exposure of a commodity to temperatures, relative humidities, and/or concentration of oxygen, carbon dioxide, and ethylene outside its optimum ranges will accelerate loss of all quality attributes. The loss of flavor and nutritional quality of fresh intact or cut fruits and vegetables occurs at a faster rate than the loss of textural and appearance quality. Thus, quality assurance programs should be based on all quality attributes and not only on appearance factors as often is the case.

Following is a list of handling steps and associated quality assurance functions:

1. Training workers on proper maturity and quality selection, careful handling, and protecting produce from sun exposure during harvesting operations.

2. Checking product maturity, quality, and temperature upon arrival at the packinghouse or processing plant.

3. Implementing an effective sanitation program to reduce microbial load and the potential for microbial contamination (with either plant pathogens or human pathogens) throughout the postharvest handling system.

4. Checking packaging materials and shipping containers to ensure they meet specifications and assuring their storage is in a clean and air-conditioned (or at least shaded) location.

5. Training workers on proper harvesting, gentle handling, careful sorting (for defects, color, size) according to the relevant grade standards, and packaging

(avoiding overpacking, uniformity of product quality within a shipping container) operations.

6. Inspecting a random sample of the packed product to ensure that it meets grade specification (such as “Class I” and “Class II” in the EU Standards) and taking corrective action immediately if this is not true.

7. Monitoring product temperature to assure completion of the cooling process before shipment and taking corrective action if this is not true.

8. Inspecting all transport vehicles before loading for their functionality and cleanliness.

9. Training workers on proper loading into refrigerated trucks and placement of temperature-recording devices in each load.

10. Keeping records of all shipments as part of the “trace-back” system.

11. Holding samples from each shipment under simulated conditions of transport and marketing and checking their quality as a basis for comparison with reports from the receiver about product quality upon arrival at destination.

12. Implementing any other steps required by the buyers.

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Produce Compatibility during Transport and Cold Storage

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Storage under conditions outside the optimal window for each commodity is a common reason for postharvest losses in produce quality and quantity. The following factors determine compatibility in mixing various fruits and vegetables together during transport and storage:

1. Temperature

Fruits and vegetables are generally divided into two groups: (a) non-chilling-sensitive commodities (such as apple, broccoli, grape, lettuce, and strawberry) that are best kept at temperatures above their freezing points (-2 to -0.5°C) and up to 2°C ; and (b) chilling-sensitive commodities (such as banana, mango, melons, orange, and tomato) that are best kept at 5°C to 15°C , depending on the commodity, cultivar, maturity-ripeness stage, and storage duration. Exposure of group (b) commodities to temperatures below their minimum chilling threshold should be avoided throughout the handling system because chilling injury is cumulative.

2. Relative Humidity (RH)

With the exception of a few commodities (dry garlic and onion bulbs, pumpkins and winter squash, dried fruits and vegetables, and nuts), fresh produce should be kept at 90-95% RH to minimize water loss. If the dried fruits, nuts, and vegetables are packaged in moisture-proof containers, they can be mixed with other produce kept at 90-95% RH.

Conditions that result in water condensation on the surface of produce should be avoided to reduce decay incidence.

3. Ethylene

Many ripening fruits (such as apple, pear, peach, banana, and tomato) produce ethylene gas, which can be detrimental to ethylene-sensitive commodities (such as broccoli, cabbage, carrot, lettuce, and watermelon). Symptoms of ethylene-induced disorders include yellowing of broccoli and cucumber, russet spotting on lettuce, bitterness of carrots, tissue maceration in watermelons, and calyx abscission of eggplant. Exposures of ethylene-sensitive commodities to ethylene are cumulative and must be avoided throughout the postharvest handling system. Continuous scrubbing of ethylene to below 1 ppm from the circulating air in the storage facility can facilitate mixing ethylene-producing and ethylene-sensitive commodities.

4. Odor volatiles

Commodities with strong odors (such as garlic, leek, onion, pepper, and potato) should not be mixed with commodities that can absorb these odors (such as apple, avocado, citrus fruits, grape, and pear). Also, fruits and vegetables can absorb some undesirable odors produced by bacteria and fungi that may be present on various surfaces of transport vehicles and storage rooms unless these facilities are kept clean and sanitized.

5. Sulfur dioxide

Some table grapes are shipped with SO_2-generating pads to control decay caused by Botrytis cinerea. These grapes should be stored alone because SO_2 can damage most other fruits and vegetables.

6. “SmartFresh” (1-methylcyclopropene)

It is OK to mix commodities that had been treated with the ethylene-action-inhibitor, “SmartFresh” (1-methylcyclopropene = 1-MCP) with untreated commodities since 1-MCP does not migrate from treated to untreated produce.

7. Organic produce

Ideally, organically-grown produce should be handled and stored separately from conventionally-grown produce to avoid any potential contamination by pesticide residues due to direct contact. Handlers of organic produce are required to keep a record of cleaning dates and products used for cleaning the storage room in which the organic produce is kept.

Produce Compatibility Groups

Most compatibility charts for mixing produce items during postharvest handling divide fruit and vegetables into 8 or more groups, which is very difficult to implement in commercial practice. Thus, we developed an easier-to-use grouping that places most produce items into the following three groups:

	Group 1	Group 2	Group 3
Temperature range:	0° to 2°C (32° to 36°F)	7° to 10°C (45° to 50°F)	13° to 18°C (55° to 65°F)
RH range:	90 to 98%	85 to 95%	85 to 95%
Commodities:	Temperate fruits	Subtropical fruits	Tropical fruits
	Non-fruit vegetables	Immature-fruit vegetables	Mature-fruit vegetables
	(cool-season vegetables)	(warm-season vegetables)	Tropical root vegetables

Following are examples of the commodities in each of these three groups:

Group 1: apple , apricot, cherry, fig, grape, nectarine, peach, pear, plum, strawberry, artichocke, asparagus, broccoli, cabbage, carrot, cauliflower, celery, lettuce, parsley, pea, spinach, sweet corn

Group 2: avocado, grapefruit, lemon, lime, mandarin, orange, pomegranate, cucumber, eggplant, green bean, okra, pepper, summer squash

Group 3: banana, mango, muskmelons, papaya, pineapple, watermelon, dry garlic and onion, potato, sweet potato, tomato, winter squash and pumpkins

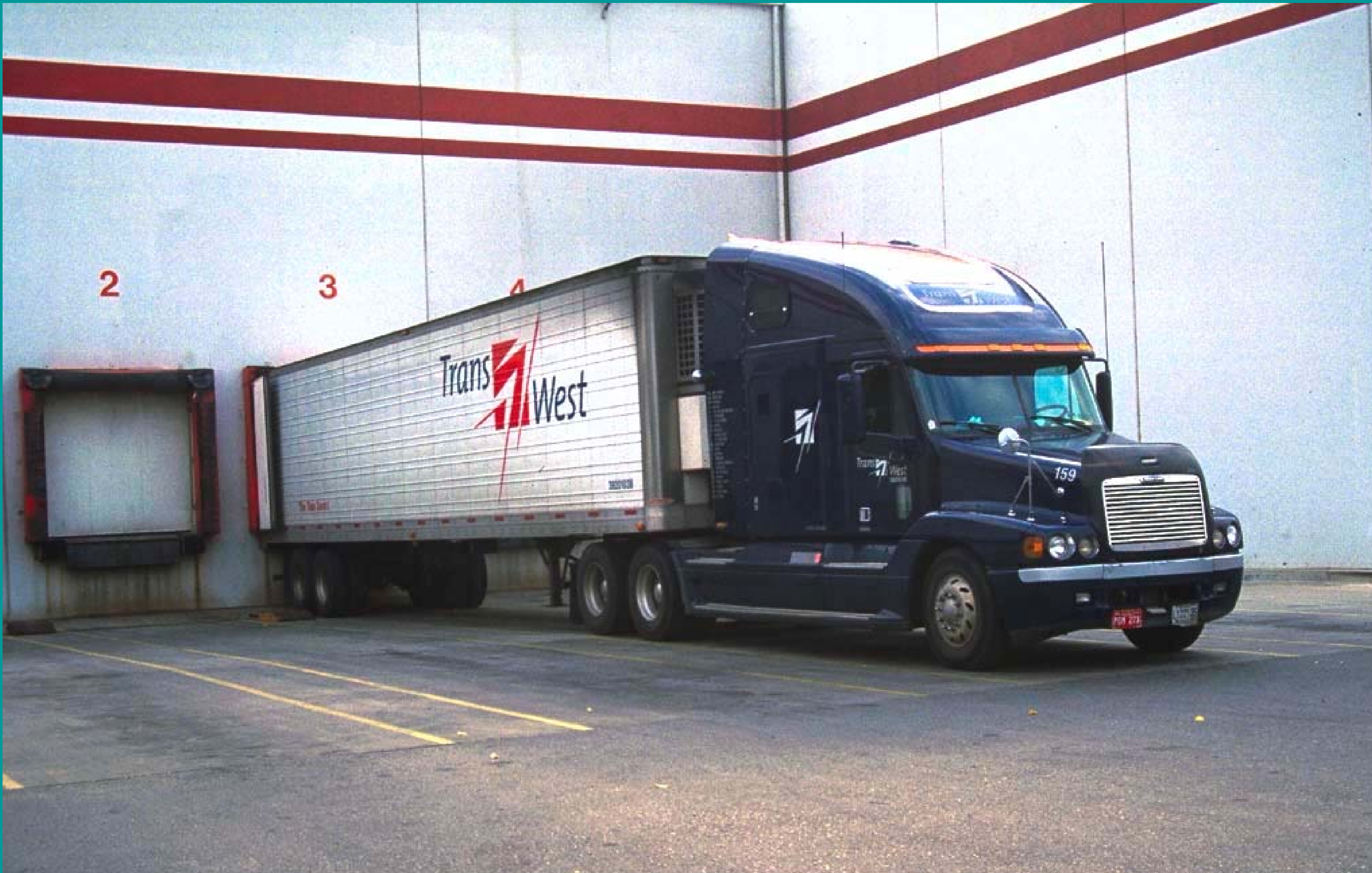
Shading to Protect Produce from the Sun

Forced Air Cooling of Cantaloupes

Forced Air Cooling of Flowers

Hydrocooling

Cold Storage Facilities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Trans West
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Refrigerated Retail Displays

Refrigerated Retail Display with Water Misting System

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