Post-harvest Technologies of Fruits & Vegetables

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CHAPTER 1

An Overview of Postharvest Losses and Causes

INTRODUCTION

THE word "harvest" triggers many sensations among people in countries that depend on agricultural production. It is the beginning of realizing the gain from all the hard work that has been put in right from the time of planting, watching the crop grow and bear fruit. It is celebrated with fervor in many countries, certainly a time to enjoy the reaps of their bounties. It is a reverberating magic word which gives the farmer the gorgeous images of a golden field of wheat or paddy ready to be brought home. Imagine the orchards of full apple, orange and cherry trees, the fields displaying a multitude of vegetables or the vines of grapes sagging with fruit.

But however natural or noble it may be when we harvest, the act isn't all that beneficial for the crops going through the harvesting process. For the bulk of fruits and vegetables it is a painful act of separation from the mother plant. When we pluck the bunch of grapes, chop the head of cabbage, cut the hands of bananas, slash the trunk of sugar cane, pull the ears of corn, lift the roots of carrots, snap the vines of beans, how can that be beneficial? This means an abrupt termination of their life. In human law, such acts would sound grave and warrant a great many punishments. However strange it may sound when we use the same words with produce, they characterize the various changes that the produce goes through during the postharvest period. Maybe for a few crops like wheat, rice and other staple food crops, it may not look that bad since they generally stay on the plant until their fruits become fully mature and relatively dry. For most produce, harvesting marks the beginning of the deteriorative process, and the longer the crop is held (stored) before use, the lower will be its quality. Exceptions may be made in the case of fruits which attain their optimal quality following a ripening period. The various handling and storage procedures followed after the harvest period are illustrated in Figure 1.1 and determine the shelf-life of these commodities.

Because produce is highly perishable, some loss is inevitable. Depending on the produce, handling procedure, storage and environmental conditions, the extent of postharvest losses vary. Some products grown in remote areas may never even reach the marketplace, while others may have a very limited loss if they are in close proximity to their consumption. The frequently used estimate for postharvest losses of a majority of common fruits and vegetables is around 25–30%. A figure called "Food Pipeline" was published in a USDA handbook (Salunke and Desai, 1984) and depicts the physical and biological ways of occurrence of food loss from production to consumption. The commodities are shown to enter the mouth of the pipeline, and the losses through the different stages of handling and the damages due to various environmental conditions are shown as leakages from the pipe. Clearly, the quantity and quality of food filling the consumer's pot will be lower than that entering. The actual movement of food from harvest to consumer may be simpler or more complex than illustrated, but it serves to demonstrate that some loss is inevitable in every handling operations such as preprocessing, transportation, storage, processing, packaging, and marketing. A modified version of the illustration is presented in Figure 1.2.

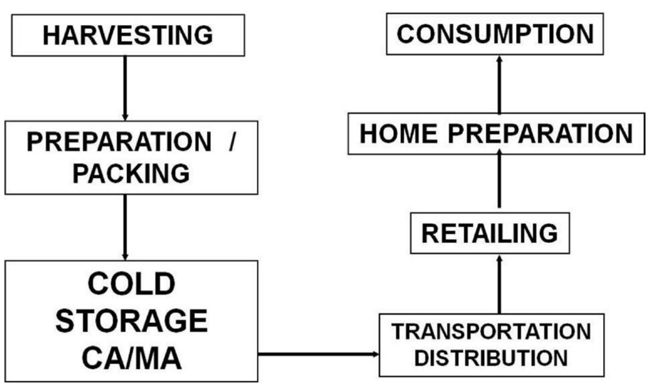

FIGURE 1.1. *Typical post harvest operations.*

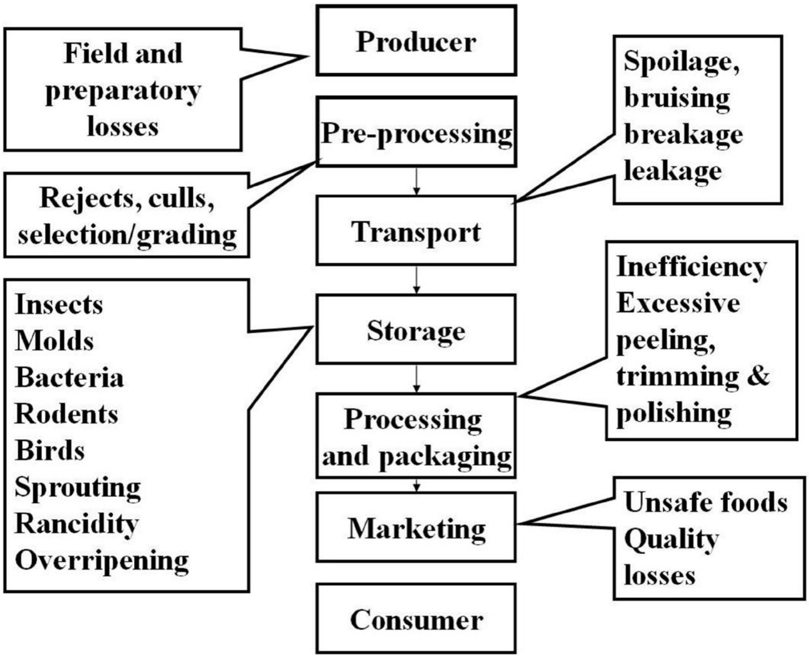

FIGURE 1.2. Losses in food chain.

Estimation of the magnitude of food losses has been the subject of considerable debate over the past several decades. Yet very little reliable information is available on the postharvest losses of perishable produce. In 1978, the U.S. National Academy of Sciences gathered some information on the postharvest losses of some commodities. These are presented in Figure 1.3 (shaded area) [data from Liberman (1981)]. Most numbers in this table are based on the "Delphi" principle, a process of summarizing the estimates (or guesses) of a number of professionals who have some standing authority in the field when hard factual data are largely unavailable. One can see that depending upon the commodity, length and conditions of storage, almost any number between 0 and 100% can be a valid estimate of the loss. One conclusion that can be drawn from this table is that it is almost impossible to quantify the postharvest losses in perishables except with reference to a particular commodity and a given location.

The above data refer mainly to nongrain commodities. The grains and other more stable food products can be expected to undergo less similar postharvest spoilage. On the other hand, since these are more durable, they are obviously stored for longer periods and one gets into types of losses other than spoilage. Infestation by insects and pests appears to be the major concern in this class of foods, and the overall loss probably is not going to be very different, especially in developing countries where storage facilities are grossly inadequate. Characteristic differences between durable and perishable food crops are detailed in Table 1.1. Notable among the differences is the low moisture content associated with the durable crops, which makes them less susceptible to microbial and enzymatic spoilage. They also are characteristically less bulky, possess harder texture and low rates of respiration.

Some data on postharvest losses in the North American scenario are provided in Table 1.2 [data from Salunke and Desai (1984); Liberman (1981)]. The estimated losses for the same commodity are at variance. For example the overall losses range from 6% to 40% from one source and they range from 2% to 30% with the other source. The total losses for apples, strawberries and peaches in one source are much higher than the magnitudes shown in the other source. The table in general indicates that softer fruits and vegetables are susceptible to greater losses, but again the magnitude depends on the commodity and the location.

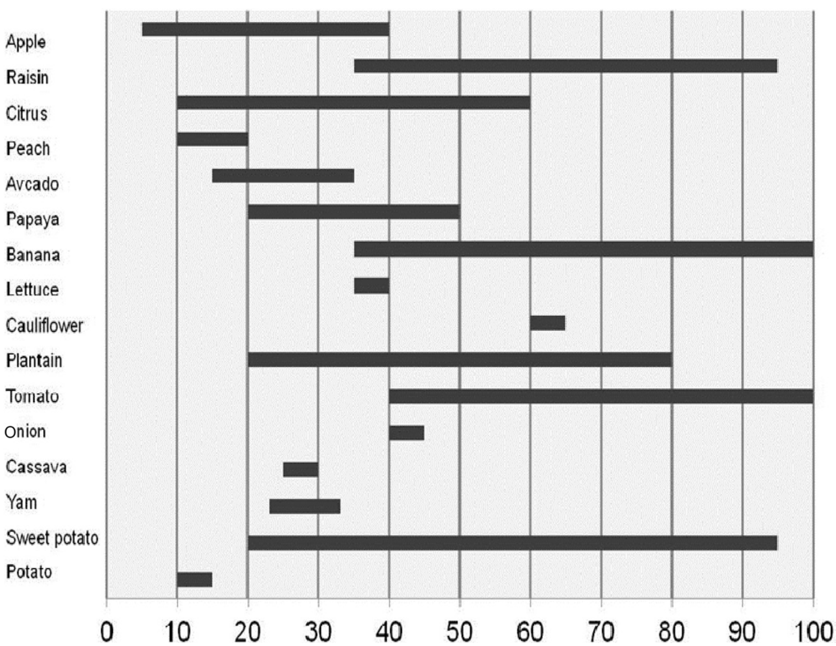

FIGURE 1.3. Range of postharvest losses in selected fruits, vegetables and staple foods.

TABLE 1.1. Characteristics of Durable and Perishable Crops.

Durables	Low moisture content, usually 10–15% or less; Small unit size, typically less than 1 g; Low-respiration rate, with very small rate of heat generation; Hard texture, not easily damaged; and Stable with natural shelf-life of several years. Losses mostly caused by external agents, e.g. agents such as molds, insects and rodents.
Perishables	High moisture content, typically 50–90%; Large unit size, typically 5 g–5 kg, occasionally even larger; High to very high respiration rate, and rate of heat production; Soft texture, easily damaged, highly perishable, with natural shelf-life of a few days to at best few months; and Losses mainly caused by external rotting by bacteria and fungi and partly by endogenous factors, respiration, senescence and sprouting.

In spite of these varying reports, one can roughly say that postharvest losses of 25% to 30% are not uncommon, especially in the absence of proper postharvest activities.

So, obviously there is a lot of wastage in the postharvest chain. What can one do about it? Shouldn't we try to reduce this wastage? Or should

TABLE 1.2. Estimated Losses of Some Fresh Fruits and Vegetables.

	Percent Loss				
Produce	**Wholesale**	**Retail**	**Consumer**	**Total**	**Ref**
Apples	2.9	2.9	2.4	**8.2**	a
Apples (Red Delicious)	0.2	0.2	1.5	**1.9**	b
Oranges, Navel	1.9	1.9	2.3	**6.1**	b
Peaches	12.3	5.8	10.8	**28.9**	a
Peaches	2.3	4.5	8.1	**14.9**	b
Pears, d'Anjou	–	2.5	1.6	**4.1**	b
Strawberries	13.5	5.5	22.2	**41.2**	a
Strawberries	5.9	4.9	18.0	**28.8**	b
Valencia Oranges	1.4	0.8	3.7	**5.9**	a
Cucumbers	–	5.0	2.9	**7.9**	b
Lettuce, Iceberg	4.1	4.6	7.1	**15.8**	b
Peppers, Bell	7.1	9.2	1.4	**17.7**	b
Potatoes, Katahdin	1.3	–	3.6	**4.9**	b
Sweet potatoes	–	5.7	9.4	**15.1**	b
Tomatoes, packaged	–	6.3	7.9	**14.2**	b

[a]Salunke and Desai (1984).
[b]Liberman (1981).

we concentrate on growing more food and/or intensify the agricultural production to compensate the losses? The early answer to this question was simply to grow more food to compensate for the loss since the food demand had to be met in spite of the loss. Increasing the world availability of food has been an increasing priority and it is especially so now with the world population expanding at a rate faster than food production. It is postulated that the world population will increase at a rate of 50% every 20 years which implies that the food production must increase at a simple annual rate of about 2.5% even to maintain the present day standards. Even so, that is considered grossly inadequate in many developing and underdeveloped countries. It is a matter of speculation as to how this increased production rate will be achieved, but it is generally accepted that except in a very few situations, there isn't much scope to bring new land into cultivation each year. In many countries, urbanization is actually reducing the available land for cultivation.

The second approach is to maximize agricultural production by employing modernized agricultural operations, intensified planting, high yield varieties, effective use of growth promoters, etc. These aspects were the foci of attention in the past several decades, especially in developed countries, but have limited scope in developing or underdeveloped countries where agricultural practices are mostly limited to multitudes of tiny farming sectors. Therefore, alternate measures should be adopted, including intensification of agricultural production where applicable.

One practical alternative that results in increased agricultural products availability is to minimize postharvest losses. This is a desirable alternative for many reasons. As detailed in Salunke and Desai (1984), there are several advantages with this approach:

1. *Nutritional advantage:* Since less food is lost for whatever reason, there will be much more nutritious and wholesome food.
2. *Economic advantage:* Wastage of food represents an economic loss. The economic loss increases as the food moves down the food pipeline, because to the cost of food that is lost must be added the costs of handling, transportation, storage, etc.
3. *Feedback incentive:* In some countries, the farmers could very well increase their production, but cannot store food for longer periods. So there is no economic incentive to increase production because they know that the increased output ends up as further wastage.

Reduction in postharvest losses would give them the feedback incentive to increase agricultural production.

4. *Cost-effective:* The food supply is significantly increased without bringing another acre of land into production and without using greater amounts of energy, water and capital.
5. *Environmentally friendly:* It will reduce environmental pollution and garbage disposal problems.
6. *Consumer satisfaction:* Consumers will be more fully satisfied and will receive more wholesome food.

CAUSES OF POSTHARVEST LOSSES

Although it is simple to suggest minimizing losses during various postharvest operations, achieving the goal is quite challenging. In order to do so, one must first understand the various causes of postharvest spoilage of fruits and vegetables and the factors that influence them, and secondly, use the postharvest conditions/operations that will result in extending the shelf-life of the produce.

The different causes of postharvest food losses may be broadly grouped as primary and secondary (Bourne, 1977; Salunke and Desai, 1984):

Primary Causes

1. *Biological and microbiological*: Consumption or damage by insects, pests, animals and microorganisms (fungi and bacteria).
2. *Chemical and biochemical*: Undesirable reactions between chemical compounds present in the food such as browning, rancidity, enzymatic changes, etc.
3. *Mechanical*: Spillages, damages caused by abrasion, bruising, crushing, puncturing, etc.
4. *Physical*: Improper environmental and storage conditions (temperature, relative humidity, air speed, etc.)
5. *Physiological*: Sprouting, senescence, other respiratory and transpiratory changes.
6. *Psychological*: Human aversion or refusal due to personal or religious reasons.

Many of these factors have synergistic effects, and the losses can be greater with a combination of factors. For example, chemical, microbial, biochemical, or physiological activity in a stored product is significantly influenced by the storage conditions, especially temperature. A ten-degree change in temperature can result in a two- to three-fold change in these activities. This is a key factor utilized for advantage in cold and controlled atmosphere storage applications where the produce is held at the lowest possible temperature without getting into problems of chilling injury or freezer burn. On the other hand, if proper precautions are not taken in handling and transportation, increased product temperatures may result in a very rapid quality loss.

Another example is the presence of mixed loading in a storage chamber. The emanations, especially trace gases like ethylene, from one product, may trigger deteriorative or ripening reactions in another. Again, the presence of ethylene is a factor that may have an advantage in controlled ripening chambers, but must be prevented in other situations.

Secondary Causes of Losses

Secondary causes usually are the result of inadequate or nonexistent input and may lead to conditions favorable for primary causes. This can include: improper harvesting and handling; inadequate storage facilities, inadequate transportation, inadequate refrigeration and/or inadequate marketing system.

The various causes of postharvest spoilage also can be grouped based on the nature of biological and environmental factors (Kader, 1985). The biological factors include:

1. *Respiration:* Respiration is a process by which all living cells break down organic matter into simple end-products with release of energy and CO_2. The result is loss of organic matter, loss of food value and addition of heat load which must be taken into account in refrigeration considerations. The higher the respiration rate of produce, the shorter is its shelf-life.
2. *Ethylene production:* Ethylene has a profound effect on physiological activities. Used in ripening chambers, it can trigger physiological activity even in trace amounts. Most living commodities produce ethylene as a natural product of respiration.
3. *Compositional changes:* Many changes occur during storage, some desirable and some undesirable. For example, loss of green color

is desirable in fruits but not in vegetables. Development of carotenoid pigments may have nutritional importance. There will be changes in carbohydrates, proteins, and all other food components.

4. *Growth and development:* In most produce there is continued growth and development even after harvest. Characteristic activities are sprouting of potatoes, onions and garlic, elongation of asparagus, seed germination in fruits like tomatoes, lemons, etc.
5. *Transpiration:* Transportation refers to water loss resulting in shriveling and wilting due to dehydration and is undesirable due to loss of appearance, salable weight, texture and quality.
6. *Physiological breakdown:* This includes *freezing injury* or frost damage in commodities subjected to temperatures below their freezing point which can occur in the field or during trasportation/storage. *Chilling injury* is mainly associated with tropical and subtropical commodities held for prolonged periods at temperatures between 5°C and 15°C. *Heat injury* can result in commodities exposed to direct sunlight or excessively high heat for prolonged intervals.
7. *Other factors:* These include physical/mechanical damage to the produce occurring during harvesting, handling, storage and transportation, as well as spoilage due to pathological causes (attack by microorganisms such as bacteria and fungi).

The environmental factors include temperature, relative humidity, atmospheric composition, light and other factors (fungicides, growth regulators, etc). It generally is recognized that higher temperature will result in increased respiratory activity and hence lowered shelf-life. Very high relative humidity conditions may lead to mold growth on produce surfaces while lower relative humidity can result in desiccation. Lowering of oxygen and increasing of carbon dioxide levels in storage atmospheres have been successfully used to promote microrespiration in produce and thus extend the shelf-life.

The various causes of postharvest losses will be discussed in greater detail in the forthcoming chapters, which also cover measures that can be taken to minimize these deteriorative changes. This chapter serves to provide an overview of the various causes of postharvest spoilages. Basically, one should try to minimize losses due to each and every factor in order to extend the duration of postharvest storage. The best technique would certainly involve harvesting the produce at the optimum stage of maturity, followed by quick cooling, packaging and transfer to a controlled atmosphere storage, where the temperature, relative humidity, air velocity and atmospheric composition are set at the most appropriate level for the produce in question.

The produce would be ideally left in this primary storage almost until ready for the final shipment to the retailer for quick transfer to the consumer to get at least a week's high-quality life for the produce under in-home refrigerated-storage conditions. They all sound relatively simple, but the fact that the harvesting, precooling, storage, transportation, packaging and handling requirement for each commodity can be different makes the postharvest handling system very complex.

CHAPTER 5

Harvesting of Fruits and Vegetables

INTRODUCTION

HARVESTING is the process of detaching a produce from the mother plant at the proper stage of maturity by an appropriate technique and as rapidly as possible with minimum damage or loss imparted to the commodity all at a relatively low cost. When quality is the primary consideration, not the cost, not the speed, and not the time, hand harvesting is the best approach. Generally, fruits intended for fresh market are hand harvested.

HAND HARVESTING

Hand harvesting has several advantages, especially with reference to selective picking at the right stage of maturity to allow for the maximum quality development in the fruit or vegetable prior to harvest (especially if the maturity stage is visually and easily assessible), with minimum damage done to the produce during picking and transfer to the appropriate container for subsequent handling, storage and transportation. In addition, it involves minimum or almost no capital investment and the harvest output is proportional to the number of people at work. The only capital required is perhaps shelter and transporation for the workers and small harvesting tools to separate the produce from the mother plant. One can supply more or fewer people based on needs.

The main problem with hand harvesting centers around the workers needed to do the job. There could be an acute shortage of labor when the need is the greatest during the harvesting season. Labor strikes in harvest time could occur and be very costly. The seasonal nature of fruit and vegetable crops makes it difficult to keep the entire work force engaged throughout the year. It would require very thorough planning and very efficient labor management. Various labor management approaches have been attempted, each with limited successes. Co-operative approaches employing the labor force for a variety of rotating jobs at locations within a reasonable distance have been successful in some sectors.

These are not just current problems; they existed in the past, they are there today and likely will continue to be there tomorrow. So is hand harvesting. Quality of fruits and vegetables is very important for successful marketing. It can only be satisfactorily obtained by hand harvesting at the right stage. Hence, even today, most of the fruits and vegetables intended for fresh market are almost entirely hand harvested.

MECHANIZED HARVESTING

Mechanical harvesting is employed for the majority of fruits and vegetables intended for processing where they normally are converted to other forms, where physical appearance is not a major consideration, where the commodity is consumed within a short time after harvest so the quality may not deteriorate seriously in spite of some damage induced by the mechanical harvesting techniques, and where the commodity is needed in large quantities.

Some advantages of mechanized harvesting are:

1. *Speed of harvest:* Substantial increase in the harvest output is possible with minimal trained labor. One mechanical harvester can potentially do the job of hundreds of manual laborers.
2. *Improved conditions for the workers:* Since only a few workers are needed to handle the mechanical harvesting equipment, better salaries, working conditions and other facilities can be provided, and the employees can be hired full time throughout the year for various activities. The workers, however, need the basic skills of operating the harvesting and other farm equipment.
3. *Reduced labor-related problems:* This is mainly because of the involvement of smaller numbers of people required, although strikes by these skilled workers could be equally costly.

The disadvantages and problems associated with mechanical harvesting systems are summarized below:

1. *Physical/mechanical damage to the crop:* Damage is one of the most serious problems associated with mechanical harvesting. Significant damage can be imparted to the commodity by the picking, screening and transferring devices or induced by the fall of the detached fruit on the lower branches of the tree or catching device. These damages serve as active sites for the invasion of pathogens, resulting in quick degeneration of the damaged crop, which can spread to surrounding crops if these are not effectively removed prior to storage and transportation.
2. *Non-selectivity:* The mechanical device cannot discriminate the fruit or vegetable based on maturity or color. Some selectivity may be possible with reference to size and shape. Grading of mechanically harvested crop is therefore a must and both size and color grading techniques are practiced. With hand harvesting it may be possible to do harvesting, grading and consumer packaging all at the same time in the field. For example, strawberries, blueberries, cherry tomatoes, lettuce, cabbage, etc. are picked and packed into the final containers in the field itself followed by quick cooling and transportation.
3. *Separation of plant debris:* The harvester generally picks up plant parts and foreign materials. These need to be sifted out, which is done by machinery in the field, while the rest is done in the packing house.
4. *Damage to fruit trees during harvesting:* Many fruit crops are mechanically harvested by shaking of the main trunk or branches and collecting the fallen fruits on a catch frame with a canvas platform. Especially the trunk shakers involve heavy duty pneumatic shaking operations and can cause considerable damage to the tree if operators are not properly trained.
5. *Large volume output:* The large volume output is an advantage in most occasions and is one of the reasons for employing mechanized harvesting, but this could become a limitation in the absence of adequate processing and handling capacity.
6. *Expensive machinery:* Machinery often needs a large capital investment. Harvester designs are very specific for a certain type of produce based on its physical characteristics and growing conditions. These often can change due to altered farm practices, use of high yielding varieties, etc. Such changes may require redefining the selec-

tion criteria for harvesters. Hence, what is best today may quickly become obsolete even before the equipment gives the expected returns.

7. *Social impact:* One machine will likely do the job done by hundreds of workers. So if deployed on community farms where the majority of people thrive on farm labor, machines could cause labor unrest.

The ever-increasing cost of manual labor, decreasing availability of timely labor and the need for high-speed high-volume output probably provide the best incentives for the development of mechanical harvesting equipment in spite of the various problems and disadvantages associated with them.

ELEMENTS OF HARVESTING: HAND/MECHANICAL

- *Detection:* This is possible only with hand harvesting operation.
- *Selection:* This also is possible only with a hand harvesting operation.
- *Detachment: Mechanical devices* involve combing, raking, pulling, lifting, digging, cutting, shaking, blowing, sucking and other operations. *Hand held devices* feature a knife, clippers, picker pole with a knife, bag.
- *Collection:* Mechanical harvesters like trunk shakers require a catch frame with canvas; others require a conveying device to fill large bins. Sometimes these are part of the harvester and most often after some preliminary cleaning, the harvesters feed a receiver truck that follows the harvester. For hand harvesting, this will initially involve small baskets or bags emptied into a storage bin.
- *Separation:* This involes the cleaning operation to separate unwanted material. Usually, this is done in the field, and the rejects are left in field.
- *Handling:* From harvester to transport trucks to packing house.

IMPORTANT FIELD/ORCHARD-CONSIDERATIONS FOR MECHANIZED HARVEST

1. *Genetic considerations:* The selected variety should be suitable for mechanical harvesting. The tree, for example, should have the strength to withstand the mechanical shaking operation. The crop should preferably attain a uniform maturity by harvest time, facilitating once-over harvesting. The crop also should have the mechanical strength to withstand aggressive mechanical handling.

2. *Planting system and tree training:* High-density planting of vegetable crops is ideal for once-over mechanical harvesting needs. High-density planting also is recommended for tree fruits because it favors dwarf trees. Tree fruits which are separated by shaking or blowing devices should be trained to take high-frequency pneumatic shaking. Dwarf trees are preferable to tall trees and similarly short branches are preferred over long branches to facilitate the effective transfer of the vibration induced by the trunk or limb shakers to the fruits and nuts. The longer the tree or branch, the less effective is the fruit separation.
3. *Crop control—Pruning:* The main reason for pruning is to maximize the fruit yield and value—it is a balance between fruiting and fruit growth; in other words, it is a balance between the number and size. Instead of having a large number of smaller fruits which are labor intensive for harvesting and handling, the trees are pruned to remove some growing parts and nonproductive branches. The process helps to produce larger fruits, although in relatively smaller numbers. Pruning effectively reduces the number of growing points and improves the vigor of those remaining, thereby increasing the crop potential. A heavy bloom and fruitset likely damage the plant and normally result in weak vegetative growth. If much of the excess can be removed before the bloom, the potential for the vegetative vigor to size the new crop and to produce healthy buds for a crop the following year is maximized. These are desirable from a mechanical harvesting point of view since they increase the strength of the mother plant.

   Fruit thinning is another concept whereby one facilitates the development of a smaller number of large fruits rather than numerous smaller ones. In this case the excess flower buds are removed either by hand or by the use of chemicals. Thinning involves: (1) application of a caustic spray during the period of bloom, (2) application of growth regulators after fruit set, or (3) mechanical or hand thinning.
4. *Harvest Control:* A certain amount of flexibility can be achieved for harvesting of some fruit crops by additional orchard management techniques. Chemicals applied in the field can either hasten the ripening of fruits or delay the ripening. Ideally, by spraying of chemicals that hasten the ripening stage to a section of the orchard the harvest date can be advanced. Similarly, another section of the

orchard can be sprayed with a chemical that delays ripening so this section could be harvested at a later date. Untreated areas could be harvested in between, thereby effectively prolonging the harvest season. Growth regulators like Alar act as growth inhibitors on some fruits and a growth promoter on others. Alar retards, for example, ripening of pome fruits and accelerates ripening of stone fruits. It also intensifies the red color of some varieties of apples. However, recently there have been several adverse reports on the use of Alar on apple orchards. Ethephon, an ethylene releasing agent has been shown to advance the maturity date. To control the fruit drop, the following chemicals have been used: 2,4,5 T (2,4,5 trichloro phenoxy acetic acid), NAA (naphthalein acetic acid), CPA (p-chloro phenoxy acetic acid) and alar (applied 60–70 days prior to harvest—apples).

TYPES OF MECHANICAL HARVESTERS

Various types of mechanical harvesting machines have been developed, mostly with each being specific to a particular commodity. These can be broadly grouped as:

1. Direct contact devices
2. Vibratory devices

Direct contact devices are based on actions such as cutting, pulling, snapping, twisting, stripping, digging, lifting, etc. Most vegetable harvesters with some used for non-tree fruits come under this group.

The vibratory devices are those which use trunk and limb shakers with a catch frame and canvas. These have been widely used for apples, apricots, cherries and nuts.

HARVEST AIDS

Harvest aids are mechanical devices and supports that assist in improving hand harvest operations. They include:

1. Picker poles with a knife and a canvas bag, for many tree fruits
2. Multi or single station platforms to properly position workers, used with tree fruits.
3. Conveyor belts to move harvested heavy fruits and vegetables, such as pineapples and melons.

4. Harvesting cages which are similar to platforms
5. Lights for night harvesting

EXTENT OF MECHANIZATION

Kader (1985) classified the extent of vegetables and fruits that have been harvested by devices, hand or mechanical. The percentages which follow are in terms of extent of mechanical harvesting. What is not mechanically harvested is hand harvested. Those with an asterisk are commodities more than 50% of which are processed.

Vegetables

- *Mechanically harvested 0–25%:* Artichoke, asparagus, broccoli*, cabbage, cantaloupe, cauliflower, cucumber*, lettuce, green onion, cress, dandelion, eggplant, endive, fennel, kale, kohlrabi, mushroom*, okra, pepper, rhubarb*, Romaine, squash, watercress, cassava, ginger, parsley root, parsnip, rutabaga, turnip, taro.
- *Mechanically harvested 25–50%:* Sweet potato, mustard greens, parsley, Swiss chard, turnip greens
- *Mechanically harvested 50–75%:* Snap beans*, dry onion, pumpkin*, tomato*.
- *Mechanically harvested 75–100%:* Carrot, potato*, lima bean*, snap bean*, sweet corn*, peas*, spinach*, horseradish*, beet*, garlic, Brussels sprouts*, radish.

Fruits

- *Mechanically harvested 0–25%:* Apple, apricot, avocado, banana, sweet cherry*, grape*, guava*, kiwi, kumquat*, lychee, mango, nectarine, peach*, pear*, persimmon, pineapple*, pomegranate, wild blueberry*, currant, gooseberry, strawberry, grapefruit, lemon*, lime, orange*, olive*, papaya, passion fruit*, tangerine, cashew, coconut*, chestnut*.
- *Mechanically harvested 25–50%:* Red raspberry, macadamia.
- *Mechanically harvested 50–75%:* Prune*, blackberry*, highbush blackberry*, black raspberry*, pecan.
- *Mechanically harvested 75–100%:* Tart cherry*, date, fig, cranberry*, almond, peanut*, pistachio, walnut.

The reader is referred to Ryall and Lipton (1978) and Ryall and Pentzer (1979) for more detailed discussion on the harvesting of individual fruit and vegetable crops. The following figures illustrate some harvesting techniques and harvest aids used in the industry.

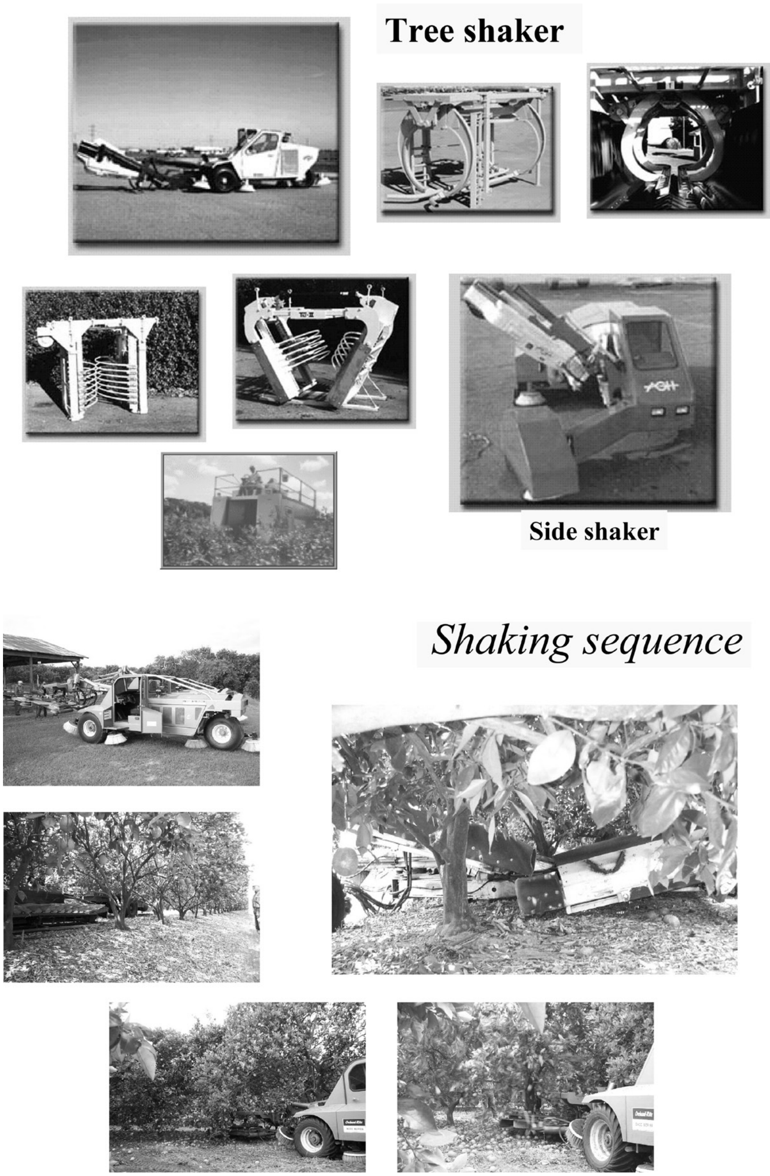

FIGURE 5.1. Tree shaker and illustrated shaking operations.

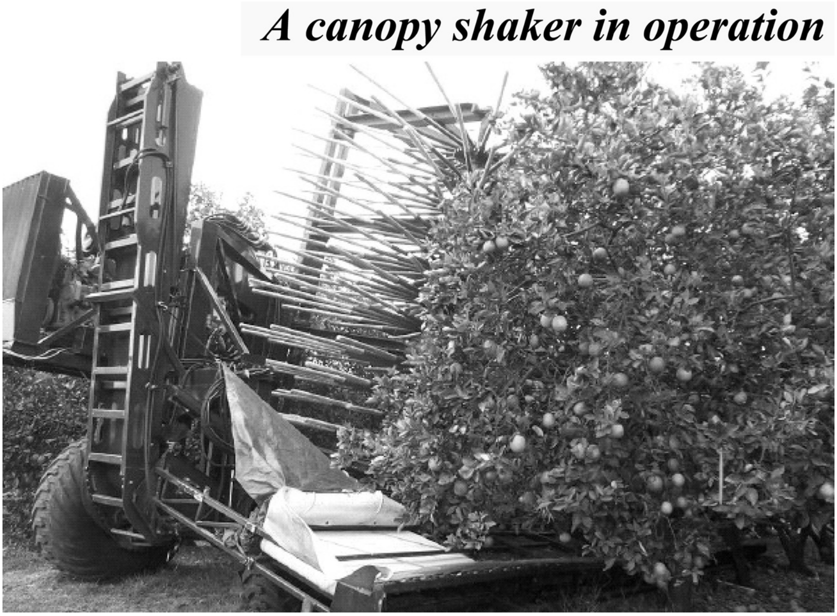

FIGURE 5.2. Canopy shaker.

FIGURE 5.3. Corn harvesting illustrations.

Cucumber harvesting

Peppers

FIGURE 5.4. Cucumber and pepper harvesters.

Carrot and Potato Diggers

FIGURE 5.5. Diggers for carrots and potatoes.

Onion Harvesters

FIGURE 5.6. Onion harvester.

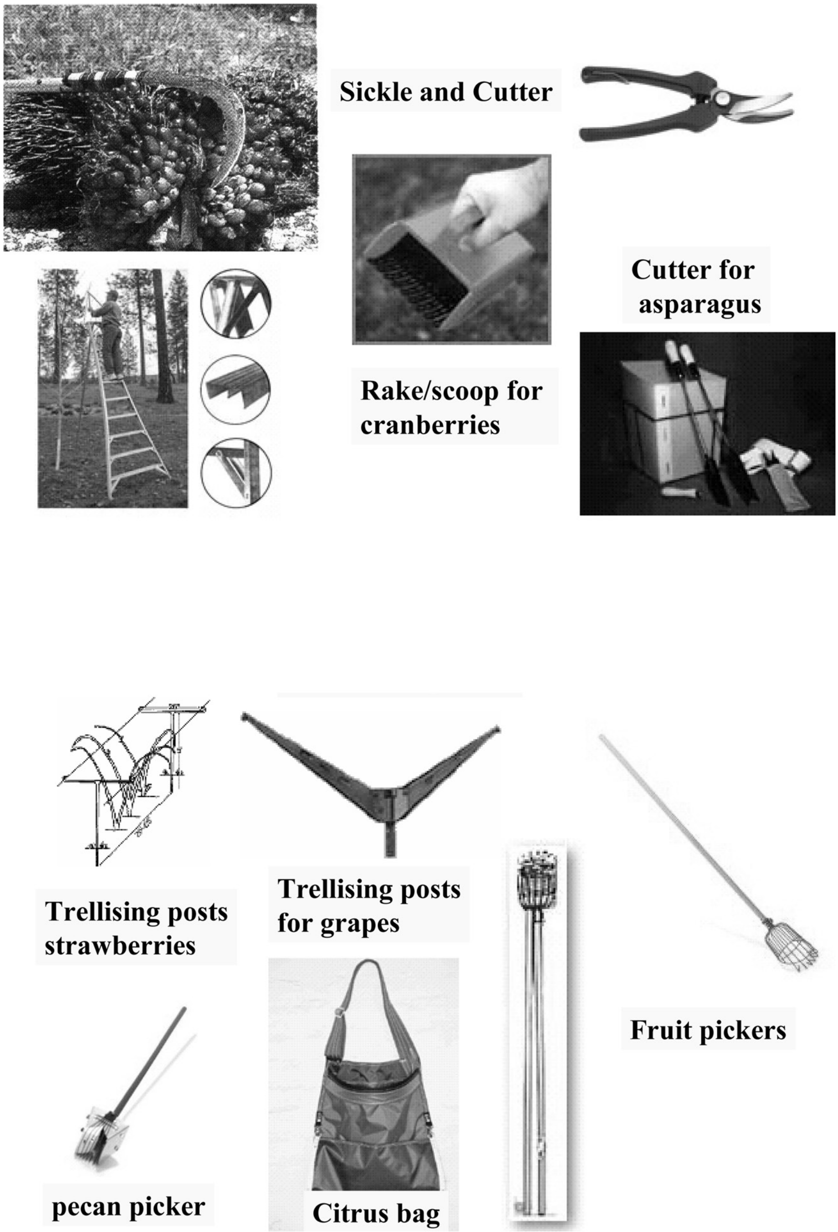

FIGURE 5.7. Harvest aids.

CHAPTER 11

Packaging of Fruits and Vegetables

INTRODUCTION

PACKAGING of fruits and vegetables provides one of the most important functions—protecting the contents during storage, transportation and distribution against deterioration, which may be due to physical, chemical or biological causes. Packaging can be applied in the field, during production, or via subsequent handling in packing houses, processing plants or distribution centers. Packaging forms the last link between the produce and the consumer and plays an important role in the safe delivery of the produce. Robertson (1992) defined packaging as "the enclosure of products, items or packages in a wrapped pouch, bag, box, cup, tray, can, tube, bottle or other container to perform the following functions: containment; protection; and/or preservation; communication; and utility or performance." There has been a tremendous growth in development and application of packaging technologies for foods processed by both traditional as well as new food processing technologies. This has been driven by evolution of new packaging materials, package designs, package functions, sophistication in distribution and marketing techniques, consumer demand for convenience and unitized products and increasing production, processing, handling and energy costs.

For fresh fruits and vegetables, packaging is one of the most important steps in the handling and marketing of the produce from the farm gate to the consumer. There are different kinds of packages—bags, crates, baskets, cartons, bins of all sizes and shapes. These also are made from varied materials like wood, paperboard, plastic, metal, etc. The diversity of the packages and packaging materials for produce alone includes more than 1000 different types of packages with scores of different materials in North America alone. The numbers appear to increase as the industry introduces new packaging materials and new concepts, while many serious and fruitful discussions have been held about standardizing containers, container sizes and pallets. Although the packaging industry generally agrees container standardization is the right way to reduce package and transportation costs and improve handling efficiency, the trend over the years indicates that new package type and sizes are continually being introduced to accommodate the diverse needs of wholesalers, consumers and processing operations.

According to Wills *et al.* (1989), modern packaging must comply with the following requirements:

1. The package must have sufficient mechanical strength to protect the contents during handling, transport and stacking.
2. The packaging material must be free of chemical substances that could transfer to the produce and become toxic to humans.
3. The package must meet handling and marketing requirements in terms of weight, size and shape.
4. The package should allow rapid cooling of the contents. Furthermore, the permeability of plastic films to respiratory gases also could be important.
5. Mechanical strength of the package should be largely unaffected by moisture content (when wet) or high humidity conditions.
6. The security of the package or ease of opening and closing might be important in some marketing situations.
7. The package must either exclude light or be transparent.
8. The package should be appropriate for retail presentations.
9. The package should be designed for ease of disposal, re-use or recycling.
10. Cost of the package in relation to value and the extent of contents protection required should be as low as possible.

PACKAGE AS A HANDLING UNIT

The first function of the package is to contain the fruits and vegetables after the harvest and then to act as a handling unit. The many different types of harvest containers range from small bags or baskets to larger wooden or plastic containers, depending on hand or mechanized harvesting operation. Additionally, the containers will be used to handle the product. The container must enclose the produce in convenient units for handling and distribution. As a handling unit, it serves to:

- Carry the commodity from the field to the packing house (bulk containers).
- Move the product within the storage facility (bulk containers).
- Move the product through the distribution and marketing chain (shipping and retail containers).

For transport after purchase the package can segregate the products. Multi-wall bags like the ones used for onions and potatoes also can serve as a self-containing home storage unit until a product is consumed. These can serve some additional functions with respect to minimizing transpiration loss, protecing from exposure to light as well as creating modified atmospheres within the package. Figure 11.1 shows examples of commercial packages/containers used as handling units.

Further, a package helps to unitize the product and facilitates unitized

FIGURE 11.1. *Some commercially diverse container types as handling units.*

handling. Container unitization and standardization are important aspects of storage and transportation. Individual containers may be consumer units which are small retail containers varying from a few hundred grams to a few kilograms. Shipping containers generally accommodate more product; for example, up to 10 to 20 kg for manual handling and up to 250 kg for bulk handling by using forklifts. There are more than one thousand types of containers with hundreds of different dimensions, used for more than 50 common commodities.

In the international trade, container standardization has been recognized as a necessity. Container and pallet size standardization are being considered seriously to help in international trade. They reduce cost of handling and improve the efficiency of loading. Most pallet racks and automated pallet handling equipment are designed for standard-size pallets. They make efficient use of truck and van space and can accommodate heavier loads and more stress. The adoption of a pallet standard throughout the produce industry would also aid efforts toward standardization of produce containers.

A standard pallet is generally 100 × 120 cm. Shipping containers are designed to maximize the pallet space. Four common sizes suggested by OECD (Organization of Economic Cooperation & Development) are: 40 cm × 30 cm; 50 cm × 30 cm; 50 cm × 40 cm and 60 cm × 40 cm. Note that all these fit the standard pallet, but space efficiency is maximum with the middle two, unless different arrangements are made by mixing two or three different sizes. Figure 11.2 illustrates the different combinations that have 100% space efficiency.

PROTECTION FROM PHYSICAL AND MECHANICAL INJURIES

Protection is the second major function of a package. The package has to offer the produce protection from various physical & mechanical injuries, such as cuts, compression, impact and vibration.

Cuts and punctures: These injury result from sharp edges on handling equipment, presence of nails and rough edges on packages resulting in rupturing of produce skin. This is predominant during harvesting and field transportation.

Compression injury: This results from the compression of produce (squeezing) due to produce weight within the package (bulk containers) and packages stacked one above the other causing over-stacking, which may be compounded by overfilling. Underfilling in such over-stacked

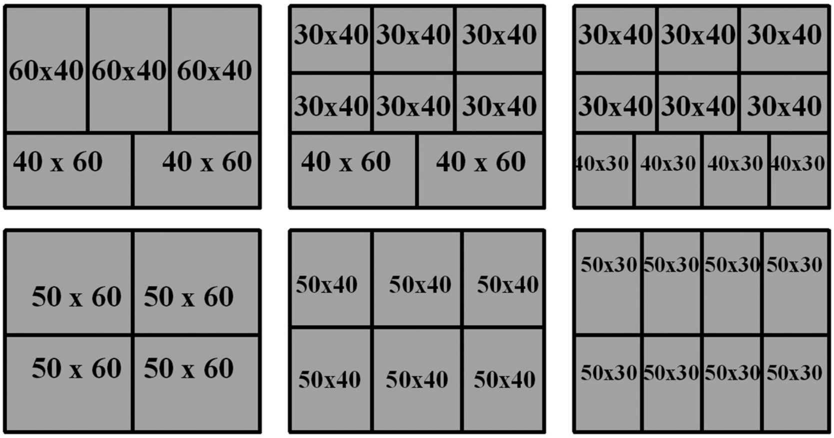

FIGURE 11.2. *Full space efficiency of different containers on a standard pallet with different arrangements.*

situations can cause package collapse. The main reasons for compression damage are therefore inadequate package or improper packaging.

Impact injury: This results from the sudden application of force on produce. It can happen because of dropping of the produce from excessive heights during harvesting and handling, dropping of filled containers, dropping of heavy objects on produce, jerky movements during transportation and impact shocks (sudden breaks, bumpy roads).

Vibration or abrasion bruise: This is a common injury caused to fruits and vegetables during transportation. It is caused essentially by product movement inside the container resulting in abrasion damage from rubbing of the produce against each other or against the container surface.

Produce types differ with respect to their sensitivity to the different kinds of mechanical damages. For example, apple, ripe banana, cantaloupe, peach, strawberry and tomato are highly susceptible to compression injury; apple, banana, peach and tomato also are susceptible to impact injury, while apricot, banana, grape, nectarine, peach, plum and squash are very susceptible to vibration injury. Grape, pear and plum are quite resistant to compression injury. Figure 11.3 illustrates the different mechanical injuries caused in the postharvest chain.

General Symptoms of Mechanical Injuries

The following are the general symptoms of the different mechanical injures: surface and internal discoloration, loss of appearance and decreased market value. All form avenues for the spread of infections, increased respiration and chemical or enzymatic activity, eventually resulting in accelerated spoilage and diminished market value.

Good handling practices are the best way of minimizing the impact of the different mechanical injuries. Cuts and similar bruises can be minimized by the use of smooth containers and handling equipment. Compression damage can be controlled by using correct filling weights, using containers of adequate strength for containing the produce and by isolating the pressure of stacked containers onto the produce. Impact damage can be minimized by reducing drop height during harvesting and handling of the produce; cushioning of all contact points; avoiding falling of the produce and jerky movements of transport vehicles; and by wrapping the produce with cushioning materials. Vibration damage can be largely eliminated by restricting and preventing produce movement within the container during transportation and handling. This is commonly done using restrainers, individual wrapping and cushioning. Figure 11.4 shows some well-designed plastic containers that can be used for harvesting instead of wooden containers, as well as several mechanisms used for preventing damage to packaged fruits and vegetables.

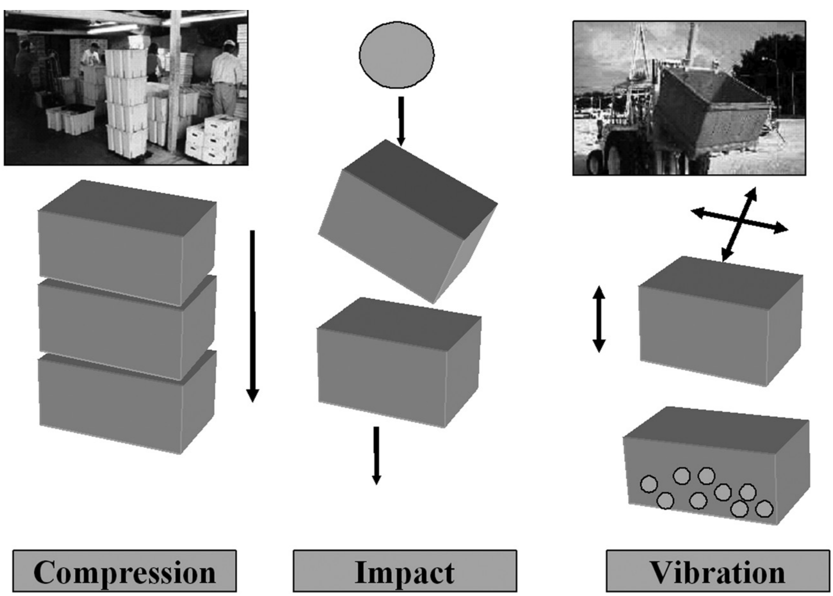

FIGURE 11.3. Illustration of different types of mechanical injuries.

FIGURE 11.4. *Well designed harvest containers and packages and cushioning materials used to prevent mechanical damage in shipping containers.*

PROTECTION FROM MOISTURE LOSS

Packaging helps to reduce moisture and weight loss by providing a gas and moisture barrier. While a moisture barrier is helpful, the gas barrier property needs to be appropriately controlled as in the case of modified atmosphere storage, otherwise it might create adverse conditions. However, if used appropriately, it can reduce transpiration losses and at the same time reduce the rate of respiration thereby helping to extend shelflife. When choosing the appropriate packaging material, the following factors should be considered: gas barrier properties, moisture barrier properties, anti-fog properties, machinability, mechanical strength, sealability and performance vs cost. One of the most important characteristics is their barrier properties to oxygen, carbon dioxide and water vapor, which varies greatly from material to material.

The barrier properties to oxygen, carbon dioxide and moisture also may be different for each material and also vary as a function of the relative humidity and temperature of the storage conditions. When gas barrier properties cannot be controlled, the package should be provided with appropriate vents to permit gas exchange. It also conserves the produce moisture within the package and hence minimizes transpiration. Such protection may be provided by wax coating of containers or boxes, protective wrappings within containers, plastic bags with holes for gas exchange, box liners, etc. In the case of bulk containers or crates in the open format, placing them under shade, cool places and occasional sprinkling with water may be helpful like, as is done in supermarket display units. Examples of packages that help reduce moisture loss are shown in Figure 11.5.

PROVIDING A SANITARY ENVIRONMENT

A package provides a sanitary environment and protects produce from extraneous contamination. Without the package, the produce may be exposed to an environment damaging to the produce, for example, plant pathogens, spoilage bacteria, chemicals and conditions that may accelerate deterioration, such as light, high or low humidity, dust, etc. Many of these may seem unimportant at the outset, but can certainly form avenues of deterioration.

FIGURE 11.5. *Examples of packaging that give protection against moisture loss.*

CHAPTER 13

Postharvest Pathology

INTRODUCTION

AMONG the factors in postharvest spoilage of fruits and vegetables previously discussed are many biochemical and physiological causes. Also presented were various means of controlling them for extension of the postharvest storage. The various factors that influence different biochemical and physiological reactions also were discussed, as well as how many of these factors could be simultaneously managed in controlled and modified atmosphere storage, thereby significantly improving the postharvest quality and shelf life of perishable produce. Another mode of spoilage of tender crops is by the attack and growth of microorganisms, one of the most obvious and common causes of postharvest spoilage, especially in the field. Microorganisms continue to cause damage during storage, but their intensity is much less due to the controlled conditions that exist under storage conditions. Not all microorganisms are of concern. Those responsible for attacking produce and subsequently making them succumb to intense spoilage are called "the plant or postharvest pathogens." Although they are pathogenic to plant tissues and cause extensive damage, not all are harmful to humans.

Economic losses caused by postharvest diseases generally are much greater. This is mostly as a result of various activities added in the later part of the postharvest management chain to increase the market value and potential of the crop. Hence, a 10% loss in the field may constitute only a small fraction of the total loss as compared to microbial spoilage at the end of the cycle, since the cost of packinghouse preparations, packaging, cooling, cold storage, transportation and handling are added to the end product with a profit mark-up at every stage. Postharvest diseases affect almost all crops, and the incidence is especially high in developing or underdeveloped countries, which often lack adequate facilities for the proper handling and storage of the produce. Developed countries are not exempt, since even under controlled conditions, pathogenic activity continues along with all other life-sustaining activities.

Specific causes of postharvest losses of fruits and vegetables may be classed as pathogenic, non-pathogenic or physical. This chapter deals with the parasitic or pathological activity of bacteria and fungi. The infections generally occur in the field and manifest themselves during the postharvest chain. Microbial infections can stay in the latent or dormant state for extended periods of time and lead to full-blown infections at a later stage when conditions become favorable for their growth and activity. Fungi are more commonly found attacking fruit, and bacteria are more common as postharvest pathogens in vegetables.

COMMON DISEASES

There are thousands of fungi and hundreds of viruses and bacteria that can attack plants and plant products. So it is important to understand disease development and to develop control methods to reduce their incidence and activity. Despite diversity in these organisms, most diseases are caused by species of just a few genera. The common fungi belong to genera: Alternaria, Botrytis, Colletotrichum, Diplodia, Monilinia, Penicillium, Rhizopus, and Sclerotinia. Pseudomonas and Erwinia are the most common bacteria associated with postharvest spoilage of most vegetables. Many of the common types of storage diseases are named after the color of the mycelium they spread or the type of wound they inflict: grey mold rot (by Botrytis on pome, stone fruits, berries, kiwi, beans, cabbage, carrot), blue/green mold rot (Penicillium on pome, stone fruits, citrus, onion), brown rot (Monilinia on stone fruits, citrus), stem end rot (Diplodia and Alternaria on citrus), watery rot (sclerotonia on carrot, lettuce, celery), soft rot (Penicillium, Erwinia and Pseudomonas on a majority of fruit and vegetables). Others are named after the causative microorganisms: Rhizopus rot (stone fruits, strawberries, papaya, tomato), Alternaria rot (pome and stone fruits, citrus, papaya, tomato), Diplodia rot (citrus, avocado), Fusarium rot (pineapple, banana), etc. Excellent descriptions of postharvest diseases are given in the ehow website: http://www.ehow.com/list_6772603_postharvest-diseases-fruits-vegetables.html.

Brown rot: This is a fungal disease that may cause serious damage to stone fruits during wet seasons. *Monilinia fructicola* is one of several species of Monilinia that cause brown rot. Prolonged wet weather during bloom may result in extensive blossom infection. Early infections appear as blossom blight or twig canker. Later infections appear as a rot of ripening fruit on the tree and in storage. Spring infections arise from mummified fruit of the previous season that remains attached to the tree or has fallen to the ground. Brown rot causes blossom blight, twig blight, twig canker, and fruit rot.

Rhizopus rot: This is a soft fungal rot of harvested or over-ripe stone fruits. Fungal growth and fruit decay are greatly retarded in cold storage but advance rapidly at warm temperatures, allowing loss of many fruits within the shipping container. The lesions are cinnamon or chocolate-colored. Rhizopus rot causes the skin to slip readily from the decaying flesh underneath. After harvest, Rhizopus rot can spread from fruit to fruit without injury at the point of contact.

Diplodia rot: Diplodia ear rot, caused by the fungus *Stenocarpella maydis*, is a common fungal disease in corn. *Diplodia ear* rot is easy to recognize with a grayish or grayish-brown mold on and between the kernels, and usually only on part of the ear. Occasionally, disease symptoms occur only at the tip-end or middle part of the ear. Diplodia stem-end rot is caused by the fungus *Diplodia natalensis*. It is a major decay organism of citrus fruit produced in warm and humid climates. Diplodia stem end rot is rarely observed on fruit attached to the tree, even when they are mature.

Erwinia rot: Bacterial wilt, caused by the bacterium *Erwinia tracheiphila*, is a destructive disease of plants in the cucumber family. Although bacterial wilt is most common on muskmelon and cucumber, it also can infect squash, pumpkins and a number of wild cucurbit plants.

Fusarium rot: Fusarium rot is one of the more common preharvest and postharvest diseases of cucurbit fruits. Symptoms of Fusarium fruit rot vary depending on the *Fusarium* species and the host. *Fusarium solani* causes foot, root, stem, and fruit rot of cucurbits. *Fusarium* fruit rot is the leading cause of cantaloupe fruit losses. Fusarium fruit rot of muskmelon is caused by the soil-borne fungus *Fusarium roseum*.

Anthracnose: This is caused by the fungus *Colletotrichum lagenarium*, which can be a destructive disease of muskmelons during warm, wet growing seasons. The disease also attacks watermelon, cucumber and gourds.

Alternaria rot: This is a fungal infection that begins while fruits or vegetables still are on the vine or tree. The spores come from decaying matter around the fruit or vegetable, and are transported directly to the fruit or vegetable by wind. Alternaria rot mostly affects carrots, broccoli, potatoes, peppers, apples, kiwis, pears and tomatoes. Symptoms of Alternaria rot are black or brown round lesions around breaks in the skin of fruit or vegetable. The rot eventually will continue to the interior of the fruit or vegetable, ruining their potential for harvesting completely. Alternaria fruit rot is a serious fungal disease of navel oranges and lemons that causes extensive damage. Symptoms of infection consist of dark spots on the fruit's skin and rotting on the inside of the fruit to the core. However, symptoms generally are not severe until postharvest, which makes control during the growing season difficult. Alternaria leaf spot, caused by the fungus *Alternaria cucumerina*, affects muskmelon and cucumber as well as other cucurbits.

Soft rot: Bacterial soft rots are caused by several types of bacteria, but most commonly by species of gram-negative bacteria, Erwinia (now Pectobacterium), and Pseudomonas. The bacteria mainly attacks the fleshy storage organs of their hosts (tubers, corms, bulbs, and rhizomes), but they also affect succulent buds, stems and petiole tissues. With the aid of special enzymes, the plant is turned into a liquid mush in order for the bacteria to consume the plant cell's nutrients. Unlike the soft rot caused by Rhizopus, bacterial rot produces an unpleasant smell.

Stem end rot: Stem-end rot in fruits and vegetables is caused by different microorganisms. Diplodia stem-end rot is a postharvest fungal disease. The fungus favors humid weather and rain for infection. While the disease infects the citrus fruit's stem during the growing season, symptoms do not appear until postharvest. Symptoms appear as brown, rotting streaks on both ends of the fruit, with rot occurring beneath the fruit's skin to the core.

Sour rot: Sour rot is particularly acute in citrus produce, and is caused by fungal spores, which thrive in the soil around a citrus tree and are carried by wind onto the fruit. Sour rot can enter fruits only through punctures or openings in the skin. Older fruits are most susceptible to sour rot. Symptoms are similar to blue mold and include watery and brown lesions.

Watery rot: Watery soft rot is caused by the fungus *Sclerotinia tri-*

foliorum. Leaves or petioles become flaccid and light brown in colour. Disease spreads through the plant to neighboring plants. Patches of clover can rot, causing a light brown slimy mass of decaying vegetation. Tufts of white fungus develop on affected tissue.

Blue mold: This is also referred to as Penicillium rot and it is a prevalent postharvest disease among fruits, most commonly apples. The symptoms of blue mold are soft, light brown areas that may be covered in white or light blue spores. Blue mold spreads quickly even in refrigerated containers, and a few infected fruits can spoil an entire harvest.

Grey mold: This is caused by *Botrytis cinerea*, a fungus that affects many plant species, although its most notable hosts may be wine grapes. The fungus gives rise to grey rot as a result of consistently wet or humid conditions, and typically results in the loss of the affected bunches. *Botrytis cinerea* affects many other plants. It is economically important on soft fruits such as strawberries, tomatoes and bulb crops. Unlike wine grapes, affected strawberries are not edible and must be discarded.

In recent years, it has been recognized that metabolites produced by fungi in foods can be *extremely toxic to humans and other animals.* The most notable example is the production by *Aspergillus flavus* infection of nuts and dried fruits of the mycotoxin aflatoxin, one of the most potent carcinogens known. Four major aflatoxins are: B1, B2, G1, and G2. Patulin, a genotoxin, occurs in apple products, is produced by Penicillium expansum and others. Patulin is heat stable and toxic to many biological systems, but its role in causing animal and human disease is unclear. Produced by *Penicillium viridicatum* and *Penicillium ochraceous*, ochratoxin A is a carcinogen, and also a blood, cardiovascular, liver, and kidney toxicant. It occurs in wine grapes and dried grapes.

Contamination of horticultural products by fecal coliforms has been increasing dramatically and has been reported to be responsible for several outbreaks linked to Salmonella, *Escherichia coli* and Listeria. These contaminations may also lead to interactions with other plant pathogens resulting in enhancement of their pathogenic activity.

DISEASE DEVELOPMENT

The common terms and terminology associated with postharvest and plant pathology are given in Table 13.1. An excellent summary of the disease development is provided by Kader (1985). Plant product dete-

TABLE 13.1. Common Terms and Terminology associated with Plant Pathology.

Name	Description
Pathogen	An entity, usually a microorganism that can incite the disease.
Parasite	An organism living on or in another living system (host) obtaining its food from the host.
Infection	Establishment of a parasite (pathogen) within a host plant.
Pathogenicity	The capability of a pathogen to cause disease
Symptom	The external or internal reactions or alterations of a plant as a result of a disease *Chlorosis:* Yellowing of normally green tissue due to chlorophyll destruction or failure of chlorophyll formation *Lesions:* Visible disease area, including, leaf spot, necrotic spot, mosaic
Sign	The pathogen or its parts or products seen on a host plant. *Examples:* Gray mold, Blue mold, Green mold, Powdery mildew on pome, stone fruits, citrus, onion
Disease	Malfunctioning of host cells and their tissues that result from their continued invasion by a pathogenic agent or environment factor and leads to development of decay symptoms.
Rots	The softening, discoloration and often disintegration of a succulent plant tissue as a result of fungal or bacterial infection.

rioration typically results from either bacterial or fungal infection. In order for the microorganisms to attack, they must first gain access to the internal tissues of the fruit or vegetable. They generally do so by one of the two modes of entry: (1) penetrate healthy tissue or (2) enter through wounds and bruises.

The healthy host plants are generally resistant to a vast majority of microorganisms but are susceptible only to a few species and in some cases only to specific strains of certain pathogen species. The protective tissues of healthy plant organs provide an excellent barrier against microbial attack and generally resist invasive pathogens. This defense mechanism is believed to be very strong in growing and healthy tissues, which can resist the spread of disease and suppress a pathogen's activity. Maturity also plays an important role in the defense of the plant organs against microbial attack. The defense, which is very strong in young tissues, continues to persist until the organ matures, after which the resistance begins to drop. Tissues are weakened as the mature fruit or vegetable goes through the stages of ripening and senescence. During these latter stages, the tissue becomes vulnerable to the attack of the same pathogens it resisted when young.

MECHANISM OF PATHOGEN ENTRY

In order to be successful on a host plant tissue, a pathogen must first gain access to the tissue and then overcome the defense responses. In other words, it must be able to attach itself to the plant tissue and then generate necessary resources so that it can penetrate and invade the tissue. During the entire process, it also should be able to overcome the defense response of the host tissue.

THE INFECTION PROCESS

When the pathogen lands and becomes attached to the plant structure, it can stay there in a dormant stage as a spore under unfavorable conditions. When favorable conditions are established (appropriate temperature, available moisture, food, etc.), the spore coat swells and produces a germ tube with the simultaneous secretion of enzymes (cutinase, pectinase) capable of hydrolyzing the epidermal layers. The spore tube develops and ruptures the softened skin tissue, eliciting a strong defense reaction from the plant tissue. The germinated spore may die if it cannot overcome this defense response. If it can overcome the defense, further development takes place and the pathogenic fungi will spread its mycelium and invade the plant tissue. More enzymes are secreted, which eventually kill the plant cell. The same series of reactions can take place when the spores land on wounds. If they can overcome the initial defense, further development takes place. Once well established in a primary host, the mycelia of some fungi can invade the healthy tissues of adjoining fruits and vegetables via stomates, lenticels, or sometimes directly via the epidermis, leading to “nesting” where several adjoining commodities in a package are destroyed by the fungus.

DEFENSE MECHANISM

Increased attention has been given in recent years to studying the exact nature of the defense mechanism and the functions of various components involved in it. It is believed that as soon as a pathogen lands on the tissue, there will be a recognition response to find out whether the invasion is natural and part of its own growth and development sequence (self-recognition) or the invasion is external (non-self invasion). In the event of non-self entry, the recognition process will continue to “see” whether the attack is species-specific or nonspecific, which may be important in the type of defense response. The message is then transferred to the nucleus eliciting the appropriate response. The defense response then follows to counteract the invasion. The defense response is termed *hypersensitivity* or *hypersensitive reaction*, which has been found to be associated with the synthesis of phenolic compounds with terpenoid and flavonoid structures. These low molecular compounds possess antimicrobial properties and are commonly called phytoalexins (or stress metabolites). Some of the phenolic compounds are naturally present in the tissue and also are formed in large quantities in response to a pathogen attack. They are formed from polyphenolic substrates by the action of the enzyme, polyphenol oxidase. Both the enzyme and the substrate exist naturally in the plant tissue; however, only when the tissue is stressed (ruptured, broken down or invaded) are the enzyme and substrate brought together. Other enzymes such as pectin methyl esterase (hydrolyzing the methyl esters in pectic acid) and polygalacturonase (hydrolyzing pectic acid to galacturonic acid) also are implicated. The oxidative reactions lead to brown pigments. These reactions in the ruptured cells are believed to activate neighboring cells and initiate the repair mechanism. The reactions have also been implicated in the wound-healing process in which the plant tissue tries to develop new periderms to patch up the bruises caused by external agents.

GROWTH BEHAVIOR OF BACTERIA AND FUNGI

Once settled on the host, microorganisms will start to grow, provided conditions are favourable, i.e., they have all the food and other requirements for their support. Microbial growth under favorable conditions generally is expected to follow a sigmoid curve (Figure 13.1) demonstrating a lag phase, a log phase and a stationary phase, which can be followed by a phase of death and population decline. In the lag phase, the microbe will try to establish and condition itself for growth in the medium. As it leaves the lag phase, it will continue to grow at a faster rate leading to an exponential (logarithmic) or accelerated growth phase. This represents the active stage. Then, while they still continue to grow in large numbers, part of the microbial population will begin to die, thereby moderating the growth. The net result is a decline in the rate of growth. Eventually, the multiplication and decline reach a state of equilibrium, which results in the stationary phase. When they cannot sustain this, the population begins to decline, which may happen due

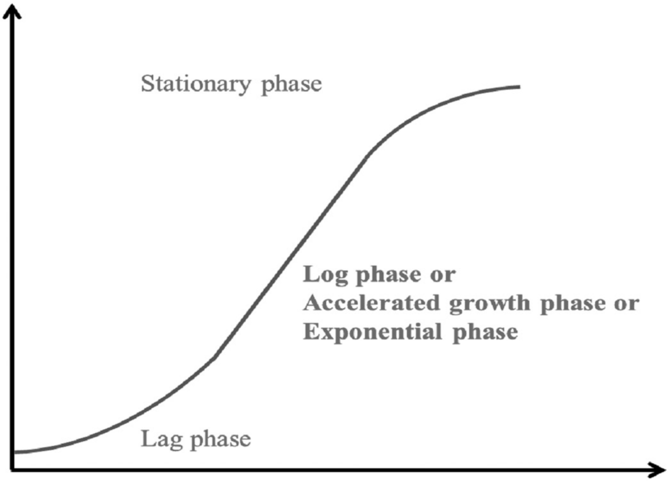

FIGURE 13.1. *The microbial sigmoid growth curve.*

to exhaustion of vital supplies or due to strong competition developing within the environment.

The microbial growth pattern is influenced by many factors. Favorable conditions shorten the lag phase and accelerate the log phase, while unfavourable conditions help to extend the lag phase and also reduce the rate of multiplication of cells in the log phase as shown in Figure 13.2. Factors that contribute to accelerated disease growth include higher temperature and higher relative humidity, delayed or slower rate

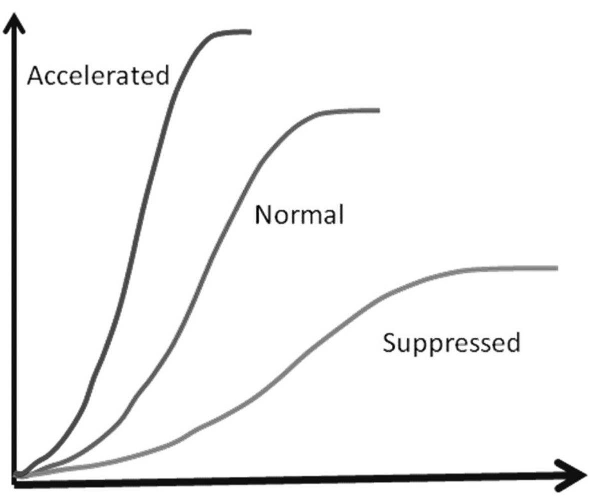

FIGURE 13.2. *The microbial sigmoid growth curve.*

References and Reading Materials

Bourne, M. 1977. *Post harvest food losses–the neglected dimension in increasing the world food supply.* Cornell International Agriculture Mimeograph 53. Published by New York State College of Agriculture and Life Sciences, Cornell University.

Brody, Aaron L. 2011. *Modified Atmosphere Packaging for Fresh-Cut Fruits and Vegetables.* New York: Wiley-Blackwell.

Chakraverty, Amalendu and R. Paul Singh. 2014. *Postharvest Technology and Food Process Engineering.* Boca Raton, FL: CRC Press.

Chakraverty, Amalendu, Arun S. Mujumdar and Hosahalli S. Ramaswamy. 2003. *Handbook of Postharvest Technology: Cereals, Fruits, Vegetables, Tea, and Spices.* Boca Raton, FL: CRC Press.

Charm, S. E. 1978. *The fundamentals of food engineering.* Westport, Conn.: AVI Pub. Co.

Codex Alimentarius. 1998. *General standard for contaminants and toxins in foods.* Annex IVB, Waningen, The Netherlands.

Dubuc, B. and C. Lahaie. 1987. *Nutritive Value of Foods.* Montreal: Société Brault-Lahaie.

Duckworth, R. B. 1966. *Fruit and vegetables.* Oxford: Pergamon Press.

European Commission. 2004. 69: European Commission (EC) Scientific Committee on Food (SCF) documents.

FAO. 1989. Prevention of post-harvest food losses fruits, vegetables and root crops a training manual. Rome: Food and Agricultural Organization of the United Nations (FAO UN).

Fellows, P. S. 1988. *Food Processing Technology: Principles and Practice.* Boca Raton, FL: CRC Press.

Fennema, O. R. 1985. *Food Chemistry.* CRC Press, Boca Raton.

Food Irradiation: International Atomic Energy Agency (IAEA) Books. http://www-pub.iaea.org/books/IAEABooks/Subject_Areas/0201/Food-irradiation.

Food Standards Agency (UK). 2002. Food Survey for Irradiated Foods—Herbs and Spices, Dietary Supplements and Prawns and Shrimps. *Food Survey Information Sheet Number 25/02*. June 2002.

Food Standards Agency (UK). 2004. Food Standards Agency Consumer Committee. *Food Irradiation Cons. Comm D030/04*.

IAEA (International Atomic Energy Agency). 1989. Acceptance, Control of and Trade in Irradiated Food. Conference Proceedings. Geneva, December 12–16, 1988, Jointly Organized by FAO, WHO, ITC-UNCTAD GATT, Vienna, Austria.

Institute of Food Science and Technology (IFST). 2006. The use of irradiation for food quality and safety. London: IFST.

Institute of Food Technologists (IFT). 2004. *Irradiation and Food Safety.* Vol. 58, No 11. www.ift.org

International Consultative Group on Food Irradiation. (1991) *Facts about Food Irradiation.* (set of 14 fact sheets covering all aspects of food irradiation issued as public information). ICGFI Fact Series 1-14. IAEA,Vienna.

Janisiewicz, W. J. and A. March. 1992. Control of storage rots on various pear cultivars with a saprophytic strain of *Pseudomonas syringae. Plant Disease* 76: 555–560.

Joint FAO/IAEA/WHO Study Group on High Dose Irradiation (1998). Weekly Epidemiological Record, Jan. 16, 1998.

Kader, A. A. 1985. Postharvest technology of horticultural crops. Regents of the University of California, Division of Agriculture and Natural Resources, Oakland, California 94608. Later version—3rd edition, 2002.

Kader, A. A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. *Food Technology* 40(5): 99–100 and 102–104.

Kester, J. J. and O. Fennema. 1989. An edible film of lipids and cellulose ethers: Barrier properties of moisture vapor transmission and structural evaluation. *J. Food Sci.,* 54 (1989), pp. 1383–1389.

Lieberman, M. (ed). 1981, 1983. Post-Harvest Physiology and Crop Preservation. NATO advanced study institutes series. Series A, Vol. 46. New York: Plenum Press.

McHenry, Robert (ed.). 1996. *Encyclopedia Britannica.* UK: Encyclopedia Britannica, Inc.

Meyer, L. H. 1960. *Food Chemistry.* New York: Reinhold Publishing Corporation.

Molins, R. A. 2001. *Food Irradiation: Principles and Applications.* New York: John Wiley & Sons.

Olaeta-Coscorroza, J. A. and P. Undurraga-Martinez. 1995. Estimacion del Indice de Madurez en Paltas. In: Harvest and Post-Harvest Technologies for

Fresh Fruits and Vegetables. *Proceedings of the International Conference, Guanajuato, Mexico, Feb. 20–24,* pp. 521–525.

Pantastico, E. B. 1975. *Postharvest physiology, handling, and utilization of tropical and subtropical fruits and vegetables.* Westport, CT: AVI Pub. Co.

Perry, R. H., D. W. Green and J. O. Maloney. 1984. *Perry's chemical engineer's handbook.* New York: McGraw-Hill.

Prosky, Dov and Maria Lodovica Gullino (eds.). 2009. *Post-harvest Pathology.* Springer.

Ramaswamy, H.S. and S. Ranganna. 1981. Thermal inactivation of peroxidase in relation to quality of frozen cauliflower (var. Indian Snowball). *Can. Inst. Food Sci. Technol. J.* 14(2):139.

Ramaswamy, H.S. and S. Ranganna. 1982. Maturity parameters for okra (*Hibiscus esculentus* (L) *Moench* var. *Pusa Sawani*). *Can. Inst. Food Sci. Technol. J.* 15(2):140.

Ramaswamy, H.S., S. Ranganna and V. S. Govindarajan. 1980. A nondestructive test for determination of optimum maturity of french (green) beans (*Phaseolus vulgaris*). *Journal of Food Quality* 3(1): 11–23.

Roberts, R. 1990. Postharvest biological control of gray mold of apple by *Cryptococcus laurentii*. *Phytopathology* 80(6): 526–530.

Robertson, G. L. 1992. *Food Packaging: Principles and Practice.* New York: Marcel Dekker Inc.

Ryall, A. L. and W. J. Lipton. 1979. *Handling, transportation and storage of fruit and vegetables. Vol 1.: Vegetables and melons.* 2nd edition. Westport, CT: AVI Publication Co.

Ryall, A. L. and W. T. Pentzer. 1979. *Handling, transportation and storage of fruit and vegetables. Vol 2.: Fruit and tree nuts.* 2nd edition Westport, Conn.: AVI Publication Co.

Salunkhe, D. K. and B. B. Desai. 1984. *Postharvest Biotechnology of Fruits.* Vol. 1 and 2. Boca Raton, Fla.: CRC Press.

Shewfelt, Robert L. and Bernhard Bruckner. 2000. *Fruit and Vegetable Quality: An Integrated View.* Boca Raton, FL: CRC Press.

Singh, R. P. and D. R. Heldman. 1993. *Introduction to food engineering.* Amsterdam: Academic Press.

Smock, R. M. 1979. Controlled atmosphere storage of fruits. *Hort. Review* 1:301.

Stevens, C., V. A. Khan, J. Y. Lu, C. L. Wilson, P. L. Pusey, M. K. Kabwe, E.C.K. Igwegbe, E. Chalutz, and S. Droby. 1998. The germicidal and hormetic effects of UV-C light on reducing brown rot disease and yeast microflora of peaches. *Crop Protection* 17(1): 75–84.

Swadling, I. R. and P. Jeffries. 1996. Isolation of microbial antagonists for biocontrol of grey mould disease of strawberries. *Biocontrol Science Technology*, 6 (1996), pp. 125–136.

Thompson, A. Keith. *Controlled atmosphere storage of fruits and vegetables.* 2010. Cabi; 2nd Revised edition.

Thompson, James F., C.F.H. Bishop and Patrick E. Brecht. Air Transport of Perishable Products. 2004, #21618. Regents of the University of California, Division of Agriculture and Natural Resources, Oakland, California 94608.

Thompson, James F., Gordon Mitchell, Tom R. Rumsey, Robert F. Kasmire, and Carlos H. Crisosto. Commercial Cooling of Fruits, Vegetables, and Flowers Rev. 2008. #21567. Regents of the University of California, Division of Agriculture and Natural Resources, Oakland, California 94608.

Thompson, Keith. 2003. Fruit and Vegetables: Harvesting, Handling and Storage, 2nd Edition. New York: Wiley-Blackwell.

US EPA. United States Environment Protection Agency. Food Irradiation. http://www.epa.gov/radiation/sources/food_irrad.html

USDA: United States Department of Agriculture. Food irradiation. http://fsrio.nal.usda.gov/food-processing-and-technology/food-irradiation.

Wikipedia: The Free Encyclopedia. FL: Wikimedia Foundation, Inc. http://www.wikipedia.org.

Willemot, C., M. Marcotte and L. Deschênes. 1996. Ionizing Radiation for Preservation of Fruits. In: *Processing Fruits: Science and Technology, Volume 1: Biology, Principles, and Applications.* L. S. Somogyi, H. S. Ramaswamy, Y. H. Hui (eds). Lancaster, PA: Technomic Publishing Co., Inc. Chap. 9, pp.221-260.

Wills, R. B. H. 1989. Postharvest: an introduction to the physiology and handling of fruit and Vegetables. Van Nostrand Reinhold, New York.

Wills, R. B. H., W. B. McGlasson, D. Graham, T. H. Lee, and E. G. Hall. 1989. Postharvest: an introduction to the physiology and handling of fruit and vegetables. Westport, CT: The AVI Publishing Co.

Wisniewski, M., C. Biles, and S. Droby. 1991. The use of the yeast *Pichia guilliermondii* as a biocontrol agent: Characterization of attachment to *Botrytis cinerea*. Biological Control of Postharvest Diseases of Fruits and Vegetables Wrkshp. Proc., Shepherdstown, W.Va., Sept. 1990. U.S. Dept. Agr.-Agr. Res. Serv. Publ. 92:160–176.

World Health Organisation. 1966. *The Technical Basis for Legislation on Irradiated Food.* WHO Technical Report Series, No. 316.

World Health Organisation. 1981. Report of the Working Party on Irradiation of Food. Joint Expert Committee on the Wholesomeness of Irradiated Food (JEFF). WHO Technical Report Series, No. 659.

World Health Organisation. 1994. Safety and nutritional adequacy of irradiated food. Geneva: WHO.

World Health Organisation. 1999. High-dose irradiation: Wholesomeness of food irradiated with doses above 10 kGy. Report of a FAO/IAEA/WHO Study Group. WHO Technical Report Series No. 890, Geneva.

Young, L., R. D. Reviere and A. B. Cole. 1988. Fresh red meats: a place to apply modified atmospheres. *Food Technology* 42 (9) pp. 65–69.

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