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Production Guide for Storage of Organic Fruits and Vegetables

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2012 Production Guide for Storage of Organic Fruits and Vegetables

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The guidelines in this bulletin reflect the authors' best effort to interpret a complex body of scientific research, and to translate this into practical management options. Following the guidance provided in this bulletin does not assure compliance with any applicable law, rule, regulation or standard, or the achievement of particular discharge levels from agricultural land.

Every effort has been made to provide correct, complete, and up-to-date pest management information for New York State at the time this publication was released for printing (May 2012). Changes in pesticide registrations, regulations, and guidelines occurring after publication are available in county Cornell Cooperative Extension offices or from the Pesticide Management Education Program web site (pmep.cce.cornell.edu). Trade names used herein are for convenience only. No endorsement of products is intended, nor is criticism of unnamed products implied.

This guide is not a substitute for pesticide labeling. Always read the product label before applying any pesticide.

Updates and additional information for this guide are available at www.nysipm.cornell.edu/organic_guide. Please submit comments or suggested changes for these guides to organicguides@gmail.com.

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INTRODUCTION

This guide is a companion to an extensive series on organic cultural and pest management practices available for fruits and vegetables grown in New York. While each guide has a section on storage, they focus largely on preharvest factors. Storage issues have tended to receive less attention to date because organic produce in New York has usually been marketed quickly. It is recognized that many positive steps to maintain quality can be made in the absence of optimal storage conditions, especially if the marketing plans do not require long term storage. However, as organic production increases, attention to proper storage techniques will become more important.

Postharvest chemicals are not commonly used for fruits and vegetables. Where such chemicals are used, for example, control of superficial scald in apples and pears, and sprouting control of potatoes, progress has been made to find organic alternatives, for example, sprout suppressors for potato. In general, development of postharvest technologies for organic fruits and vegetables has not kept pace with preharvest developments. Regardless of whether a product is grown under organic or conventional systems, however, best postharvest practices are required to maintain product quality, even for short term storage, and are common for both systems.

A primary requirement for organic fruits and vegetables however, is that identity must be maintained and contamination with postharvest chemicals avoided. In operations that are producing both organic and conventional crops (split operation), organic fruits and vegetables are identical in appearance to non-organic ones, and therefore bin tags, labels, scale tickets and lot-control documents must clearly identify the products as organic. Clear and consistent labeling prevents inadvertent misidentification or comingling by employees. Organic and non-organic fruits and vegetables can be stored in the same rooms provided that each type of product is clearly designated. However, it is critical to ensure that no volatilizing substances are present, for example, diphenylamine from apple fruit.

It is also important to note that it is necessary to use potable water with organic fruits and vegetables and it is critical to obtain the organic certifier's approval for use of cleaning and sanitizing materials (whether for direct food contact or food contact surfaces) prior to their use.

This guide presents issues related to storage of organic fruits and vegetables from three aspects.

1. An overview of the principles that underpin the responses of these products to harvest, handling and storage.

2. An overview of the pre- and post-harvest factors that affect storability of organic fruits and vegetables is presented. These factors are important since maturity at harvest, handling, storage atmospheres and temperatures, and exposure of products to contaminating volatiles can have a profound effect on their quality and storability.

3. Specific recommendations for the major fruits and vegetables grown in New York. However, because the limiting factor for many of these products is preharvest disease management, which is affected greatly by cultural practices in organic systems, this guide should be read in conjunction with the specific product guide http://www.nysipm.cornell.edu/organic_guide/default.asp.

The National Organic Standards available on the Northeast Organic Farming Association of New York web site: http://www.nofany.org/organic-certification/manuals, should be reviewed as appropriate.

This guide also draws extensively on information in USDA Handbook 66, available on line at http://www.ba.ars.usda.gov/hb66/ ; Food Safety Begins on the Farm by Rangarajan et al. <http://www.gaps.cornell.edu/educationalmaterials.html>; Postharvest Technology, edited by Kader (2002); Produce Handling and Direct Marketing, by Bartsch and Kline (1992), and other resource materials listed on page 60.

1. PRINCIPLES UNDERLYING STORABILITY FOR FRUITS AND VEGETABLES

1.1 The Living Fruit and Vegetable

All fruits and vegetables are living organs. They use oxygen and produce carbon dioxide during respiration, the process by which carbohydrate and other substrates, such as organic acids, proteins and fats, are metabolized. Respiration thereby provides the energy necessary for cells to maintain structure and for ripening processes such as color and flavor development. The substrates cannot be replenished once the fruit or vegetable has been removed from the plant, and therefore faster respiration rates will result in loss of food nutritional value, loss of saleable weight, poorer flavor, and thus reduced product quality.

Horticultural products can be regarded as "water inside pleasing packages" or "water with a mechanical structure"! Therefore, water loss or transpiration is a major factor affecting quality of fruits and vegetables. In addition to lower saleable weight, loss of water can affect quality in many ways, including wilting, shriveling, flaccidness, soft texture and loss of nutritional value. The rate of water loss, and the impact of this loss, will vary by product (Table 1.1). For example, maximum permissible losses can range from 3% for lettuce to 10% in onions. Products vary in potential for water loss by morphological differences such as cuticle thickness and composition and presence or absence of stomata and lenticels, which are structures that allow gases and moisture to move in or out of the plant. For some products these differences are affected by development stage. Also, within products, morphological differences exist among varieties. Water is another product of respiration. Water loss can be reduced by cooling products, maintaining a high relative humidity in the storage environment, controlling air circulation, and where permitted, the use of surface coatings or plastic film.

Because active metabolism continues after harvest, a number of desirable and undesirable changes occur in storage and shelf life conditions. These changes include development of pigments; for example, lycopene synthesis in tomato, anthocyanin synthesis in strawberry, and development of carotenoids (yellow and orange colors) in apricots and peaches. These compounds also contribute to the antioxidant status of these fruit and associated health benefits. Other changes include softening to edible ripeness, loss of chlorophyll (green color), and development of aroma and flavor characteristics. The same processes can be positive in some situations and negative in others; loss of chlorophyll is desirable in tomatoes, but undesirable in cucumbers and broccoli. Conversion of starch to sugars is desirable for apples, but undesirable for potatoes, while conversely, conversion of sugars to starch is desirable for potatoes but undesirable for peas and sweet corn.

Table 1.1 Transpiration losses* for fruits and vegetables stored at various relative humidities.

Crop	Storage Temperature °F	Percent Weight Loss Per Day 95% RH	90% RH	85% RH	80% RH
Apples	32	0.011	0.022	0.033	0.044
Brussels sprouts	32	1.61	3.22	4.84	6.42
Cabbage	32	0.058	0.116	0.175	0.233
Carrots	32	0.315	0.63	0.945	1.26
Celery	32	0.46	0.92	1.38	1.84
Table grapes	32	0.036	0.064	0.096	0.128
Leeks	32	0.21	0.42	0.62	0.82
Lettuce (avg.)	32	1.93	3.86	5.79	7.73
Parsnips	32	0.5	1	1.5	2
Peaches	32	0.15	0.3	0.45	0.6
Pears	32	0.018	0.036	0.054	0.072
Potatoes					
Uncured	45	0.07	0.141	0.211	0.282
Cured	45	0.021	0.042	0.063	0.084
Tomatoes	45	0.06	0.119	0.18	0.24

*% Weight loss per 24 hours. Calculated from ASHRAE data.

1.2 Fruit and Vegetable Varieties

Quality for most crops cannot be improved during storage, only maintained, and therefore any consideration of storage must take into account the importance of variety and preharvest factors. Growers usually select varieties on the basis of marketability (visual qualities specific to the market of choice) and yield, because these factors directly affect the bottom line. However, varieties can vary greatly in storage and shelf life. The absence of postharvest chemical treatments for organic growers makes it even more important that varieties are selected with these factors in mind. Variety selection should also include resistance to postharvest diseases and physiological disorders.

Differences in storage potential within specific products result from different physiologies and biochemistries of each variety. In some cases, genes which control processes such as low ethylene production, low respiration and slower softening are bred into the commodity. For example, the rin mutant has been bred widely into most commercial tomato varieties. Also, breeders have sometimes favored slower ripening selections with better resistance to the handling abuses during harvest, handling and transport that result in bruising and skin damage. While the result has sometimes been development of varieties that have tougher skins and sometimes reduced eating quality, qualities associated with extended shelf life can also provide assistance to organic growers.

1.3 Maturity at Harvest

Decisions associated with harvest maturity and the way the commodity is handled and stored can greatly affect storage life of even the most long-lived fruit or vegetable. Figure 1.1 shows the horticultural maturity in relation to the developmental stages of the plant – the physiological stage that horticultural products are harvested for commercial utilization. These stages range from sprouts and seedlings that are harvested when the plant is in very early stages of growth to seeds and dry beans that are harvested at the senescent stage of development.

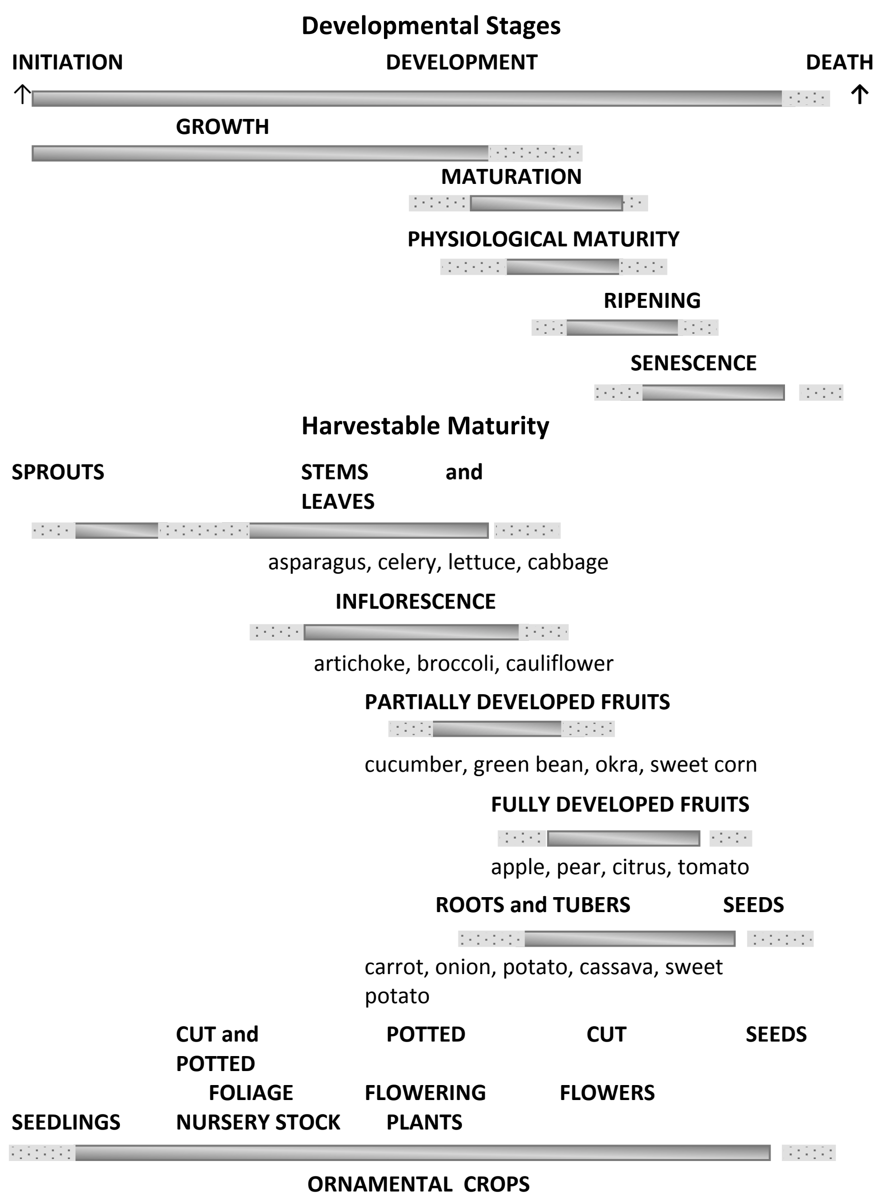

Figure 1.1. Horticultural maturity in relation to developmental stage of the plant (from Watada et al., 1984).

For fully developed fruits, two competing factors often exist. On one hand, characteristics of the products such as sweetness and flavor that are desired by the consumer increase as they mature and ripen. At the same time, the storability of the product continues to decrease (Figure 1.2). The outcome of these competing factors is that fruit destined for storage should be harvested earlier than one that is suitable for immediate consumption.

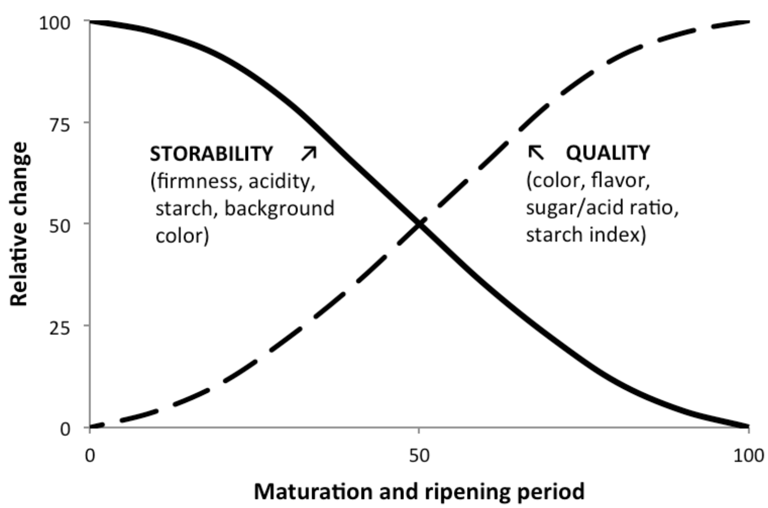

Figure 1.2. The relationship between the storability of a ripening horticultural product and the quality characteristics desired by the consumer. As a fruit ripens, the quality attributes such as color and flavor increase, but the suitable storage period declines.

Examples include an apple that is picked at full ripeness, with low starch content, high soluble solids and is highly aromatic but will have a short storage life, while one destined for long term storage must be harvested much earlier when the fruit has high starch content and less developed aroma volatiles. Strawberries that are fully red and fully flavored will have a much shorter storage life than when harvested at the white tip stage of maturity. However, the fruit harvested at the white tip stage will have less intense flavor than the later picked one.

1.4 Preharvest Management Affects Storage Quality

It is widely recognized that the storability of fruits and vegetables is affected by the mineral composition at harvest. High calcium levels are usually associated with good storability, and conversely, low calcium with shorter storage life and susceptibility to storage disorders and pathogen infection. In tomato, for example, a disorder known as blossom end rot is associated with low calcium concentrations in the fruit. Nitrogen is often applied to increase yield, but usually negatively affects postharvest quality. Product size is larger, respiration rates are higher, and calcium levels are lower because of increased competition for the mineral. Another example is the onion, where high nitrogen improves yield but increases storage rots. High nitrogen causes the onions to develop thick necks that are prone to wounding when topped and therefore greater decay development. High levels of potassium, magnesium and boron, and low levels of phosphorus, can also lower storability. Therefore, recommendations for appropriate nutrition of each horticultural product should be followed.

Good organic pest and pathogen management in the field or orchard must also be applied to minimize disease potential of the produce after harvest. Examples include powdery mildew in winter squash and decay in strawberries, but see the respective product guides for details.

1.5 Respiration

Respiration also involves the production of water and the release of heat (energy). This heat results in higher temperatures around the commodity if it is not removed by refrigeration or ventilation. Because carbon dioxide is also a product of respiration, this gas can build up around the product if ventilation is inadequate, and conversely oxygen can be depleted, resulting in fermentation. If a product is kept in a sealed plastic bag for example, cell death can occur as a result of inadequate oxygen and excessive carbon dioxide. Reduced oxygen and elevated carbon dioxide in the storage environment can be used purposefully however, to increase the storage life of certain fruits and vegetables, as described later in this guide.

Different fruit and vegetable types have a wide range of respiration rates, from very low to very high (Table 1.2; Figure 1.3). As a general rule, the rate of deterioration of the many different types of fruits and vegetables after harvest is associated with their respective respiration rates (Table 1.3).

Table 1.2 Horticultural commodities classified according to their respiration rates.

Class	Range at 41°F (5°C) ($mg\ CO_2/kg{\cdot}hr$)*	Horticultural Products
Very low	Less than 5	Dates, dried fruits and vegetables, nuts
Low	5-10	Apple, beet, celery, cranberry, garlic, grape, honeydew melon, onion, papaya, potato (mature), sweet potato, watermelon
Moderate	10-20	Apricot, banana, blueberry, cabbage, cantaloupe, carrot (topped), celeriac, cherry, cucumber, fig, gooseberry, lettuce (head), nectarine, olive, peach, pear, pepper, plum, potato (immature), radish (topped), summer squash, tomato
High	20-40	Blackberry, carrot (with tops), cauliflower, leeks, lettuce (leaf), lima bean, radish (with tops), raspberry, strawberry
Very high	40-60	Artichoke, bean sprouts, broccoli, Brussels sprouts, endive, green onions, kale, okra, snap bean, watercress
Extremely high	More than 60	Asparagus, mushroom, parsley, peas, spinach, sweet corn

*Vital heat (Btu/Ton·24 hrs) = mg CO_2/kg·hr x 220.

Modified from Kader (2002).

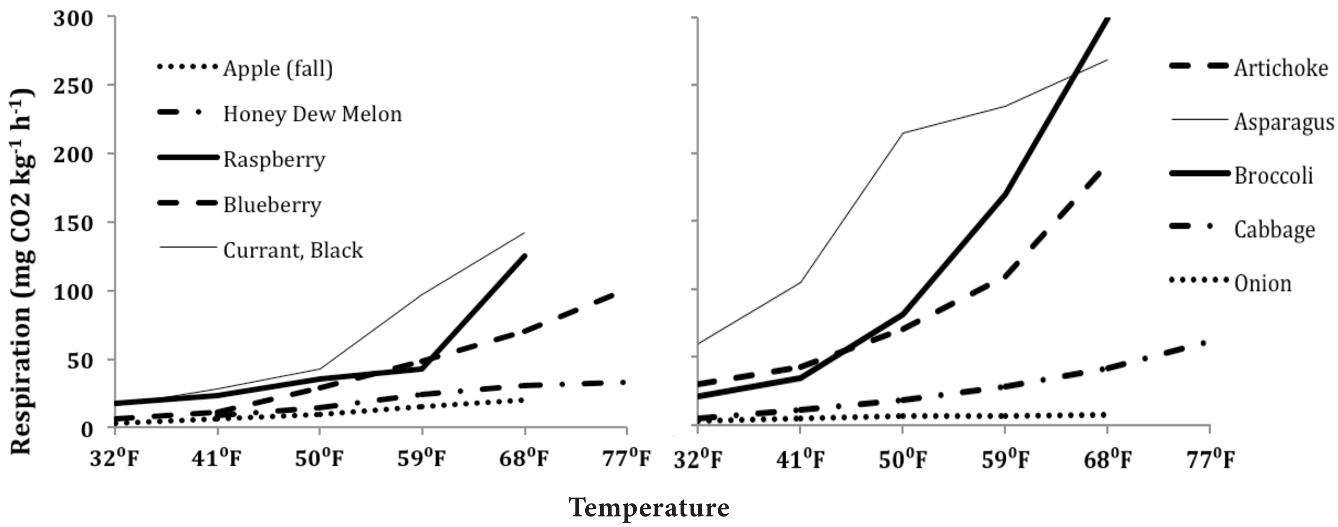

Figure 1.3. Respiration rates of selected fruits and vegetables.

Table 1.3 Fresh horticultural crops classified according to relative perishability and potential storage life in air at near-optimal temperature and RH.

Relative perishability	Potential storage life (weeks)	Commodities
Very low	>16	Tree nuts, dried fruits and vegetables
Low	8-16	Apple and pear (some cultivars), potato (mature), dry onion, garlic, pumpkin, winter squash, sweet potato, taro; bulbs and other propagules of ornamental plants
Moderate	4-8	Apple and pear (some cultivars), grape (SO_2-treated), pummelo; table beet, carrot, radish, potato (immature)
High	2-4	Grape (without SO_2 treatment), melons (honeydew, crenshaw, Persian), nectarine, papaya, peach, pepino, plum; artichoke, green beans, Brussels sprouts, cabbage, celery, eggplant, head lettuce, okra, pepper, summer squash, tomato (partially ripe)
Very High	<2	Apricot, blackberry, blueberry, cherry, fig, raspberry, strawberry; asparagus, bean sprouts, broccoli, cauliflower, cantaloupe, green onion, leaf lettuce, mushroom, pea, spinach, sweet corn, tomato (ripe); most cut flowers and foliage; fresh-cut (minimally processed) fruits and vegetables

A summary of the respiration rates for specific fruits and vegetables is shown in Appendix 1. While the range of average respiration rates for each product type can be affected by seasonal growing conditions, variety and postharvest management, the storage life of products is broadly consistent – products with very high respiration rates such as asparagus, mushroom, parsley, peas, spinach and sweet corn deteriorate much more rapidly than those such as apple, beet, celery, garlic, grape, honeydew melon and onion, with low respiration rates.

1.6 Ethylene

A further factor that must be considered in storage of fruits and vegetables is ethylene, a naturally occurring plant growth regulator that affects many aspects of growth and development of plants. It is a gas that can exert its effects at very low concentrations, from parts per billion (ppb) to parts per million (ppm). Ethylene is naturally occurring in plant tissues, and is a critical part of normal ripening for many fruits. However, increased ethylene production can occur as a result of disease and decay, exposure to chilling temperatures, and wounding. In addition, ethylene is produced by internal combustion engines, smoke and other sources of pollution. Other gases such as propylene, carbon dioxide and acetylene can exert similar effects to those of ethylene, but only at much higher concentrations. Exposure of fruits and vegetables to ethylene can stimulate respiration.

1.6.1 Two types of ethylene-producing fruit

Fruit, including vegetable fruit, can be divided into two categories, those that do not produce ethylene as part of ripening and senescence and those where ethylene production is critical for normal ripening to occur. The two types of fruit have different respiration patterns during maturation and ripening (Figure 1.4): in the non-climacteric type which does not produce appreciable ethylene, respiration rates gradually decrease over time, while in climacteric fruit a surge in respiration is associated with the onset of ethylene production.

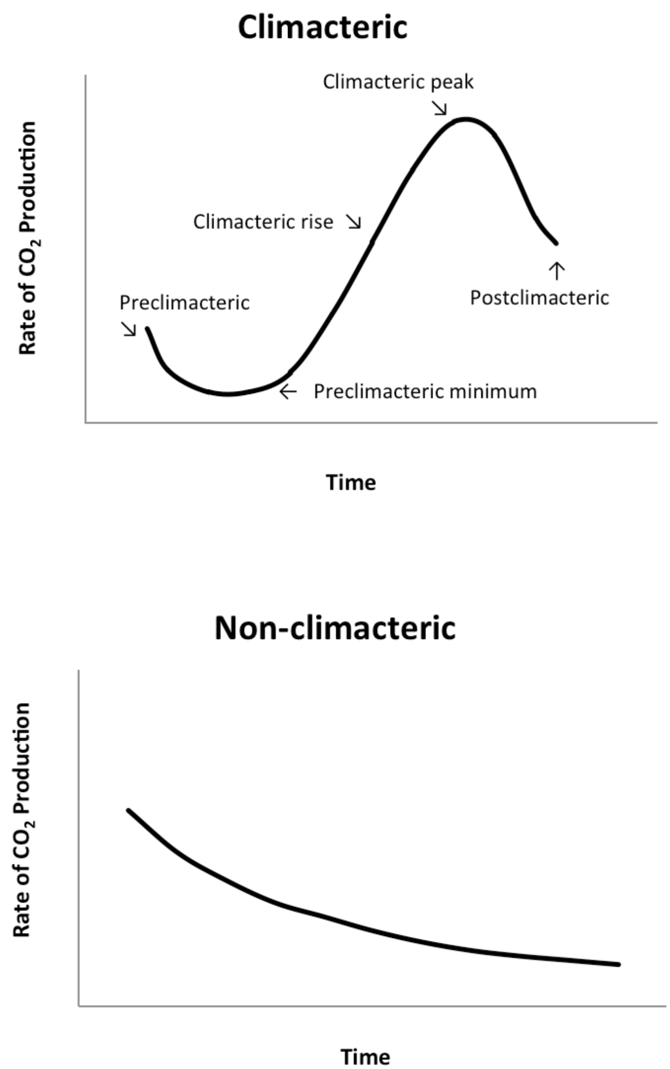

Figure 1.4. Phases in respiration in a ripening climacteric and non-climacteric fruit. Note, in a climacteric fruit, ethylene production is typically very low prior to the pre-climacteric minimum and increases rapidly as the respiratory climacteric occurs.

Table 1.4 provides examples of climacteric and non-climacteric fruits. Many popular fruits are listed in the climacteric category, including apples, peaches, plums and tomatoes. Ensuring low ethylene levels around these fruit can help delay the start of ripening but normal ripening cannot occur without the presence of ethylene. For example, without ethylene tomatoes will not develop red color or soften. While the non-climacteric fruits do not need increased ethylene production in order to ripen, they can be affected, usually negatively, by exposure to exogenous (outside sources) ethylene from ethylene producing fruits and vegetables, damaged commodities and contamination. The rates of ripening and senescence among different fruits and vegetables are not a factor of their climacteric status. Climacteric fruit can be relatively short and long lived, e.g. peach and apple, respectively, as can non-climacteric fruit, e.g. strawberries and lemons, respectively. Therefore, while fruits and vegetables vary greatly in rates of ethylene production (Table 1.5), no clear association with these rates and storage life exists.

Table 1.4 Fruits (including vegetable fruits) classified according to respiratory behavior during ripening.

Climacteric	Non-climacteric
Apple	Blackberry
Apricot	Cherry
Blueberry	Cranberry
Muskmelon	Cucumber
Nectarine	Eggplant
Peach	Grape
Pear	Pea
Plum	Pepper
Tomato	Raspberry
	Strawberry
	Summer Squash
	Watermelon

Modified from Kader (2002).

Table 1.5 Fruits and vegetables classified according to ethylene production rates.

Class	Production rate at 68°F (20°C) (µl C_2H_4/kg·hr)	Commodities
Very low	Less than 0.1	Artichoke, asparagus, cauliflower, cherry, citrus fruits, grape, jujube, strawberry, pomegranate, leafy vegetables, root vegetables, potato, most cut flowers
Low	0.1-1.0	Blackberry, blueberry, casaba melon, cranberry, cucumber, eggplant, okra, olive, pepper (sweet and chili), persimmon, pineapple, pumpkin, raspberry, tamarillo, watermelon
Moderate	1.0-10.0	Banana, fig, guava, honeydew melon, lychee, mango, plantain, tomato
High	10.0-100.0	Apple, apricot, avocado, cantaloupe, feijoa, kiwifruit (ripe), nectarine, papaya, peach, pear, plum
Very high	More than 100.0	Cherimoya, mammee apple, passion fruit, sapote

Modified from Kader (2002).

1.6.2 Beneficial and detrimental effects of ethylene

Exposure to ethylene can be beneficial or detrimental, not only depending on the specific fruit or vegetable, but also when the exposure occurs. Responses of commodities to ethylene can be affected by species, variety, cultural practices, prior exposure to hormones, and levels of past and current stresses. There is no set standard for ethylene concentrations at which detrimental effects will occur and there are important differences in ethylene sensitivity among fruit and vegetable types (Table 1.6). Climacteric fruit such as apples and pears have high ethylene production and high sensitivity, while other products (e.g. broccoli, cabbage, carrots and strawberries) can have low rates of ethylene production but are highly sensitive to ethylene. Most non-climacteric fruit, such as cherry, grape, berries and pepper, have low ethylene production and low sensitivity to ethylene.

Detrimental effects of ethylene are often of more concern to growers and marketers. Exposure of ethylene to unripe climacteric fruit can cause earlier than desirable ripening, resulting in overly soft and mealy fruit. More commonly in the marketplace, ethylene exposure can result in undesirable yellowing of green vegetables such as cucumbers, parsley and broccoli, and many other negative effects (Table 1.7). Exposure of vegetables and non-climacteric fruits also increases their respiration rates, meaning that the carbohydrate reserves are used more rapidly, as well as increasing water loss. Typically, exposure occurs from mixing ethylene producing and ethylene sensitive commodities in the same storage room. Although ornamental commodities are not formally part of this guide, exposure to ethylene is often exhibited as loss of flowers and leaves from the plant as ethylene increases abscission.

Table 1.6 Ethylene production and sensitivity of several commodities.

Commodity	Ethylene production	Ethylene sensitivity
Climacteric Fruit		
Apple, Kiwifruit, Pear, Cherimoya	high	high (0.03 - 0.1 ppm)
Avocado, Cantaloupe melon, Passion fruit	high	medium (> 0.4 ppm)
Apricot, Banana, Mango	medium	high (0.03 - 0.1 ppm)
Nectarine, Papaya, Peach, Plum, Tomato	medium	medium (> 0.4 ppm)
Vegetables and non-climacteric fruit		
Broccoli, Brussels sprouts, Cabbage, Carrot,	low	high (0.01 - 0.02 ppm)
Cauliflower, Cucumber, Lettuce, Persimmon	low	high (0.01 - 0.02 ppm)
Potato, Spinach, Strawberry	low	high (0.01 - 0.02 ppm)
Asparagus, Bean, Celery, Citrus, Eggplant	low	medium (0.04 - 0.2 ppm)
Artichoke, Berries, Cherry, Grape, Pineapple	low	low (> 0.2 ppm)
Pepper	low	low (> 0.2 ppm)

Modified from Martinez-Romero et. al. (2007).

Ethylene can be used for pre-harvest treatment of apples and tomatoes to stimulate red color development. However, because ethylene is a gas, it is released from a liquid chemical formulation, ethephon (2-chloroethane phosphonic acid), which is not permitted for use by organic growers. After harvest, ethylene is applied commercially to accelerate chlorophyll loss and ensure even ripening of bananas. Increasing efforts are being made to develop 'ready to eat' protocols for avocadoes and pears, by treating them with ethylene at the time of packing in California and Washington. Consumers can also use ethylene producing fruit such as apples to ripen firm kiwifruit by enclosing both fruits in a paper bag.

Table 1.7 Summary of the detrimental effects of ethylene related to quality.		
Ethylene effect	**Symptom or affected organ**	**Commodity**
Physiological disorders	Chilling injury	Persimmon, Avocado
	Russet spotting	Lettuce
	Superficial scald	Pear, Apple
	Internal browning	Pear, Peach
Abscission	Bunch	Cherry tomato
	Stalk	Muskmelon
	Calyx	Persimmon
Bitterness	Isocoumarin	Carrot, Lettuce
Toughness	Lignification	Asparagus
Off-flavors	Volatiles	Banana
Sprouting	Tubercle, Bulb	Potato, Onion
Color	Yellowing	Broccoli, parsley, cucumber
	Stem browning	Sweet cherry
Discoloration	Mesocarp	Avocado
Softening	Firmness	Avocado, Mango, Apple, Strawberry, Kiwifruit, Melon

Modified from Martinez-Romero et. al. (2007).

The same response to ethylene, though identical on different commodities, can be beneficial or detrimental. Acceleration of chlorophyll loss, promotion of ripening, and stimulation of phenolics production can be beneficial or detrimental depending on the product (Table 1.8).

Table 1.8 Examples of how the same ethylene response can be beneficial in one system and detrimental in another.		
Ethylene response	**Example of benefit**	**Example of detriment**
Accelerates chlorophyll loss	Degreening of citrus	Yellowing of green vegetables
Promotes ripening	Ripening of climacteric fruit	Overly soft and mealy fruit
Stimulates phenylpropanoid metabolism	Defense against pathogens	Browning and bitter taste

Modified from Saltveit (1999).

1.7 Storage Temperature

The most fundamental postharvest tool available to the fruit and vegetable grower is temperature control. It is critical to decrease the temperature of fruits and vegetables as quickly as possible after harvest to slow down their metabolism, unless curing is part of postharvest management.

Curing is used for onions to dry the neck and outer scales, and for potatoes to develop wound periderm over damaged surfaces. Curing is usually carried out in the field or in curing rooms.

Benefits of lower temperatures include reduced respiration rates, reduced water loss, reduced sensitivity to ethylene, and decreased susceptibility of commodities to decay. In general, the lower the storage temperature, the longer the storage life of a given commodity, as long as the freezing temperature for the product is not reached. However, the lowest safe storage temperature is not the same for all commodities as many of them are sensitive to low temperatures and develop chilling injuries such as irregular ripening, failure to ripen, pits on the skin surface and increased susceptibility to decay. Therefore the optimum temperature for storage is higher for chilling sensitive than for non-chilling products.

Figure 1.5 illustrates the differences between non-chilling-sensitive and chilling-sensitive fruits and vegetables. In non-chilling sensitive products, the longest storage life is associated with the lowest storage temperature. However, for chilling sensitive products, the storage life increases with decreasing storage temperature to reach a maximum from 45 to 64°F depending on the product. At lower temperatures, the storage life decreases because of susceptibility to chilling injuries.

Because sensitivity to chilling injury is commonly associated with produce of sub-tropical and tropical origin, many of the fruits and vegetables of interest to New York growers are non-chilling sensitive (Table 1.9). Yet, there are several important fruits and vegetables listed in Table 1.9 that are chilling-sensitive. The time of exposure to low temperatures is also important: it is common for tomatoes to be kept in the refrigerator despite their chilling sensitivity, but unless the time period is extended, chilling injury is not detected. Also, storage recommendations can be complex, e.g. fruit such as peach develop chilling injuries at a slower rate at 32°F than at temperatures between 40 and 50°F, and therefore the lower storage temperature is recommended.

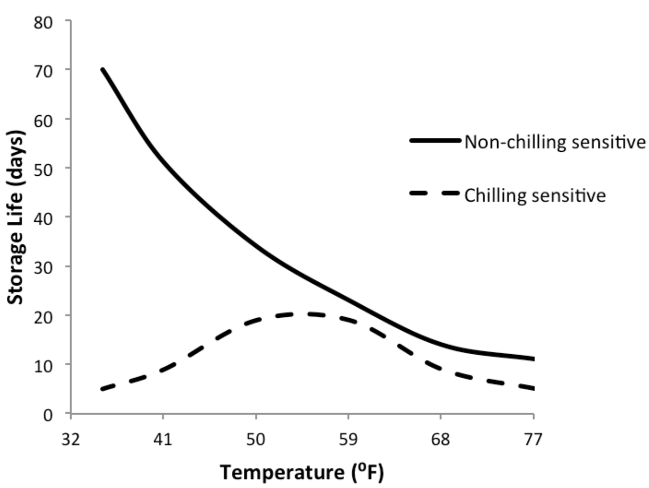

Figure 1.5. The shelf life of chilling and non-chilling sensitive produce.

Table 1.9 Fruits and vegetables classified according to sensitivity to chilling injury.		
Non-chilling Sensitive Commodities		**Chilling Sensitive Commodities**
Apples *	Garlic	Bean, snap
Apricots	Grapes	Cranberry
Artichokes	Lettuce	Cucumbers
Asparagus	Mushrooms	Eggplant
Beans, Lima	Nectarines*	Muskmelons
Beets	Onions	Peppers
Blackberries	Parsley	Potatoes
Blueberries	Parsnips	Pumpkins
Broccoli	Peaches*	Squash
Brussels sprouts	Pears	Sweet potatoes
Cabbage	Peas	Tomatoes
Carrots	Plums*	Watermelons
Cauliflower	Prunes	Yams
Celery	Radishes	
Corn, sweet	Raspberries	
Cherries	Spinach	
Currants	Strawberries	
Endive	Turnips	

*Some cultivars are chilling sensitive.

2. HARVEST AND STORAGE MANAGEMENT

The primary objective is to maintain quality by:

1. Reducing metabolic rates that result in undesirable changes in color, composition, texture, flavor and nutritional status, and undesirable growth such as sprouting or rooting.

2. Reducing water loss that results in loss of saleable weight, wilting, shriveling, softening, and loss of crispness.

3. Minimizing bruising, friction damage and other mechanical injuries.

4. Reducing spoilage caused by decay, especially of damaged or wounded tissues.

5. Prevent development of freezing injuries or physiological disorders such as chilling injury or senescent disorders.

These guidelines can be met by understanding that maintaining quality from the time of harvest to the consumer's plate is an integrated process of handling, storage, transport and retail display that recognizes the biology of each fruit and vegetable type. Products must be harvested at optimum maturity or quality, handled carefully to avoid mechanical injury, cooled quickly to remove field heat, stored in modified atmospheres if appropriate for the product, and maintained at acceptable temperatures during storage and marketing. Contaminating chemicals must be avoided, as well as attention to avoiding injurious effects of naturally occurring chemicals such as ethylene. The organic grower must also rely on optimal management in the field to ensure that decay potential is as low as possible at the time of harvest. All of these activities must be carried out with attention to food safety; good sanitation practices must be maintained during harvest and all subsequent handling steps.

2.1 Harvest and handling

Critical harvest and handling factors for organic fruits and vegetables involve two overlapping considerations; the first includes maintaining product quality, while the second is ensuring food safety.

2.1.1 Handling considerations

All fruits and vegetables should be handled carefully to avoid bruises, skinning, damage due to impact and compression injury, and friction damage. Workers must be trained to harvest produce without causing damage. Injuries can occur at the time of harvest if care is not taken. These injuries can include finger bruises, inappropriate removal of plant parts, e.g. stems from the fruit, and impact bruising if produce is dropped into picking containers. Finger bruising of produce, e.g. strawberry, may not show up for several hours. Even short drops can damage fruits and vegetables.

Containers should be clean and should be used only for organically grown produce to avoid any possibility of chemical contamination. High pressure wash, rinse, and sanitize all containers prior to use. Clean containers should be covered to avoid contamination after cleaning. Containers should not have rough surfaces that can damage produce. Damaged or spoiled produce should be left in the field to reduce contamination by decay organisms. Containers must be appropriate for the product; shallow for soft fruit, for example, to avoid compression damage. Over-filling of containers can further damage product, and increase damage if containers are stacked.

Most fruits and vegetables are damaged by heat and sunlight after harvest, and storage potential of short lived and highly perishable products can be greatly reduced. When possible, highly perishable fruits and vegetables should be harvested during the morning when product temperatures are lowest. Harvesting early in the day can be especially important if refrigeration capacity is limited. One exception is watermelon where it is recommended that harvest is later in the day to reduce chances of cracking (section 3.56).

Regardless, produce should be moved out of the field as efficiently as possible, with frequent trips to avoid rapid warming of produce on the top layers of containers and bins. If produce cannot be taken directly to a packing shed, providing shade will prevent excessive warming. A number of approaches can be taken including:

1. Providing shade in the field by utilizing shady areas under plants/trees but remember that shady areas change during the day. Covers on containers may be necessary however, if there is a risk of bird droppings from the shade trees.

2. Using a light colored tarp or similar covering to protect produce against direct sunlight. A gap of at least 4 inches should be left between the tarp and produce to allow air circulation that will prevent solar and respiratory heat build-up.

3. For short trips, use covered trucks to transport produce from the field.

Fruits and vegetables should be transported carefully to avoid damage. In addition to impact damage that can occur by allowing fruits and vegetables to bounce around, friction damage can occur as a result of products moving against each other and against container walls. Strategies to making the transport smoother include grading rough farm roads (usually before the season) and reducing tire pressure on transport vehicles.

Cooling methods at the packing shed are discussed in section 2.3.

All produce should be washed before consumption, but unless the produce is soiled, washing should be left to the consumer. Washing produce in bulk may spread decay-causing organisms and reduce shelf life. Use of approved chemicals in the wash water is highlighted in section 2.2.

2.1.2 Food safety

All freshly harvested produce has naturally occurring bacteria, yeast and mold cells. These "contaminants" are associated with dust, insects, soil, rainfall, and sometimes humans. Food safety scares have been associated with contamination of produce by animals and by human contact. Our focus in this guide is on storage, and production-related issues are addressed by resources such as Food Safety Begins on the Farm, <http://www.gaps.cornell.edu/educationalmaterials.html>, which outlines good agricultural practices (GAP).

Planning for food safety should be included in any crop management plan. A GAP program that includes harvest, handling and storage procedures should be developed and formalized for each crop.

Food safety begins with worker hygiene as harmful microbes can contaminate fruits and vegetables. Guidelines to minimize risks during handling are outlined in the resource cited above, but in brief:

Convenient, well maintained and serviced toilet facilities should be provided in the packinghouse and in the field. There should be one unit for every 20 employees according to OSHA rules. Rest room facilities must be within 1/4 mile of the fields where workers are located. This can include a portable unit or access to transportation to a house or barn to use facilities there as one might find on smaller farms.

1. Liquid soap in dispensers, potable water and single use paper towels should be used for hand washing.

2. Workers should be educated about the importance of restroom use and proper hand washing.

3. Monitor and enforce the proper use of these facilities.

4. Do not allow sick workers to directly handle produce.

5. Use of disposable gloves should be encouraged for workers on packing lines.

6. Clean gloves, hairnets, aprons and bandages should be provided as needed.

Similarly, where an operation has a packinghouse, it should be kept clean and sanitary. Where appropriate, GAP protocols should be followed:

1. Ensure that contaminated water or livestock waste cannot enter the packinghouse via run-off or drift.

2. Wash, rinse, and sanitize packing areas and floors at the end of each day.

3. Exclude birds and animals, both domesticated and wild (i.e. rodents).

4. Pests may be controlled mechanically or physically, using traps, light and sound, or lures and repellents with non-synthetic or synthetic substances consistent with the National list.

5. Eating and smoking should not be allowed in the packing area.

6. Field clothes, especially shoes and boots, should not be worn into the packinghouse.

7. Washing operations and packing lines should be kept clean and sanitary, using organically allowable disinfectants, frequent water changes and daily attention to sanitizing all food contact surfaces at the end of each working day.

2.2 Approved Chemicals for Use in Organic Postharvest Systems

Sourced from <http://www.extension.org/pages/18355/approved-chemicals-for-use-in-organic-postharvest-systems>.

Chemicals used in organic postharvest operations must comply with the National Organic Program (NOP) rules. Most synthetic inputs are prohibited; those that are allowed may be used only with restrictions.

2.2.1 Sanitation and Disinfection

Adequate sanitation and disinfection during postharvest processes are vital components of a postharvest management plan. As food safety regulations become increasingly important to the sale and marketing of crops, the establishment of proper measures to ensure the elimination of food-borne pathogens is essential. In addition to mitigating potential food-borne illness, proper sanitation during postharvest handling can also minimize the occurrence of postharvest disease and decay. As is the case during the production stage of the crop, all products used during the postharvest period must adhere to NOP regulations.

2.2.2 Chlorine

Chlorine is a very common disinfectant that can be added to transport flumes or to produce cooling or wash water. Liquid sodium hypochlorite is typically used, with the pH of the water maintained between 6.5 and 7.5 to optimize effectiveness (Suslow, 2000). The NOP approves chlorine's use in postharvest management as an algicide, disinfectant, and sanitizer. These regulations restrict the residual chlorine levels in the water at the discharge or effluent point to the maximum residual disinfectant limit under the Safe Drinking Water Act, currently established by the Environmental Protection Agency (EPA) at 4ppm for chlorine. However, the levels of chlorine used to prepare water to be used for sanitation of tools, equipment, product, or food contact surfaces may be higher than 4ppm and should be in high enough concentration to control microbial contaminants. Thus, the concentration of chlorine at the beginning of a disinfection treatment is generally greater than 4ppm, so care must be taken to ensure that the effluent water does not exceed this limit.

Chlorine can exist in water in various forms. Free chlorine may be found as hypochlorous acid and hypochlorite ion, with the hypochlorous acid form providing the strongest antimicrobial properties. At a pH of 6.5, 95% of the chlorine is in the hypochlorous form; maintaining the water pH at this range provides the greatest disinfecting power. Chlorine may become bound to soil, debris, and other organic matter in the water; once chlorine becomes combined with these materials, it is no longer available for disinfection. In order to maximize the effectiveness of any chlorine treatment, it is beneficial to perform additional cleaning steps to produce arriving from the field. This may include a vigorous prewash with brushes or sponges to remove excess debris from the produce, or a clear water rinse to remove soil and other debris, prior to using the sanitizer solution. Also, cleaning out dump tanks and residue screens will help minimize the presence of soil and debris and maximize chlorine's effectiveness.

2.2.3 Ozone

Ozone is becoming an increasingly popular alternative to chlorine for water disinfection. Ozone is considered GRAS (Generally Regarded As Safe) for produce and equipment disinfection. Exposure limits for worker safety apply. Ozone, through its action as an oxidizer, provides comparable disinfection power to chlorine, rapidly attacks bacterial cell walls and thick-walled spores of plant pathogens. Ozone treatments have the benefit of forming fewer undesirable by-products than chlorine treatments, such as trihalomethane, chloroform, and other dangerous compounds. Ozone is faster acting than chlorine and allows for adequate disinfection with short-term contact to the produce. The use of ozone does require a greater capital investment and ongoing operating costs than the use of chlorine, however. Because of the instability of the compound (20 min in clean water), ozone must be generated on-site, requiring investment in ozone-generating equipment. These generators create ozone through the action of a high energy source (UV light or corona discharge), splitting oxygen molecules that then recombine to form ozone. Small-scale ozone generating units are available for a few thousand dollars.

2.2.4 Peroxyacetic acid

Peroxyacetic acid (PAA, also called peracetic acid), in combination with hydrogen peroxide, is another popular alternative to chlorine that is allowed in organic production. Like chlorine, PAA performs well in water dump tanks and water flumes. However, like ozone, the treatments result in safer byproducts than chlorine treatments. The disinfection performance of PAA is comparable to chlorine and ozone. To maximize effectiveness, PAA should be maintained at a level of 80 ppm in the wash water. A post-treatment wash with clean water is required after a disinfection treatment with PAA.

2.2.5 Other Cleaners and Sanitizers Allowed with Restrictions (Suslow, 2000)

Please note that a clear water rinse is required after the use of most detergents. Each product needs to be evaluated by the certifier on a case by case basis.

- **Acetic acid.** Allowed as a cleanser or sanitizer. Vinegar used as an ingredient must be from an organic source.

- **Alcohol, Ethyl.** Allowed as a disinfectant. To be used as an ingredient, the alcohol must be from an organic source.

- **Alcohol, Isopropyl.** May be used as a disinfectant under restricted conditions.

- **Ammonium sanitizers.** Quaternary ammonium salts are a general example in this category. Quaternary ammonium may be used on non-food contact surfaces. It may not be used in direct contact with organic foods. Its use is prohibited on food contact surfaces, except for specific equipment where alternative sanitizers significantly increase equipment corrosion. Detergent cleaning and rinsing procedures must follow quaternary ammonium application. Monitoring must show no detectable residue prior to the start of organic processing or packaging (example: fresh cut salads).

- **Bleach.** Calcium hypochlorite, sodium hypochlorite and chlorine dioxide are allowed as a sanitizer for water and food contact surfaces. Product (fresh produce) wash water treated with chlorine compounds as a disinfectant cannot exceed 4ppm residual chlorine measured downstream of product contact.

- **Detergents.** Allowed as equipment cleaners. Also includes surfactants and wetting agents.

- **Hydrogen peroxide.** Allowed as a water and surface disinfectant.

- **Carbon dioxide.** Permitted for postharvest use in modified and controlled atmosphere storage and packaging. For crops that tolerate treatment with elevated CO_2 (≥15%), suppression of decay and control of insect pests can be achieved.

2.3 Cold Storage Management

Awareness of ideal storage temperatures for different fruits and vegetables is critical to product management. Unfortunately, temperature management is one of the most difficult aspects of small farm operations, either organic or conventional. In contrast to large apple storages, refrigeration units are often in short supply for many growers, and it is unusual to find the ideal situation of more than one cold storage unit. Therefore, it is common for fruits and vegetables to be stored at incorrect temperatures; storage at a lower than recommended temperature for each product can result in chilling injury, while storage at a higher than optimum storage temperature will compromise its storage life.

Table 2.1 shows the compatible fruits and vegetables for a 7 day storage period. Note that both ethylene sensitive and high ethylene producers are included at the lowest temperature of 32-36°F. While less than ideal, the reduced ethylene production and action at these low temperatures make it less likely that injury will occur within a short storage period. Ethylene should be kept below 1ppm, but depending on the volume of each product can be unrealistic to achieve, e.g. in the presence of apples, and therefore the 7 day 'safe' period may be reduced. Regardless, longer storage periods are potentially damaging and fruits should be stored separately from vegetables.

The selection of the cooling unit is very important when a cooler is designed. If the temperature difference between the air and the cooling unit is too large, then the condensers will accumulate ice from the moisture in the air. This drying of air can dehydrate many fruits and vegetables. The atmosphere typically should be humid enough to prevent water loss. Ideally then a cooler should be able to maintain a RH of 90 to 95% at 32°F, but these types of coolers are more expensive and less common than for dry goods. Consult an engineering specialist when selecting a cooling unit and building a storage facility.

Temperatures in storage rooms can be kept as low as 30°F. However, even for fruits and vegetables that can be stored at this temperature, we do not recommend a set point of less than 32°F. This slightly warmer temperature allows a margin for error and reduces the risk of freezing injury. In this guide, we do not discuss freezing injury in detail, but growers storing any product should be aware that all fruits and vegetables have a lower temperature below which freezing injury can occur.

If three rooms are available, they can be set to meet the requirements of the three groups of fruits and vegetables shown in Table 2.1 – 32 to 36°F, 45 to 50°F, and 55 to 64°F. Note that vegetables require a higher RH than fruits at 32 to 36°F, and so if mixed a compromise of 90% may be needed.

If only two rooms are available, one should be kept at 32 to 36°F, and other set at 50-57°F as a compromise between groups 2 and 3.

If only one room is available, it should be kept at a compromise temperature of 41°F, and group 3 fruits and vegetables kept in an air conditioned area.

While mechanical refrigeration is the preferred method for obtaining precise temperature control for fruits and vegetables, a new technology known as CoolBot™ has been developed (http://www.storeitcold.com) that may be useful for smaller farmer operations. CoolBot™ has been tested extensively by UC Davis researchers for use in developing countries. It is a technology that allows the lower temperature limit of an air conditioner to be modified so that rooms without mechanical refrigeration units can be converted into cold rooms. The controller operates so as to force the air conditioner unit to produce low air temperatures without building up ice on the evaporator fins. Two temperature sensors and a small heater are used. The heater is fastened to the air conditioning unit's temperature sensor, and thus 'tricks' the air conditioner into continuing to cool below its normal set point. The CoolBot's first sensor measures the temperature of the cool-room, and once the desired room temperature is achieved, turns the heater off, so that the air conditioner sensor cools and its compressor turns off. The controller's secondary sensor is attached to the evaporator fins, and is adjusted to sense the presence of ice. When ice starts to build up, the controller turns the heater off, so that the air conditioner compressor turns off until the ice is melted. Since the controller prevents the evaporator from falling

Table 2.1. Compatible fresh fruits and vegetables during 7-day storage. Ethylene should be kept below 1 $\mu L\ L^{-1}$ (1 ppm) in the storage area.

From Thompson et al. (1996)

	Groups 1A and 1B 32 to 36 °F, 1A: 90 to 98% RH, 1B: 85 to 95% RH				Group 2 45 to 50 °F with 85 to 95% RH		Group 3 55 to 66 °F with 85 to 95% RH	
Vegetables	alfalfa sprouts	Chinese cabbage*	mushroom	**1A**	basil*		bitter melon	
	amaranth*	Chinese turnip	mustard greens*		beans; snap, green, wax		boniato*	
	anise*	collard*	parsley*		cactus leaves (nopales)*		cassava	
	artichoke	corn; sweet, baby	parsnip		calabaza		dry onion	
	arugula*	cut vegetables	radicchio		chayote*		ginger	
	asparagus*	daikon*	radish		cowpea (Southern pea)		jicama	
	beans; fava, lima	endive*-chicory	rutabaga		cucumber*		potato	
	bean sprouts	escarole*	rhubarb		eggplant*		pumpkin	
	beet	fennel*	salsify		kiwano (horned melon)		squash; winter (hard rind)*	
	Belgian endive*	garlic	scorzonera		long bean		sweet potato*	
	bok choy*	green onion*	shallot*		malanga*		taro (dasheen)	
	broccoli*	herbs* (not basil)	snow pea*		okra*		tomato; ripe, partially ripe & mature green	
	broccoflower*	horseradish	spinach*		pepper; bell, chili		yam*	
	brussels sprouts*	Jerusalmen artichoke	sweet pea*		squash; Summer (soft rind)*			
	cabbage*	kailon*	Swissh chard*		tomatillo			
	carrot*	kale*	turnip		winged bean			
	cauliflower*	kohlrabi	turnip greens*					
	celeriac	leek*	waterchestnut					
	celery*	lettuce*	watercress*					
	chard*	mint*						
Fruits and Melons	apple[e]	elderberry	prune*	**1B**	avocado, unripe[e]	limequat	atemoya[e]	sapodilla[e]
	apricot[e]	fig	quince*		babaco	madarin	banana[e]	sapote[e]
	avocado, ripe[e]	gooseberry	raspberry		cactus pear, tuna	mango, ripe[e]	breadfruit[e]	soursop[e]
	Barbados cherry	grape	strawberry		calamondin	olive	canistel[e]	watermelon
	blackberry	kiwifruit*[e]			carambola	orange	casaba melon	
	blueberry	loganberry			cranberry	passion fruit	cherimoya[e]	
	boysenberry	longan			custard apple[e]	pepino	crenshaw melon[e]	
	caimito	loquat			durian, ripe[e]	pineapple	honeydew melon[e]	
	cantaloupe[e]	lychee			feijoa	pummelo	jaboticaba	
	cashew apple	nectarine			granadilla[e]	sugar apple	jackfruit[e]	
	cherry	peach			grapefruit*	tomarillo	mamey[e]	
	coconut	pear (Asian and European)			guava[e]	tamarind	mangosteen[e]	
	currant	persimmon*			Juan canary melon[e]	tangelo	papaya[e]	
	fresh-cut fruits[e]	plum, ripe*			kumquat	tangarine	Persian melon[e]	
	date	plumcot, ripe*			lemon*	ugli fruit	plantain[e]	
	dewberry	pomegranite			lime*		rambutan	

*Sensitive to ethylene damage; [e] produce significant ethylene below the selected frost point, moisture condensed on the evaporator fins is returned to the cold room air, resulting in high RH which will reduce water loss in stored perishables.

The air conditioning unit must be sized appropriately for the dimensions of the cooler, and the room must be well insulated and without air gaps. In the US, the cost of a room air conditioner and the CoolBot™ control system is 1/10th that of a commercial refrigeration system (Table 2.2).

temperature by half again, and so on. So, seven-eighths cooling is three times as long as half-cooling.

Whatever of the following cooling methods is used, condensation on fruits and vegetables can be a problem. Cold fruits and vegetables removed from storage on a warm day will become moist with condensation quickly. In fruit such as strawberry, the loss of 'gloss' can be concerning. Also, moist conditions can be favorable for decay organisms.

Table 2.2 U.S. costs of installing conventional or CoolBot-controlled refrigeration in an insulated room (courtesy of Dr. Michael Reid, UC Davis)

Refrigeration system	Conventional 1 ton refrigeration system	CoolBot – controlled room air conditioner
Refrigeration equipment	$3000	$350
Electrical, piping, refrigerant	$2000	$300
Labor	$2000	$50
Total cost	$7000	$700

2.4 Cooling Methods

Cooling methods will vary according to product type and scale of operation. These methods include room cooling, forced-air cooling, hydro-cooling, package icing and vacuum cooling. Full details of each are available from many book and web-based sources. The most common cooling method used by New York growers and storage operators is room cooling. Forced-air cooling, icing, hydro-cooling and vacuum cooling are used extensively in major fruit and vegetable growing regions.

For any cooling method, it is important to understand that the cooling rate of products follows standard laws of physics in that it becomes progressively slower to cool products down over time. The typical cooling curve for a fruit or vegetable in a cold storage room (Figure 2.1) illustrates the concept of "half-cooling" or "seven-eighths-cooling" times. Half-cooling refers to the time taken to reduce the initial product temperature from that when first placed in the cold room halfway to the set temperature in the room. For example, if the product temperature was 68°F when placed in the room and air temperature in the room was set at 32 or 50°F, half cooling would refer to the time that it took for the product temperature to reach 50 and 59°F, respectively. It will then take the same time period to reduce the product

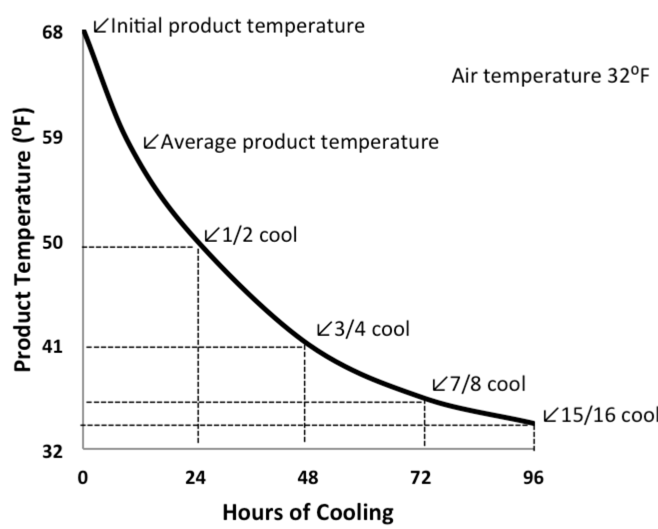

Figure 2.1. A cooling curve for a perishable product in room cooling.

The best way to avoid condensation is to maintain refrigeration through the whole marketing period, but this requires facilities that many small operations may not have. The best way to avoid condensation is to cover the fruit or vegetable with a plastic sheet before it is brought out from the cold storage. The plastic must be left on until the product has reached a temperature above its dewpoint. Remember not to cover the fruit or vegetable with plastic until it is cooled if it is placed back in storage. Otherwise, the plastic will cause condensation and a good environment for decay development.

2.4.1 Room cooling

Field or shipping containers are placed in a refrigerated cold room, and cooling of the crop occurs passively by heat exchange between the product and the cold air. The rate of cooling is affected by the heat of respiration of the product, the refrigeration capacity, the final temperature desired, and the airflow around the product. While passive cooling is the most widely used method of cooling, it has the disadvantage of being slow and can result in excessive water loss by the product. As discussed in section 2.2, refrigerated storages used commonly in small farm operations may not be ideal for horticultural products because of limited refrigeration capacity and difficulties of maintaining a high relative humidity (RH). Nevertheless, cooling rates can be improved by stacking containers in patterns that maximize contact between cold air and the product, and ensuring that containers have ventilation.

2.4.2 Forced-air cooling

Field or shipping containers are stacked in patterns so that cooling air is forced through, rather than around, the individual containers. A pressure gradient is developed using a fan (Figure 2.2). All areas other than vent holes in containers are sealed, resulting in direct contact of the product with cold air. The cooling rates can be 75 to 90% faster than those in passive room cooling, depending on the size of the product. Water loss from the produce can be lower than found for room cooling, but a high RH is required to minimize desiccation of products susceptible to drying, such as strawberries and grapes. Excessive airflow and cooling for longer periods than necessary to cool the product can result in undesirable desiccation. Therefore the flesh temperature of the product should be monitored throughout the cooling process. The fan should be cut off when the temperature is within 5°F of the desired temperature to avoid dehydration of the product. Small scale forced air systems can be set up using fans obtained from a hardware store.

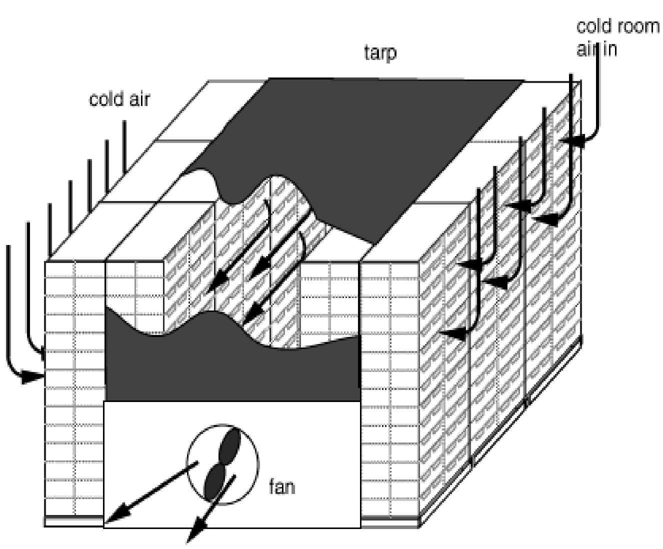

Figure 2.2. Schematic of a tunnel-type forced-air cooler (from Thompson et. al., 2002)

Components of a forced air cooling system are:

1. Vented containers to allow air to flow past the product;
2. Fan capacity appropriate to the volume of the product being cooled (2 cubic feet per minute per pound of product);
3. Air ducts to deliver cool air to the product and warm air back to the cooling coils;
4. Control of escaping air by plugging gaps and tarping the containers.

2.4.3 Ice cooling

Ice is used for cooling, sometimes in storage and for retail display if the product is tolerant of exposure to wet conditions at 32°F. The ice should be made with potable water. Ice absorbs heat from the product, the cooling rate being very fast initially. As the ice melts and the cooling rate slows down, the supply of melt water maintains a high humidity around the product. Containers holding the products also need to be tolerant of wet conditions. Icing for cooling and packaging is generally either package icing or top icing. In package icing, the crushed ice is distributed within the container to cool the product, whereas in top icing, a layer of ice is placed over the top layer of the container. Top icing is less expensive and less labor intensive, but the cooling rate can be slow – only the product at the top of the container is in contact with the ice. Top icing can be applied to maintain low temperatures and high RH after the product has been initially cooled.

2.4.4 Hydro-cooling

Hydro-cooling, which involves showering the product with refrigerated water, is more effective at removing heat than forced air cooling because the heat capacity of refrigerated water is greater than for air. Hydro-cooling also does not remove water from the product, and may actually add water to a slightly wilted commodity. Efficient cooling depends on adequate water flow over the product.

The hydro-cooling water is recirculated and can become contaminated with decay organisms over time. Therefore the water must be sanitized as well as changed frequently. If possible products should be prewashed, especially if excessive field soil is present on the product, containers, bins, totes and pallets. Disinfectants serve to help prevent post-harvest diseases and food borne illnesses.

No prohibited substances are permitted in the hydro-cooling water. Chlorine compounds (sodium hypochlorite, calcium hypochlorite, chlorine dioxide) are allowable for disinfestation purposes, but residual chlorine in the water must not exceed the maximum concentration (currently 4ppm) allowable under the Safe Water Drinking Act. An alternative to chlorine is ozone, which is a powerful oxidizing agent. However, capital and operating costs are much higher than for chlorine based disinfestation methods.

2.4.5 Vacuum cooling

Vacuum cooling involves using very low atmospheric pressures to increase evaporation of water from the product. It is very rapid and efficient for products with a high surface-to-volume ratio. In commercial practice the products are wetted with disinfected water. Vacuum chamber systems are costly to purchase and operate and are normally restricted to larger operations.

2.4.6 Other cooling methods

Although not appropriate for cooling to low storage temperatures, misting or sprinkling of potable water over harvested products such as field corn, can be used. Products are cooled as a result of evaporative cooling.

2.5 Storage rooms

Storage rooms should look and smell clean, and any diseased fruits and vegetables removed promptly. They should be cleaned with organically allowable sanitizers at least once a year to reduce potential sources of decay causing spores and other microbes.

According to federal regulations, the handler of a split organic/conventional (or transitional) operation must implement measures necessary to prevent comingling of organic and non-organic products and subsequent contact with prohibited substances. Cross-contamination can occur though volatilization, e.g. if apples have been treated with the scald inhibitor, diphenylamine (DPA), it is possible for other products near the apples to become contaminated by the DPA volatilization.

Rooms should be insulated, including the floor, and checked for gaps or cracks that will result in extra load on the refrigeration. Within the rooms, products should be stacked and spaced to ensure that good airflow is maintained over the fruits and vegetables.

Thermometers should be calibrated routinely. Do not rely only on an external setting without checking accuracy of readings within the storage room.

2.6 Relative humidity

Relative humidity (RH) is defined as the ratio of water vapor pressure in the air to the saturation vapor pressure at the same temperature. The RH directly affects the storage quality of products as excessive water loss results in wilting, shriveling, flaccidness, soft texture and loss of nutritional value as well as saleable weight. For most fruits and vegetables the humidity should be kept high, but important exceptions exist; standard recommendations should be followed (Table 2.1). While high RH approaching 100% can encourage growth of microorganisms and splitting of skin surfaces, it is usually more of a problem to maintain sufficiently high humidity than the opposite.

The RH is affected greatly by the refrigeration unit installed in the storage room. Evaporator coils for a refrigeration unit suited for horticultural crops should have a large surface area and refrigeration controls that will minimize the difference between coil and desired room temperatures, and reduce moisture removal from the air. In addition to rapid cooling of fruits and vegetables, which will reduce water loss from the products, methods available to help increase RH where less ideal refrigeration units are available include:

1. Adding moisture to the storage room by wetting the room floor or using potable water misting/spray units.

2. Using plastic inside containers or placing plastic sheeting over containers once the product has cooled.

2.7 Ethylene Management

The importance of ethylene production and action is described in section 1.6. Management of ethylene in the storage environment is clearly important. However, it is also important to understand that as with storage temperature, the degree of concern about ethylene will be affected by the size of the operation involved. Detrimental effects of ethylene depend on a number of variables including its concentration, duration of exposure and temperature. Therefore, ethylene management in a small retail operation with rapid turnover of product is less critical that one that involves prolonged storage in a consolidated facility.

2.7.1 Avoidance—removing sources of ethylene

Avoidance of exposure to ethylene begins with careful harvesting, grading, and packing to minimize damage to the commodities. In the case of climacteric products it is difficult to reduce the internal levels of ethylene once autocatalytic production has started. Products should be cooled rapidly to their lowest safe temperature to reduce naturally occurring ethylene production and to decrease sensitivity to ethylene.

Use of internal combustion engines around ethylene-sensitive commodities should be avoided, by using electric forklifts, or isolating vehicles from handling and storage areas. Natural sources of ethylene such as overripe and decaying produce should be removed from storage and handling areas. Ethylene producing and ethylene sensitive commodities should not be stored together for long periods of time. Retail displays should avoid placement of ethylene producing fruits such as apples and tomatoes close to commodities such as lettuce and cucumbers, although good ventilation in such areas probably reduces the severity of contamination.

2.7.2 Ventilation

Ethylene concentrations in the storage environment can be reduced by ventilation with clean fresh air. However, the fresh air has to be cooled and increasing ventilation is therefore energy intensive. Higher ventilation rates will also reduce the ability to maintain high RH in the cold room. Ventilation is also not suitable for CA storages or even packaged produce within normal storages because atmospheres are tightly controlled.

2.7.3 Ethylene adsorbers, oxidation and catalysis

A number of commercial products are available for storage operators to consider. All of the technologies outlined below are compatible with organic fruit and vegetable storage, but cost effectiveness and proven benefit should be considered before making investments.

Ethylene in storage rooms can be lowered by adsorption or oxidation. Adsorbers such as activated carbon and zeolites (microporous aluminosilicate minerals) have been available for many years. Zeolites incorporated into plastic films can maintain sensory quality and reduce microbial growth during storage. Ethylene can be oxidized using a number of strategies. Potassium permanganate ($KMnO_4$) is available in sachets, films and filters; direct contact with products must be avoided because of its toxicity. Studies show effectiveness with some products, but effectiveness with high ethylene-producing products is commercially questionable. Because ethylene is absorbed by the potassium permanganate its effectiveness is based on the presence of a large surface area, although systems have been developed where room air is drawn though the scrubber to increase efficiency.

Ozone will also oxidize ethylene, and its use in slowing down ripening, as well as a disinfectant that lowers mold and bacterial contamination, has been documented. However, commodities vary in sensitivity to ozone exposure. Also, ozone is unstable and therefore maintaining stable concentrations in storages can be difficult. Ozone is a toxic gas and OSHA recommends limited exposure of workers of 1.5 minutes for a 0.3ppm concentration. Ozone can be used effectively as a disinfectant and sanitizer.

Ethylene catalysis can be separated into two types. In the first, pure metallic elements can be used to increase the rate of chemical reactions, and in the case of ethylene increase the effectiveness of its oxidation to carbon dioxide and water. Most work on ethylene removal has centered on Pd (palladium) and TiO_2 (titanium dioxide) using activated carbon as the catalyst support. This technology is still under commercial development, but delayed ripening of tomatoes and avocadoes has been demonstrated using Pd-activated carbon.

Ethylene catalysis can also be activated by UV light, the primary catalyst being TiO_2. Commercial units are available. Advantages include destruction of ethylene where it is produced, Ti is cheap, photostable and clean, RH in the storage room is unaffected, and ethylene destruction can be achieved at room temperature.

2.7.4 Inhibitors of ethylene action

Inhibitors of ethylene action such as SmartFresh™ (1-methylcyclopropene; 1-MCP) are not permitted by organic growers and storage operators. Non-chemical means that are available include the use of controlled atmosphere (CA) storage as described in section 1.8. CA storage involves the modification of the atmosphere around the commodity, usually by decreasing the oxygen concentration from 21% in ambient air to levels in the range of 1-5%, and increasing the carbon dioxide concentrations from 0.03% in the ambient air to as high as 20%. Modification of the storage atmosphere has the effect of inhibiting ethylene action and/or rates of ethylene production.

In summary, smaller scale operations are largely limited to avoidance, ventilation and temperature control, and product turnover to mitigate the effects of ethylene. Active research continues to identify non-contaminant and environmentally friendly technologies, but few of these are yet suitable for small storage/retail operations.

It should be noted that fruits and vegetables may also be incompatible in storage because of tainting of produce that is not always associated with ethylene (Table 2.3). However, off-flavors probably will not develop noticeably during overnight storage. Therefore, you can compromise if storage of incompatible produce is brief.

2.8 Modified Atmosphere (MA) and Controlled Atmosphere (CA) Storage

Modified atmosphere (MA) storage refers to a change in the atmosphere around the product, typically a reduction of oxygen levels from 21% in ambient air, and an increase in carbon dioxide from 0.03% in ambient air. MA can be developed passively by product respiration or by active means where desired gas composition is injected into a bag, often in a package (MA packaging; MAP). Subsequently, the atmosphere in the bags is then a function of factors such as product type and temperature that affect respiration rates, permeability of the plastic film to oxygen and carbon dioxide

Table 2.3 Products which are incompatible in long-term storage.

Products			Effects
Apples or Pears	with	Celery Cabbage Carrots Potatoes Onions	Ethylene from apples and pears damages or causes off flavors in vegetables. Potatoes cause "earthy" flavor in fruit. Potatoes are injured by cold temperatures. High humidity causes root growth in onions. Ethylene causes bitterness in carrots.
Celery	with	Onions or Carrots	Odor transfer occurs between products.
Meat Eggs Dairy	with	Apples and Citrus	Fruit flavors are taken up by the meat, eggs, and dairy products.
Leafy Greens and Flowers	with	Apples Pears Peaches Tomatoes and Cantaloupe	Ethylene produced by the fruit crops damages greens and flowers.
Cucumbers Peppers and Green Squash	with	Tomatoes Apples Pears	Ethylene from tomatoes, apples, and pears causes loss of green color. This is aggravated by storage temperatures of 45-50°F which are too warm for apples and pears.

Modified from Hardenburg et. al. (1986).

diffusion, and the ratio of product to the bag. Controlled atmosphere (CA) is a subset of MA, but as the name suggests, the atmosphere around the product is controlled. The control is by use of equipment such as nitrogen generators and carbon dioxide scrubbers.

Each commodity has a safe range of oxygen and carbon dioxide based on the tolerance of each to low oxygen (Table 2.4) and high carbon dioxide (Table 2.5), and these levels can be affected by growing region and by variety. Reducing oxygen concentrations around fruits and vegetables slows down respiration (carbon dioxide production) rates until a point known as the anaerobic compensation point is reached, when respiration rates dramatically increase (Figure 2.3). This respiration is associated with fermentation and injurious accumulations of acetaldehyde and ethanol that result in damage. Similar damage due to fermentation can occur if the carbon dioxide concentration is too high.

Use of CA storage in New York is limited to apples, pears and cabbage. Apples are the major commodity stored in CA worldwide. The reason for limited use of CA to relatively few products, despite its benefits on quality of many others (Tables 2.6 and 2.7), is that it requires significant capital investment. Structures must be air tight and refrigerated, with precise temperature control and equipment to modify the atmospheres. The volume of these storage rooms is also necessarily large to maximize the value of the equipment. Therefore, the return on investment requires long lived horticultural products that are stored for months and not days or even weeks. In addition, extension of storage life is often too small to warrant investment. If the storage potential of a particular product is a week, for example, then adding on a few days extra, is often not commercially significant.

However, newer tent-based CA storage systems, with lower cost oxygen and carbon dioxide control monitors, are now available, and maybe more useful for shorter lived products. The tents and controllers are placed in cold storage rooms and have been used successfully for local market strawberries for example.

Other atmosphere based technologies such as hypobaric storage, in which commodities are stored at low atmospheric pressures provide potential for non-chemical storage, but practical cost-affordable systems are not available. Dynamic CA (DCA), where the oxygen around commodities is lowered to levels close to the anaerobic compensation point where fermentation occurs is commercially available. The metabolism of the fruit is monitored by measuring fluorescence signals or ethanol concentrations in the fruit, and the oxygen concentrations adjusted to avoid damage – hence the term 'dynamic'. Only limited use of this technology has occurred in North America, being restricted to a few organic apple storages in Washington State. DCA is used more extensively in Italy and other European countries.

Table 2.4 Fruits and vegetables classified according to their tolerance to low O_2 concentrations

Minimum O_2 concentration tolerated (%)	Commodities
0.5	Tree nuts, dried fruits, and vegetables
1	Some cultivars of apples and pears, broccoli, mushrooms, garlic, onion, most cut or sliced (minimally processed) fruits and vegetables
2	Most cultivars of apples and pears, kiwifruit, apricot, cherry, nectarine, peach, plum, strawberry, papaya, pineapple, olive, cantaloupe, sweet corn, green bean, celery, lettuce, cabbage, cauliflower, Brussels sprouts
3	Avocado, persimmon, tomato, peppers, cucumber, artichoke
5	Citrus fruits, green pea, asparagus, potato, sweet potato

Modified from Kader (2002).

Table 2.5 Fruits and vegetables classified according to their tolerance to elevated CO_2 concentrations	
Maximum CO_2 concentration tolerated (%)	**Commodities**
2	Apple (Golden Delicious), Asian pear, European pear, apricot, grape, olive, tomato, pepper (sweet), lettuce, endive, Chinese cabbage, celery, artichoke, sweet potato
5	Apple (most cultivars), peach, nectarine, plum, orange, avocado, banana, mango, papaya, kiwifruit, cranberry, pea, pepper (chili), eggplant, cauliflower, cabbage, Brussels sprouts, radish, carrot
10	Grapefruit, lemon, lime, persimmon, pineapple, cucumber, summer squash, snap bean, okra, asparagus, broccoli, parsley, leek, green onion, dry onion, garlic, potato
15	Strawberry, raspberry, blackberry, blueberry, cherry, fig, cantaloupe, sweet corn, mushroom, spinach, kale, Swiss chard

Modified from Kader (2002).

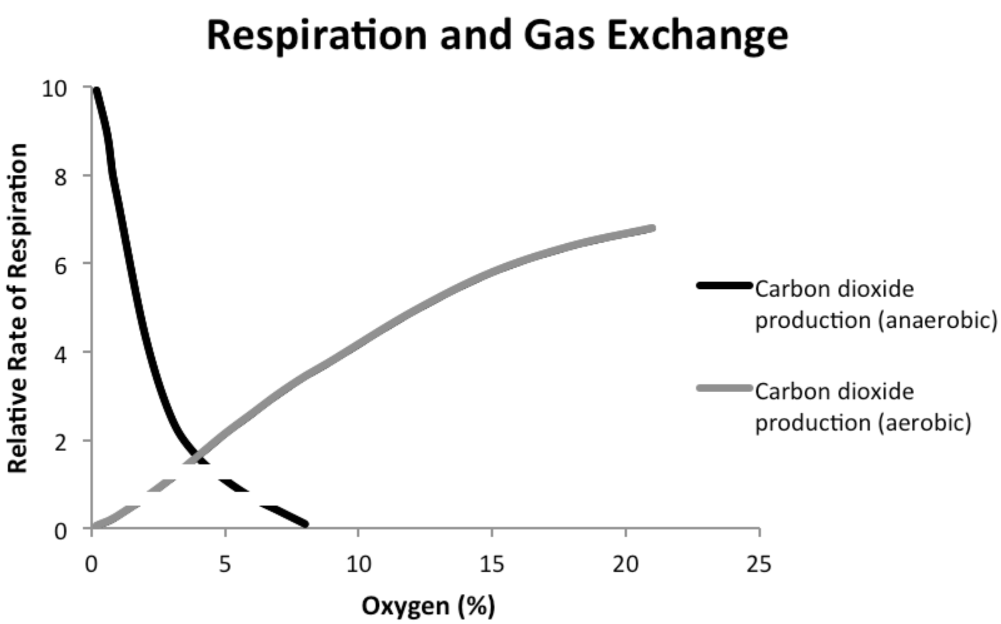

Figure 2.3. A schematic representation of the effects of oxygen concentration on aerobic and anaerobic respiration rates of fresh fruits and vegetables. Modified from Kader and Saltveit (2003).

Table 2.6 Summary of recommended CA or MA conditions during transport and/or storage of selected fruits			
		CA†	
Commodity	Temperature Range* (^{0}F)	%O_2	%CO_2
Apple	32-41	1-2	0-3
Apricot	32-41	2-3	2-3
Avocado	41-55	2-5	3-10
Banana	54-61	2-5	2-5
Blackberry	32-41	5-10	15-20
Blueberry	32-41	2-5	12-20
Cherimoya and atemoya	46-59	3-5	5-10
Cherry, sweet	32-41	3-10	10-15
Cranberry	36-41	1-2	0-5
Durian	54-68	3-5	5-15
Fig	32-41	5-10	15-20
Grape	32-41	2-5	1-3
		5-10	10-15
Grapefruit	50-59	3-10	5-10
Kiwifruit	32-41	1-2	3-5
Lemon and lime	50-59	5-10	0-10
Lychee (litchi)	41-54	3-5	3-5
Mango	50-59	3-7	5-8
Nectarine	32-41	1-2	3-5
		4-6	15-17
Nuts and dried fruits	32-50	0-1	0-100
Olive	41-50	2-3	0-1
Orange	41-50	5-10	0-5
Papaya	50-59	2-5	5-8
Peach, clingstone	32-41	1-2	3-5
Peach, freestone	32-41	1-2	3-5
		4-6	15-17
Pear, Asian	32-41	2-4	0-3
Pear, European	32-41	1-3	0-3
Persimmon	32-41	3-5	5-8
Pineapple	46-55	2-5	5-10
Plum	32-41	1-2	0-5
Pomegranate	41-50	3-5	5-10
Rambutan	46-59	3-5	7-12
Raspberry	32-41	5-10	15-20
Strawberry	32-41	5-10	15-20
Sweetsop (custard apple)	54-68	3-5	5-10

Source: Kader 1997; and Kader 2001 (in CD-ROM, Postharvest Horticulture Series 22, University of California, Davis).

Notes:

*Usual or recommended range; a relative humidity of 90-95% is recommended.

† Specific CA combination depends on cultivar, temperature, and duration of storage. These recommendations are for transport or storage beyond 2 weeks. Exposure to lower O_2 and or higher CO_2 concentrations for shorter durations may be used for control of some physiological disorders, pathogens, and insects.

Table 2.7 Summary of recommended CA or MA conditions during transport and/or storage of selected vegetables				
Vegetable	**Optimum temperature (ºF)***	**Temperature range (ºF)***	**% O_2†**	**% CO_2 †**
Artichokes	32	32 to 41	2 to 3	2 to 3
Asparagus	36	34 to 41	Air	10 to 14
Beans (green snap)	46	41 to 50	2 to 3	4 to 7
Beans (processing)	46	41 to 50	8 to 10	20 to 30
Broccoli	32	32 to 41	1 to 2	5 to 10
Brussels sprouts	32	32 to 41	1 to 2	5 to 7
Cabbage	32	32 to 41	2 to 3	3 to 6
Cantaloupes	37	36 to 45	3 to 5	10 to 20
Cauliflower	32	32 to 41	2 to 3	3 to 4
Celeriac	32	32 to 41	2 to 4	2 to 3
Celery	32	32 to 41	1 to 4	3 to 5
Chinese cabbage	32	32 to 41	1 to 2	0 to 5
Cucumbers (fresh)	54	46 to 54	1 to 4	0
Cucumbers (pickling)	39	34 to 39	3 to 5	3 to 5
Herbs‡	34	32 to 41	5 to 10	4 to 6
Leeks	32	32 to 41	1 to 2	2 to 5
Lettuce (crisphead)	32	32 to 41	1 to 3	0
Lettuce (cut or shredded)	32	32 to 41	1 to 5	5 to 20
Lettuce (leaf)	32	32 to 41	1 to 3	0
Mushrooms	32	32 to 41	3 to 21	5 to 15
Okra	50	45 to 54	Air	4 to 10
Onions (bulb)	32	32 to 41	1 to 2	0 to 10
Onions (bunching)	32	32 to 41	2 to 3	0 to 5
Parsley	32	32 to 41	8 to 10	8 to 10
Pepper (bell)	46	41 to 54	2 to 5	2 to 5
Pepper (chili)	46	41 to 54	3 to 5	0 to 5
Pepper (processing)	41	41 to 50	3 to 5	10 to 20
Radish (topped)	32	32 to 41	1 to 2	2 to 3
Spinach	32	32 to 41	7 to 10	5 to 10
Sugar peas	32	32 to 50	2 to 3	2 to 3
Sweet corn	32	32 to 41	2 to 4	5 to 10
Tomatoes (green)	54	54 to 68	3 to 5	2 to 3
Tomatoes (ripe)	50	50 to 59	3 to 5	3 to 5
Witloof chicory	32	32 to 41	3 to 4	4 to 5

Source: Saltveit 1997; and Saltveit 2001 (in CD-ROM, Postharvest Horticulture Series 22, University of California, Davis).

*Optimum and range of usual or recommended temperatures. A relative humidity of 90-95% is usually recommended.

†Specific CA recommendations depend on cultivar, temperature, and duration of storage.

‡Herbs: chervil, chives, coriander, dill, sorrel and watercress.

2.9 Packaging

Packaging materials, storage containers or bins must be free of synthetic fungicides, preservatives or fumigants. They also must be free of any residue from cleaning and sanitizing. Containers that are to be reused must be of the type that can be thoroughly cleaned prior to use.

Packaging has four primary functions: containment, protection, convenience and communication.

1. Containment. Containment is a basic requirement for movement of a product from one point to another. The package type and size will be a function of the product and market requirements. For example, a shallow container will be used for a product such as a peach or strawberry to avoid compression damage compared with a harder fruit such as an apple.

2. Protection. Packages provide protection for the product against environmental factors such as dust and water, as well as impact and compression bruising, and friction injuries that can occur during handling and transport. Cartons must have stacking strength and durability to prevent collapse or crushing while they are on pallets, especially under high relative humidity conditions. Trays, cups, or other protective measures may be contained within the package to prevent movement and/or contact between product items.

3. Convenience. Products are packaged in sizes that are convenient for the consumer, but may be larger for transport because of economies of scale. The product may be removed from the container and placed in display as single units, or repackaged. Smaller, primary packages may be placed in larger secondary containers. Package size is affected by regulations that ensure that package weights are safe and manageable for everyone.

4. Communication. In addition to advertising the type and source of the produce, information is provided about gross and net package weight, unit size of product, as well as any declaration of the use of any postharvest treatments that may be required by state or national regulations.

Packaging requirements for a farm side retail stand or a farmers market are less stringent than for larger scale operations. In the latter, using standard size containers that can be palletized and consolidated across farms for transport becomes more important. Packaging can insulate against temperature change, but will also slow cooling rates of a product. Conversely, package ventilation that permits rapid cooling of a product can result in faster warming if packages are not kept under good temperature control.

2.10 Transport

Transportation vehicles should be clean and sanitary. Comingling of organic and non-organic fruits and vegetables is prohibited unless organic products are protected from contact with prohibited substances.

Refrigerated trucks should be used where possible, but at the very least produce should be covered. Refrigerated trucks cannot cool horticultural products and at best can only maintain their temperatures if they have been precooled. Therefore, the refrigeration system should be turned on well before loading, and precooled products loaded rapidly. The more open the containers holding the produce, the faster they will warm if not kept under refrigerated conditions.

2.11 Retail display

Depending on the size of market operation, and availability of cold storages that can be operated at optimum temperatures (see section 2.2), products will be stored on site, transported in from a wholesaler, or marketed immediately after harvest.

A number of options are available depending on the size of the operation and fruit and vegetable requirements:

No cooling. Products that are normally stored at 55-66°F can be displayed without refrigeration. Also, long shelf life products such as apples and pears will maintain quality for short periods of time. Attention to turn-over of produce is important, ideally with restocking of produce kept in refrigerated storage. Using smaller display areas will help improve turn-over.

Refrigerated displays. Refrigerated displays are effective but costly. Where refrigerated displays are available, the fruits and vegetables should already be cold; refrigerated displays cannot cool products, and at best can maintain the temperature. Good air circulation should be ensured by checking that discharge air and return air outlets are not blocked, and are equipped with easy to read calibrated thermometers.

Because of differences in product sensitivity to cold temperatures, the ideal situation would be to have the ability to refrigerate products at 32 to 36°F and 45 to 50°F (Groups 1 and 2 in Table 2.1).

Iced displays. Iced displays can be an attractive substitute for refrigerated display cases and provide flexibility and portability. For appropriate vegetables (Table 2.8), iced displays provide a good temperature and humidity environment.

Ice used for displays must be made from potable water. Displays should be cleaned regularly with organically permitted disinfectants to avoid development of slime molds and offensive odors.

Table 2.8 Iced display of vegetables.

Should be displayed on ice	*Should not be displayed on ice*
Asparagus	Beans, snap
Beets (bunched)	Cucumbers
Broccoli	Cantaloupe *
Brussels sprouts	Eggplant
Carrots	Peppers
Cauliflower	Squash (all kinds)
Celery	Tomatoes
Endive	Watermelon *
Leeks	
Lettuce	
Onions (green)	
Parsley	
Radishes	
Spinach	
Watercress	

* Cut, wrapped portions may be displayed on Ice, but melons should not be stored at cold temperatures.

From Bartsch et al., 1980

3. SPECIFIC PRODUCT RECOMMENDATIONS

The following overview provides harvest, handling and storage recommendations for fruits and vegetables grown in New York. Additional information is available from the IPM guidelines for specific organic crops (http://www.nysipm.cornell.edu/organic_guide/default.asp), USDA Handbook 66 http://www.ba.ars.usda.gov/hb66, and Vegetable MD Online < http://vegetablemdonline.ppath.cornell.edu/>, and Bartz and Brecht (2003).

The reader should note that the recommendations below have been drawn extensively from these sources. However, the literature is dominated by recommendations developed to maximize storage potential using ideal conditions and equipment more commonly found in the industrial-dominated production areas such as those in California and Florida. While large scale production of several fruits and vegetables occurs in New York and many of the recommendations are directly applicable, it is recognized that many smaller organic farms do not have access to expensive equipment such as hydro-coolers and vacuum coolers, and indeed may have limited refrigeration capacity.

The ideal storage conditions for each product listed below should be considered by each farmer and storage and marketing decisions adjusted to reflect limitations within any operations. Within New York, each organic farmer develops marketing strategies that range from long term storage to a focus on immediate sales. As emphasized in section 2, these decisions impact the maturity at which products are harvested, the extent to which cooling technologies are applied, and the emphases on avoiding different products affecting each other (especially effects of the naturally occurring plant growth hormone ethylene). Simple steps such as always ensuring shade and moving products to cooler places will always have benefits for quality presented to the consumer. In reviewing the following recommendations by fruit and vegetable type, we stress the importance of considering each of the critical storage factors in terms of your marketing emphases.

The importance of fruit and vegetable variety selection cannot be over-emphasized, however. Within each of the products listed below there is often a remarkable range of storage potentials that are fundamentally genetically based. The potential storage life of different tomato varieties for example, can vary from a few days to a few weeks, and these differences reflected in quality factors such as intensity of flavor—many newer varieties often store well, but have lesser flavor than heirloom varieties.

As mentioned in section 1.2, growers usually select varieties on the basis of marketability (visual qualities specific to the market of choice) and yield, because these factors directly affect the bottom line. However, varieties can vary greatly in storage and shelf life. The absence of postharvest chemical treatments for organic growers makes it even more important that varieties are selected with these factors in mind. Variety selection should also include resistance to postharvest diseases and physiological disorders. We need greater emphasis by breeders on developing the sets of quality and storage characteristics that are best suited to the needs of organic farmers, while also ensuring economically viable yields.

- Each product type is listed alphabetically, but each of them is categorized based on storage life potential in Table 3.1. A summary table of optimal handling conditions for fresh fruits and vegetables can be found in appendix 2.

3.1 Apple

High quality apples should possess a pleasing combination of visual appearance (specific to variety as well as freedom from blemishes), texture and flavor. Harvest maturity varies according to variety, and within each variety will be earlier in the harvest window for fruit that will be stored for longer periods. Fruit that are fully flavored and softening when harvested should not be kept in long term storage. Some supermarkets have minimum standards for firmness and soluble solids content for fruit, regardless of whether they are organic or conventional.

Wooden bins are common in apple operations, but certifying agents may require organic growers to use plastic bins exclusively to avoid the risk of contamination with non-compliant materials. Plastic bins are more easily steam cleaned to remove microbial contaminants or pesticide residues. Packing lines may be shared between organic and non-organic fruit, but the entire line must be thoroughly cleaned before grading and packing organic fruit. Line brushes must be used exclusively for organic apples.

Table 3.1 Products categorized by optimal storage life.

Very short 1 week or less	**Short** 1-2 weeks	**Moderate** 2-6 weeks	**Long** 2 months and longer
Bean, Lima	Apricot	Asparagus	Apple
Blackberry	Artichoke	Brussels sprouts	Asian pear
Raspberry	Bean, green	Cherries	Bean, dry
Herbs	Beets with tops	Currant	Beet, topped
Sprouts	Blueberry	Gooseberry	Cabbage
	Broccoli	Lettuce	Carrots, topped
	Carrots with tops	Melon	Celeriac
	Corn, sweet	Onion, green	Celery
	Cucumber	Parsley	Garlic
	Eggplant	Peach and nectarine	Grape
	Leafy greens	Pepper	Kohlrabi
	Mushroom	Plum	Leek
	Pea	Radish	Onion, dry
	Squash, summer	Rhubarb	Parsnip
	Strawberry	Tomato	Pear
		Watermelon	Potato
			Pumpkin
			Rutabaga
			Squash, winter
			Sweet potato
			Turnip

Apples are climacteric fruit and produce ethylene. Apple varieties differ greatly in the rates of ethylene production, and in general, high ethylene producing cultivars ripen more rapidly than low ethylene producing ones. Ethylene, while desirable for ripening, is a major cause of softening, and its actions should be controlled. Fruit destined for storage should be harvested earlier and cooled rapidly. Room cooling is usually used. Care should be taken to load rooms in a manner that will allow good air circulation around the bins. The effects of slow cooling are magnified as the storage period increases. The recommended storage temperature for most apple varieties is 32°F with 90 to 95% RH. Varieties that are susceptible to low temperature injuries should be stored at 36 to 38°F, with 90 to 95% RH. Usually warmer temperatures reduce the storage life of the fruit, but the Honeycrisp variety is a notable exception. This variety can be stored for three months or more at these warmer temperatures without major loss of quality because of its unique texture characteristics.

Conventional growers use postharvest chemicals that are not permitted for use by organic growers. These include diphenylamine (DPA), an antioxidant that is used to prevent development of a physiological storage disorder known as superficial or storage scald, and fungicides and calcium salts that are sometimes also applied to reduce decay and maintain firmness. Also, use of the inhibitor of ethylene action, 1-methylcyclopropene (1-MCP; SmartFresh™), to maintain quality is not permitted. Apples treated with DPA should not be stored with organic fruit as it can volatilize and contaminate untreated fruit.

Caranuba waxes are permissible under NOP, but they are not used commonly on organic apples. Waxes are used primarily for improving fruit appearance, but also help reduce water loss and respiration rates.

Controlled atmosphere storage is used routinely in the apple industry to maintain quality of the fruit, and increasing demand for quality in the marketplace is decreasing the acceptable air storage period. Use of low oxygen storage, either at a set point, or dynamic, where the oxygen level is adjusted to the physiology of the fruit, is available. However, success with these technologies in New York has been limited, restricting the opportunity to exploit these non-chemical means of scald control.

These limitations reinforce the need for preharvest management of disease pressure, careful handling, use of clean picking buckets and bins, attention to rapid cooling of fruit, and cleanliness in the packing shed. Varieties that are susceptible to scald development should not be stored in air for more than two to three months. Sample fruit periodically while in cold storage, including a couple of days at ambient temperatures to follow changes in quality over time. Cut the fruit to look for development of external and internal disorders.

For retail outlet display, refrigeration is best, but because of the longer shelf life of apples, is not commonly used. Ensure turnover of product by keeping displays small, keep out of direct sunlight and in cooler areas of the market. Return fruit to a cooler overnight if possible. Remember that apples absorb odors from products such as onions and potatoes (Table 2.3) and therefore storage with these products for more than a day or two should be avoided.

3.2 Apricot

High quality apricots have good size, shape and are free from defects (including gel breakdown and pit burn) and are without decay. Most varieties are delicate and soften fast; subsequently they are susceptible to bruising and decay. The optimum flavor of apricots occurs when they are harvested but storage potential is restricted. Fruits should be harvested when firm if storage is required, but they will never develop the full rich flavor of fully ripened fruit. Apricots are always harvested by hand, usually into picking bags or plastic totes.

Apricots should be cooled in the field or immediately thereafter, usually by room cooling. If picked at the firm mature ripening stage and stored at 32°F with 90 to 95% RH, fruit can be stored for one to two weeks or more, depending on the variety. Some varieties are susceptible to chilling injury, but injury symptoms such as gel breakdown, flesh browning and loss of flavor occurs more rapidly at 41°F than at 32°F.

Controlled atmospheres of 2 to 3% oxygen and carbon dioxide can have moderate commercial benefits. Apricots are climacteric and exposure of fruit to ethylene can hasten softening, color change from green to yellow, and decay.

Apricots are usually sold at retail outlets at ambient temperatures, rather than the preferred refrigeration. Because of loss of texture, however, the fruit should be monitored to ensure turnover of product.

3.3 Artichoke

A high quality artichoke has tightly closed, firm and turgid outer bracts, free of browning on the outer bracts or violet discoloration on the inner bracts. Rough handling of artichokes during harvesting, transportation and packing can result in splitting of the bract tip. Surfaces of the bracts can be easily scratched and bruised, resulting in the development of browning and blackening that detracts from appearance and quality. These abraded areas are also susceptible to decay.

Artichokes should be cooled by room cooling or hydro-cooling to below 41°F within 24 hours of harvest. The recommended storage for artichoke is 32°F with 95 to 100% RH. The storage period under these conditions can be two weeks, this length decreasing with increasing storage temperatures. Controlled atmosphere storage reduces bract browning, but is not commonly used.

Artichokes have very low ethylene production and are not responsive to exposure.

Artichokes should be kept in refrigerated displays with misting at retail outlets.

3.4 Asian pear

High quality Asian pear fruit have the color and russetting that is appropriate for the variety. The fruit are sweet, crisp and juicy when eating ripe, and they are therefore unlike European pears, which have a melting texture when ripe. Loss of quality is associated with bruising and skin abrasions and shriveling. Damaged areas on the skin become brown or black. Internal breakdown or core breakdown as well as brown water soaked areas in the flesh can be found in fruit without any external symptoms. Late harvest of fruit may contribute to development of these disorders.

Asian pears should be handled gently as for tree ripened soft fruit; pickers should wear soft gloves and picking buckets should be clean and padded. Stem punctures can cause damage to the skin of adjacent fruit, and stem clipping may be useful to avoid damage if fruit are packed in two or more layers.

Asian pears are usually cooled using room cooling. Forced air cooling is not recommended as it may increase risk of flesh spot decay. The recommended storage temperature is 32°F with 90 to 95% RH. Storage with polyliners helps reduce water loss from the fruit. The storage life of Asian pears is typically between one and three months but this period can be influenced by variety. Some varieties can develop chilling injuries.

Depending on the variety, Asian pear can be either non-climacteric and produce little ethylene (e.g. Nijisseki, Kosui and Niitaka), or climacteric and produce moderate amounts of ethylene (Ya Li, Chojuro, Shinsui, Kikusui and Hosui). The climacteric cultivars lose color and soften slightly faster if exposed to external ethylene.

Responses of fruit to controlled atmosphere storage are variable by variety. Fruit are susceptible to low oxygen and high carbon dioxide injuries during storage.

For retail outlet displays, Asian pears should be kept as cold as possible without contact of fruit with ice.

3.5 Asparagus

High quality asparagus spears have straight stems that are dark green and firm (turgid) with tightly closed and compact tips. Asparagus has one of the highest respiration rates of any crop and is very perishable. Deterioration of quality is associated with loss of flavor and tenderness, loss of nutritional value, and susceptibility to bacterial and fungal decay. Spear toughening, which begins at the butt, results from tissue lignification and fiber development, and is faster at temperatures above 50°F. Feathering, where the bracts of the spear tips become apparent, is a sign of senescence. Asparagus continues to grow and elongate after harvest if not cooled immediately and stored at less than 41°F. At warmer temperatures, contact of water at the butt end can promote spear growth and elongation. Tips will bend up if spears are placed horizontally.

Asparagus should be harvested as they emerge from the soil from underground crowns, typically when the spears are eight to ten inches. They are very tender, bruise easily and therefore must be handled carefully.

The spears should be cooled immediately after harvest as delay of as little as four hours can result in increased toughness and loss of quality. Hydro-cooling of spears is the most effective cooling method. The storage temperature of asparagus should be 32°F for periods of less than 10 days, but 35°F for longer periods because of sensitivity of spears to chilling injury. Symptoms of chilling injury are flaccidity and a dull, dark gray-green tip. A high RH of 95 to 99% is important to prevent desiccation and maintain freshness. Water soaked pads are useful, especially in packages; excessive free water during storage may lead to development of decay.

Controlled atmosphere storage, typically elevated carbon dioxide concentrations of 5 to 10%, retards bacterial soft rot, toughening, water loss and yellowing of the spears.

Ethylene production of asparagus is low to intermediate, but it increases after harvest. Exposure to ethylene can increase toughening of the asparagus.

The preferred retail outlet display method is a refrigerated display with misting, but effective maintenance of quality can be obtained by placing the butt ends in chilled water, keeping the tips dry. Asparagus will also tolerate ice. The spears must always be displayed upright to avoid tip bending.

3.6 Bean (dry—black, blackeye, kidney, navy, pinto)

Dry beans are ready to harvest when some of the pods are dry and most are yellow. It is best to harvest when the moisture level is 15-18% since lower moisture results in more splitting and checked seed coats. Dry beans will continue to ripen after they are cut and too many dry pods at harvest will result in heavy shattering.

They are mechanically harvested around the first frost. All bean types (especially whites) need to be harvested when it is not raining to avoid seed discoloration, but store better if harvested at night or early morning. They are put into bins to dry, using fans and propane heat if needed. If beans will be kept at room temperature (70°F), the recommended long-term storage moisture content is about 13-14%, which keeps the RH in the beans below 65%, limiting mold growth.

The acceptable moisture content can be higher if the beans are kept cooler. If kept at 60°F, the beans will store well for 6 months with a moisture content of 14%. Beans with 16% moisture content should be cooled to 40°F and with 18% moisture content, cooled to 30°F. The temperature and moisture content of the beans should be checked at least monthly.

Dry edible beans must be handled with care since they are fragile. They are more susceptible to handling damage at lower moisture contents and cold temperatures. Recommended storage temperatures of 40-50°F with an RH of 40-50% should allow for long term storage of 6-10 months.

3.7 Bean (edamame or green soybean)

Also known as branch beans, edamame is ready to harvest after the seeds have reached almost full size but before any pod yellowing begins. The timing of harvest is critical for maximum flavor and texture. If the pods have turned yellow, it is not acceptable to market. Edamame can be sold as bunched whole plants. The beans then retain sugars for several days and quality remains high. Edamame should be cooled quickly, using either room cooling, vacuum cooling or ice water. Under ideal storage conditions of 32°F at 95% RH, the beans can be kept for up to 2 weeks. Edamame is most often found in farmer's markets.

3.8 Bean (green or snap)

High quality beans are well formed and straight, with a bright and fresh appearance, tender and firm, without defects. Poor quality is most often associated with over-maturity (expanded seeds in the pod), broken beans, water loss, chilling injury and decay.

Snap beans are harvested about 12 to 16 days after flowering, while pod beans are harvested when the pod is bright green and fleshy, and the seeds small and green. Harvest is usually by hand for fresh consumption and by machine for processing. If possible, do not begin harvesting until moisture on the plant has evaporated. This will prevent the spread of postharvest diseases and result in less contamination by soil and foreign matter. Beans can be room cooled, but forced air cooling or hydro-cooling is necessary for large scale operations. Hydro-cooling for fresh beans can result in damage if they remain wet after treatment.

Fresh beans should be stored between 41 and 46°F with 95-100% RH. Lower storage temperatures can be used for a few days, but beans are sensitive to chilling injury manifested as opaque discoloration along the pod. Chilling injury symptoms at 41 to 46°F are more commonly seen as discrete rusty brown spots. This russetting is aggravated by free moisture. The storage life is reduced at warmer temperatures because of seed development, water loss and yellowing. Beans are susceptible to oxidative browning when the pod is damaged, but incidence of browning can be reduced by rapid cooling. Beans respond to controlled atmosphere storage, but the technology is generally not used.

Beans produce low levels of ethylene, but exposure to low levels can promote yellowing, browning and shorten the storage life.

Displays should be small to avoid excessive handling. Ideal display temperatures are about 45°F. Beans can develop condensation and increased decay risk if taken from storage and left at ambient temperatures. Contact of beans with ice or water, including misting, should be avoided because of development of translucent or water soaked areas on the pods.

3.9 Bean (Lima, butter)

Quality lima beans are uniform in shape, fresh and free from damage and decay. Fresh lima beans are very perishable and can only be stored for 5-7 days at 41-46°F and 95% RH. Lower storage temperatures result in chilling injury expressed as darkening or dullness. They are low ethylene producers and moderately sensitive to ethylene. After harvest they are quickly pre-cooled using hydro-cooling.

Fresh lima beans may be found at farmer's markets but it is easier to find them frozen.

3.10 Beet

High quality table beets or red beetroot are firm, smooth, clean and free from defects. Loss of quality of bunched beet is associated with discoloration of the leaves, weight loss and decay.

Bunched beets should be precooled rapidly after harvest using hydro-cooling, forced air or icing. Topped beets can be cooled using room or forced air cooling. Bunched beets should be stored at 32°F with 98% RH, while topped beets should be stored at 33 to 36°F with 98% RH. Red beets can be stored in air-ventilated common storage for four to six months and in refrigerated storage for as long as eight to ten months. Beets should be topped and sorted to remove all diseased and injured roots before storage. Shriveling is visible with about 7% water loss in topped beets and 5% in bunched beets. If hydro-cooling is not used, beets can be washed just prior to being sold. Beets can be packed in perforated or semi-permeable plastic bags to reduce water loss.

Controlled atmosphere has no benefit for beets. Beetroots produce very low amounts of ethylene and they are not particularly sensitive to the gas.

For retail outlet display, bunched beets should be iced or refrigerated at 37 to 41°F, while beetroot should be kept at less than 50°F.

3.11 Blackberry and Raspberry

High quality of the bramble fruit, blackberries and raspberries, are uniformly colored, glossy and appear turgid, soft and juicy with high flavor. The fruit should be free from injury, decay, calyxes (caps) and sunscald. Many of the harvest and handling recommendations are very similar to those described in detail for strawberries (section 3.50) and therefore the reader should also review that section. In brief, the fragile nature and rapid deterioration of the berries after harvest requires extreme care during harvest operations. Appropriate varieties should be selected for retail compared with pick-your-own operations, the former requiring longer storage and shelf life potentials. These berries are non-climacteric and do not develop sweetness after harvest; partly colored berries can be overly astringent and too acid for the consumer. Some raspberry varieties color after harvest at the pink stage of maturity but can have poorer flavor and higher acidity. The quick and non-uniform ripening in the field means that berries should be harvested frequently. Mixed ripening stages of berries in the consumer pack is unattractive.

Temperature management is the most important factor in minimizing blackberry and raspberry deterioration and maximizing berry storage life. Neither berry type should be left in the field if they are exposed to direct sunlight, and containers should be shaded if not transported quickly. Low storage temperatures maintain berry quality while minimizing growth of decay causing pathogens. Rapid cooling within an hour of harvest is critical to maintain quality of berries after harvest, but the rapidity of cooling is more important with longer storage requirements.

Room cooling is commonly used in New York, but forced air cooling is highly recommended to maintain the quality of blackberries and raspberries. The berries are not chilling sensitive and they should be stored at 32°F with 90 to 95% RH. Under these conditions, storage periods of two to fourteen days are achievable, but the actual storage periods are affected by berry type, variety, berry maturity, and pre- and post-harvest conditions. Condensation, which can result in undesirable loss of fruit 'glossiness' when fruit are warmed can be avoided by using plastic sheets (see section 2.4).

Controlled atmosphere storage using high carbon dioxide (10 to 15%) maintains berry firmness and inhibits decay, but we are not aware of the application of controlled atmosphere systems in the northeast.

Ethylene production of blackberries and raspberries is variable across varieties from very low to low. However, exposure of berries to ethylene can stimulate gray mold (Botrytis cinerea), and for raspberries, stimulate unattractive purple red color development.

At retail outlets, blackberries and raspberries should be displayed under refrigerated conditions, without misting. Covering the baskets with plastic film maintains a higher RH around the berries and reduces water loss and shriveling.

3.12 Blueberry

Blueberries are hardier than raspberries and blackberries. Highbush or cultivated blueberries are most often harvested by hand if destined for the fresh market. Some varieties may be picked soon after turning dark blue while others take longer to get fully ripe. The latter should be picked after developing good flavor but when they are still firm enough for successful marketing. Blueberries that do not come off the branch easily are not ready for harvest and should be left on the bush for a few more days. Handling the berries should be minimized to reduce fruit damage. The berries should be harvested into small containers or baskets to reduce bruising and damage.

Blueberries can be stored at 32°F with 90-95% RH for 10-18 days. They have only low ethylene production and sensitivity. There is limited use of CA with elevated carbon dioxide during transport to control decay. Blueberries are sensitive to freezing injury. In retail operations, covering the small blueberry containers with plastic will keep the berries from shriveling. Refrigeration will help maintain freshness.

3.13 Broccoli

High quality broccoli have firm, compact clusters of small flower buds or florets, which should be tightly closed with a dark green color. Some varieties have a purplish cast over the green surface. Enlarged or open florets are a sign of overmaturity. Stems should not be too long or thick, or discolored. Bunched broccoli is usually trimmed to eight inches in length and packed into containers as bunches (two or more heads banded together). Loss of quality during storage is evidenced by wilting, yellowing, loosening or opening of flower buds, and decay.

Broccoli heads are fragile and highly perishable, and bruise easily with rough handling. Package icing of broccoli in the field is highly effective. In the absence of that technology, hydro-cooling and forced air cooling are options to rapidly remove field heat from the broccoli. Broccoli can be stored at 32°F with 98 to 100% RH for 2 to 3 weeks. Broccoli is not susceptible to chilling injury. Broccoli responds well to controlled atmosphere storage.

Broccoli has a low ethylene production rate, but is highly sensitive to ethylene. Exposure to relatively low levels of ethylene causes yellowing of florets and a reduction of shelf life.

Broccoli should be iced during retail outlet display and ensure contact with ice by not overloading the display case. Refrigerated displays with misting are also effective.

3.14 Brussels sprouts

The outer leaves of high quality Brussels sprouts should be green and tightly overlapping. Sprouts are harvested when they are about one to two inches in diameter. Leaves should not have black specks or other discolorations, and yellowing and loss of texture indicates senescence. Cool weather late in the harvest season enhances flavor of the sprouts.

Brussels sprouts maintain good storage quality if kept at 32°F with RH close to 100%, and with good air circulation. Typical storage periods are three to five weeks under these conditions.

Controlled atmosphere storage can inhibit yellowing, decay and discoloration, but only when they are stored at above optimum atmospheres. Commercial use is low. Film liners can be used to help reduce water loss.

Ethylene concentrations as low as 0.5ppm can accelerate yellowing and abscission of the outer leaves and therefore Brussels sprouts should not be stored with ethylene producing products.

Brussels sprouts by the stalk may be sold at the retail outlet level. However, whether they are sold as stalks or singly, they should be displayed on ice or refrigerated. Vent any packaging used.

3.15 Cabbage (Common)

Cabbage heads should be crisp, firm, and compact. They should be harvested promptly when the heads are mature and solid as delays will result in heads that are split and have increased susceptibility to disease. The heads are crisp and fresh if they squeak when rubbed together. Immature heads are smaller and softer. During harvest of fresh-market cabbages, four to five wrapper leaves should be retained to protect the head, but for storage cabbage all but one or two wrapper leaves should be trimmed away to avoid interference with air circulation around the heads during storage.

The storage life for cabbage is affected by variety. Loss of cabbage quality during storage is associated with bruising, yellowing, toughening, loss of flavor and decay. While cabbage is one of the least perishable vegetables, its temperature should be reduced rapidly after harvest. Cabbage is generally room cooled without pre-cooling. Cabbage should be stored at 32°F with 98 to 100% RH, and even a small increase in storage temperature to 34°F may promote senescence related losses in long term air storage. The high RH reduces decay and trimming losses. Whether cabbage is stored in bulk or in bins, even air flow will ensure good temperature control. Cabbages are not susceptible to chilling injury. The storage life of cabbages can be extended by several months using controlled atmosphere storage (2 to 3% oxygen and 4 to 5% carbon dioxide).

Cabbages are low ethylene producers but exposure to ethylene concentrations as low as 1ppm can accelerate yellowing, wilting and abscission.

Outer wrapper leaves should be trimmed for retail outlet display. The greatest concern is water loss, which can be prevented by wrapping each head in clear plastic film, frequent water sprinkling and/or use of a refrigerated display case.

3.16 Carrot

High quality carrots are firm, straight from the shoulder to the tip, smooth, sweet with no bitter or harsh taste, and show no signs of cracking or sprouting. Harvest maturity varies by end usage, with fresh-cut carrots being harvested immature to ensure tenderness and sweetness, while fresh market carrots are harvested at the more mature stage. Late harvesting may improve storability by reducing decay development during long term storage. Bruising, longitudinal cracking, and tip-breakage are signs of rough handling.

Hydro-cooling is the best option for pre-cooling of carrots, after they have been pre-washed. Although carrots are not as perishable as many other vegetables, they still need to be cooled on the day of harvest to reduce wilting and shriveling, prevent heating due to carrot respiration, and prevent decay. Smaller carrots are more susceptible to water loss than larger carrots because of their large surface area to volume ratio. If hydro-cooling is not used, carrot washing can be delayed until they are sold.

Mature topped carrots can be stored for several months at 32 to 34°F at 98 to 100% RH. Commercial storage can run as high as 41°F with 90 to 95% RH. Warmer storage temperatures can result in sprouting and decay. A high RH is essential to maintain freshness and prevent desiccation. Bunched carrots are highly perishable because of the presence of leaves. Carrots are sometimes stored in the field, but well drained and excellent soil conditions are necessary for success. Controlled atmosphere storage is not useful for carrots.

Whole carrots produce very low levels of ethylene, but exposure to ethylene sources will result in development of bitterness.

In retail outlet display, high water loss can be prevented by use of perforated or semi-permeable plastic bags. Otherwise a high RH must be maintained on the shelf with misting.

3.17 Cauliflower

High quality cauliflowers have compact flower heads and white to cream curds. Over-mature heads lose compactness with loose and spreading curds. Heads should be surrounded by a whorl of trimmed green turgid leaves. Trim the remaining outer leaves in the field because if they are left on, cauliflower loses its moisture very quickly. The curds should be free of mechanical damage, decay, browning or yellowing, which can be caused by sun exposure. Heads should be handled carefully to prevent bruising and associated browning and decay.

Cauliflower is mostly pre-cooled by hydro-cooling or vacuum cooling, but forced air cooling is also effective. Quality of the heads can be maintained for 3 to 4 weeks if they are stored at 32°F with 95 to 98% RH with good airflow. Cauliflowers are not chilling sensitive. Storage at warmer temperatures increases riciness development, expressed as loose curds with floral parts protruding.

Controlled atmosphere storage can extend storage life though cauliflowers are sensitive to both low oxygen and high carbon dioxide injuries. The benefits do not appear to warrant the investment in equipment. Film overwraps can be applied during field packing to help reduce water loss and wilting, but must be perforated to ensure that oxygen and carbon dioxide levels do not become injurious.

Cauliflowers produce very low levels of ethylene, but they are highly sensitive to ethylene exposure. Symptoms of ethylene exposure are curd discoloration, leaf yellowing and abscission.

The shelf life of cauliflowers can be enhanced during retail outlet display by icing. Plastic overwraps also help prevent wilting.

3.18 Celeriac

Celeriac, also known as turnip-rooted celery, is a variety of celery cultivated for its edible roots, hypocotyls and shoots. It should be harvested when roots are 3-4 inches in diameter. High quality celeriac should be smooth and firm with no soft spots that would indicate decay. The roots increase in flavor after the first frost but should be harvested before a hard frost.

Celeriac stores well if you leave it unwashed and unpeeled. It should store for 6-8 months at 32-35°F and 98-100% RH. The storage life can be less than 4 months if held at 38°F. Celeriac is susceptible to freezing injury which will appear as water-soaked areas and softening. It produces very little ethylene and has low sensitivity. Controlled atmosphere storage is not generally used. Water sprinkling and top ice are beneficial for retail outlet displays.

3.19 Celery

High quality celery should be crisp and fresh looking with green color. The petioles should be straight and compact. Celery should be harvested before the outer stalks become pithy or yellow. Any leaves remaining after trimming should not be wilted, yellow or decayed. Storage potential is improved by harvesting celery with a small portion of the root system attached. Loss of quality during storage is evidenced by wilting, decay and development of pithiness (whitish regions and air spaces within the tissue).

Celery can be kept for two to three months if cooled rapidly and stored at 32°F with 98 to 100% RH. Pre-cooling options include hydro-cooling, forced-air and vacuum cooling. Celery is not sensitive to chilling injury. CA storage has only moderate benefit on celery quality.

Celery produces low levels of ethylene, and it is not very sensitive to the gas at low storage temperatures. However, exposure to ethylene levels of 10ppm or more to celery kept at 50°F causes faster yellowing and pithiness development.

For retail outlet display, celery can be kept in plastic sleeves or pre-packed consumer bags. Top ice and misting will reduce water loss and maintain freshness.

3.20 Cherry (Sweet and Sour)

High quality sweet cherries are bright and shiny with fruit colors ranging from dark red to yellow. It is important that the stem be green with no brown discoloration. Fruit color is used as a maturity index and different cultivars are harvested at different color stages. The fruit should be firm and juicy, with high soluble solids and titratable acidity. Sweet cherries should be pre-cooled within 4 hours of harvest. Hydro-cooling, forced-air cooling and room cooling are all used. Sweet cherries can be stored at 32°F with >95% RH for 2 to 4 weeks. They are not sensitive to chilling. They produce only very low levels of ethylene and respond to ethylene with increased respiration, quality loss and a shortened storage life.

Sour cherries are smaller and softer than sweet cherries and are primarily bright to dark red. They should be of uniform color and shape, and free from decay, pulled pits, attached stems, scars, sun scald, shriveling, disease and insect damage. Optimal storage temperature and RH is the same as for sweet cherries but they will only last up to 1 week.

Pitting and bruising of the fruit are caused by harvest injury and rough post harvest handling. Visual symptoms often do not appear until the fruit are in wholesale or retail markets. Low temperature and high RH are necessary to minimize water loss and stem browning. It is important to carefully handle the stems as well as the fruit since wounding the stems will cause them to brown.

Fungal pathogens may be present at harvest or fruit can be infected through rain splits or wounds occurring at harvest or during packing. Postharvest sanitation and low temperature storage are critical to slow pathogen growth.

CA storage and modified atmosphere packaging (MAP) can reduce darkening of the cherries, acid and firmness loss, stem browning and incidence of decay. Fruit harvested at a more advanced stage of maturity will not benefit as much as if less mature. The fruit can go anaerobic in MAP if held at a higher temperature.

Fruit should be displayed at 41°F or less to slow shrivel, decay development and stem browning. There should be no free moisture on the cherries or they may split.

3.21 Chinese cabbage

High quality Chinese cabbage should have uniform, tightly formed heads with yellow-green, crinkly leaf blades. The petioles and midribs should be white without black spots or other discoloration. Loss of quality is associated with wilting and discoloration of the leaves. Damaged leaves should be removed.

Pre-cooling can be carried out using hydro-cooling, vacuum cooling or forced air cooling. The recommended storage temperature is 32°F with 95 to 100% RH. A storage period of two to three months can be obtained under these conditions. However, some varieties are susceptible to chilling injury, which is expressed as browning of midribs, after prolonged storage. Water loss can be reduced by storing heads in polyethylene bags. Controlled atmosphere storage is effective but commercial use is limited by differing varietal, temperature and storage duration requirements.

Chinese cabbage has very low ethylene production, but loss of condition can occur if the heads are exposed to ethylene.

At retail outlets, Chinese cabbages are displayed as individual heads with leaves removed. Refrigerated storage with misting helps to reduce water loss. Avoid exposure to ethylene-producing fruits.

3.22 Cranberry

Cranberries are ready to be harvested when they turn a deep red in the fall. They can either be harvested by hand, or with two-handed comb scoops or by machine in a dry field. If the field is flooded (bog), a machine can be used to water rake the fruit off the shrubs. Dry-picked berries have a lower yield and labor costs are higher, but the fruit are less bruised and can be sold as fresh fruit. Wet-picked berries are most often frozen and processed.

Cranberries are chilling sensitive and should not be stored below 37-38°F. They are low ethylene producers with low sensitivity to ethylene exposure. The RH in the storage should be 90-95% and controlled atmosphere conditions can maintain the fruit in good condition for 1-3 months. Since the bulk of fresh market cranberries are harvested in cooler weather, they are often stored in thick-walled barns with no refrigeration. Vents are opened and closed to regulate temperature. Fresh market cranberries are stored in shallow bins or boxes with perforated bottoms so air can circulate, keeping decay to a minimum. They are generally sold in perforated plastic bags in the retail market.

3.23 Cucumber

High quality cucumbers are straight, uniformly cylindrical, dark-green, firm, and turgid. External glossiness and formation of jelly-like material around the seeds are indicators of proper maturity. The fruit should be free of injury and decay. Loss of quality is associated with pitting, a symptom of chilling injury, wrinkling (i.e. pinched) of the ends, a symptom of water loss, flaccidity, and yellowing. Bruising and compression injuries are common when careful harvest and handling procedures are not followed.

Cucumbers are chilling sensitive, but if exposure to cold temperatures during pre-cooling is short (less than six hours), hydro-cooling and forced air cooling methods can be used. Room cooling is recommended only for those cucumbers harvested in mild weather conditions. Cucumbers should be stored at 50 to 55°F, however, with 95% RH. The storage period under these conditions is about two weeks. Cucumbers are sometimes wrapped in plastic to help reduce water loss. Controlled atmosphere storage has little beneficial effect on quality of cucumbers.

Cucumbers produce low levels of ethylene, but exposure to ethylene concentrations of 1ppm or more accelerate yellowing and decay.

Chilling temperatures should be avoided for display of cucumbers at the retail outlet. Periodic sprays of water or packaging the fruit in ventilated films can minimize water loss. High RH retards softening and pitting. Cucumbers should not be displayed with ethylene producing fruits.

3.24 Currants and Gooseberries

Currants are borne on strigs, or clusters. Black currants ripen from the top down, while red currants ripen all at once. Red currants are used mainly for juice, jellies and purees. White currants (albino reds) have the same uses as the red currant but since they have lower levels of acidity, can also be used for fresh eating. Black currants are astringent and only used for processing.

Berries for fresh eating should hang on the plant for 3 weeks after developing color. To minimize damage, the whole cluster should be picked and then the individual berries stripped. Currants can be stored for up to 2 weeks at 32°F with 85-90% RH.

Gooseberries have a greater potential for the fresh market. Berries are green, yellow or red when ripe. The bushes have thorns which slow harvesting. Fresh gooseberries can be stored for up to 3-4 weeks at 32°F with 90-95% RH.

Cultivars of gooseberry and currant should be white pine blister rust (WPBR) and powdery mildew (PM) resistant. These specialty crops are relatively easy to grow so there may not be a steady market demand. Preserving the berries to sell in the off season may help diversify and open new target markets. A controlled atmosphere can keep currants in good condition for 3-6 months. There are no recommendations for CA of gooseberries at this time.

3.25 Eggplant

High quality eggplants are dark purple, firm, and glossy with a dark green calyx and stem. Excessive water loss and senescence is exhibited by dull and shriveled skin, and browning of the calyx.

Careful handling is required in the field as even slight bruising will disfigure the fruit. Rapid cooling to 50°F immediately after harvest will retard discoloration, water loss, calyx drying and decay. Room cooling is effective, but hydrocooling and forced air cooling is more effective.

Eggplants are sensitive to chilling injury (surface pitting and scald) and should be stored at 50 to 54°F with 90 to 95% RH. The storage life is usually less than 2 weeks. Controlled atmosphere storage has little benefit for eggplants.

Ethylene production of the fruit is low, but exposure to exogenous ethylene (>1ppm) can cause calyx abscission and browning.

Eggplants should be kept in the shade and in cooler areas of retail outlets, but never in contact with ice. Eggplants absorb odors from onions and other products.

3.26 Garlic

The garlic bulb consists of cloves individually wrapped in dried leaf sheaths or skins attached to a compressed stem plate. Garlic bulbs should be cured. Cloves should be firm to the touch. The bulbs are usually harvested mature, when the tops have fallen and not completely dried, but may be harvested at earlier stages for specialty markets.

Curing recommendations are similar to those described for onions. Curing is carried out using forced-air ventilation that is controlled thermostatically by an air proportioning system. Airflow should be uniform throughout the storage facility to maintain consistent temperature. At a weight loss of about 5%, the tight neck and dry scales form an effective barrier to further reduce water loss and susceptibility to pathogens.

For long term storage (six months or more), garlic should be stored at 32°F with 60 to 70% RH. Garlic bulbs are not susceptible to chilling injury. Good airflow through bins or containers is necessary to prevent any moisture accumulation. A high RH will promote mold growth and rooting. Garlic can also be stored in common storage for three to four months with low temperatures, good airflow and low RH. Garlic can be kept at ambient temperatures, if humidity is low, for one to two months, but the bulbs will eventually become soft, spongy and shriveled because of water loss.

As with onions, garlic loses dormancy and sprouting is initiated. Use of sprout inhibitors such as maleic hydrazide is not permitted by organic growers. Controlled atmosphere storage may suppress sprouting but is not used commercially.

Garlic produces very low levels of ethylene and is not affected by exposure to the gas. Garlic odor contaminates other products.

For retail outlet display, garlic bulbs should be kept cool and dry. Garlic is often hung by the tops in bundles or dried on racks. If the bulbs are peeled, they should be stored in rigid plastic containers or carton boxes with plastic film covers at 32 to 41°F.

3.27 Grape

Optimal harvest maturity is based on the soluble solids concentration (SSC) of the fruit. The titratable acidity (TA) and sugar to acid ratio are also considered. These parameters can be measured using a refractometer (%SSC) and commercially available total acidity titration kits. The minimum SSC is 14-18% depending on cultivar and the SSC:TA ratio should be 20 or more. Varieties that are not green also have minimum color requirements. This is based on the number of fruit in a cluster that have a set percentage of skin that is colored to a particular minimum color intensity. Quality berries should be firm with no disorders or decay, and attached to green, pliable stems.

Grape clusters should be clipped and placed directly into field lugs. They can lose a lot of moisture following harvest and should be pre-cooled as quickly as possible. The preferred pre-cooling method is forced air cooling. Moisture loss can result in stem drying and browning, berry shatter and wilting and shriveling. The respiration rate of stems can be as much as 15 times higher than the berries and this can also contribute to stem browning. Consequently, an inspection of the stems can determine whether or not the grapes were quickly pre-cooled and indicate the likely storage life of the grape clusters.

Another indicator of quality is the natural wax or bloom on the berries. Rough handling can remove the bloom, making the skin appear shiny instead of lustrous.

Grapes stored at 32°F with 90-95% RH should remain in good condition for 1-2 months. The berries are more susceptible to decay if harvested after rain than after a dry period. Molds, especially gray mold *(Botrytis cineria)* requires constant attention during the harvest and storage periods. Traditionally sulfur dioxide is used as a fumigant at the time of pre-cooling and periodically during storage. A controlled (or modified) atmosphere with high carbon dioxide can be used instead of sulphur dioxide to control decay for up to 4 weeks. Ozone can also be used to sanitize the surface of grapes to extend the storage period and shelf life. Other possible alternatives are acetic acid vapors, ethanol dips, chitosan (a natural polysaccharide) coatings and biological control agents *(Auriobasidium pullulans, Cryptococcus laurentii, Muscodor albus)*. Grapes are low ethylene producers and have low sensitivity to it.

Most grapes at retail are packaged in clam shells or plastic cluster bags. These bags reduce dropped loose berries (consumer slipping hazard), water loss and fruit damage during marketing. Grapes will pick up odors from leeks and green onions. They should ideally be kept refrigerated. Make displays shallow to avoid damaging grapes at the bottom of the pile.

3.28 Herbs

High quality herbs should appear fresh and green, of uniform size, and with flavor and aroma strong and characteristic of the herb. Loss of quality is associated with wilting, yellowing, decay, insect damage, or mechanical damage. The visual appearance can be maintained longer than the concentration of essential oils and aroma that make up the culinary shelf life. Herbs are particularly sensitive to contamination by human pathogens so attention to sanitary conditions is critical.

Herbs may be hydro-cooled before packaging and room cooled after packaging. For most herbs the optimum storage temperature is 32°F with 95 to 98% RH. The effect of storage temperature is shown in Table 3.2. Over a 10 day period most herbs have better quality if stored at 32°F, but herbs such as basil and shiso have reduced quality at this temperature because of sensitivity to chilling injury. The expected

Table 3.2 Effect of temperature and ethylene on visual quality of fresh culinary herbs after 10 days. Relative humidity was 90 - 95%.			
	Visual quality score after 10 days at indicated temperature*		
Herb	**32°F**	**50°F**	**68°F**
Basil	2	8	7
Chervil	8	6^t	1
Chives	9	6	3
Cilantro	9	4^t	1
Dill	9	6^t	2
Epazote	9	7^t	5
Mache	8	5	2
Marjoram	9	8^t	1
Mint	9	6^t	2
Mitsuba	9	7^t	4
Rosemary	9	9	7
Sage	9	8	—
Shiso	6	8^t	3
Tarragon	8	6	—
Thyme	9	8	7

Source: Adapted from Cantwell and Reid 1990.

Notes:

*Quality score: 9=excellent; 7=good, minor defects; 5=fair, moderate defects,

limit of salability; 3=poor, major defects; 1=unusable.

^{t}Herbs that showed reduced visual quality at 50°F when exposed to 5-10 ppm ethylene.

shelf life for most herbs is up to three weeks at 32°F, but because basil is a component of many mixed herbs an intermediate temperature of 41 to 50°F is required. This compromise temperature results in lower risk of chilling injury for basil, but a faster rate of deterioration for the other herbs. Controlled atmosphere storage can benefit herb quality, but it is not used commercially. The preferred way to reduce water loss of herbs is to package them in plastic films.

Ethylene production by herbs can vary and is generally higher than that for leafy green vegetables. Sensitivity to ethylene is high, and even low levels of ethylene can cause leaf abscission, epinasty (stem curvature) and yellowing. Some herbs such as sage, thyme, basil and rosemary are minimally affected or are not affected by ethylene at all.

Herbs can be displayed in retail outlets shaded and cool, or under refrigeration. Use of misting is acceptable. Basil and rosemary are damaged by icing.

3.29 Kohlrabi

High quality kohlrabi, also known as turnip-rooted cabbage, has a succulent and tender leaf stem. The stem should be free of blemishes, wilting and decay. Tops are either removed or left in place.

Kohlrabi can be pre-cooled by hydro-cooling, package icing or forced air cooling. Topped kohlrabi can be stored for two to three months at 32°F with 98 to 100% RH, but only two to four weeks with leaves. Storage quality is improved by using perforated polyethylene film bags to maintain high RH. Kohlrabi is not susceptible to chilling injury. There is no benefit of using controlled atmosphere storage.

Kohlrabi produces very little ethylene and are not sensitive to the gas. Kohlrabi should be displayed in retail outlets using bottom ice.

3.30 Leafy greens (spinach, Swiss chard, collards, kale, rape, mustard, turnip)

High quality leafy greens should be fresh, fairly tender and clean, well trimmed, free of decay, discoloration, pests and damage. The leaves should have varietal color characteristics. Spinach leaves are typically harvested about mid-maturity, while other greens may be allowed to grow until the leaves have reached full size. Leafy greens are very perishable, especially prone to wilting, and therefore harvested leaves should be shaded and cooled immediately. Pre-cooling can be carried out using hydro-cooling, liquid icing, package icing, and top-icing. Leafy greens are not chilling sensitive and they should be kept at 32°F with 95 to 98% RH. Harvest of most leafy greens in the cooler part of the day, rapid cooling, and topping with ice can result in 10 to 14 days of storage. Turnip greens are more perishable, while kale has a longer storage potential of 21 days.

Ethylene production of leafy greens is very low, but exposure to ethylene will cause yellowing of the leaves.

Retail outlet stands should be refrigerated or use ice. Use misting if the environment is dry. Turnover is helpful in maintaining quality, so use of small display areas and restocking frequently with refrigerated produce is encouraged. Retail mixing of greens in modified atmosphere packaging or clam shells is risky since some greens will degrade more quickly than others, rendering the entire package unacceptable.

The leaves of high quality Swiss chard are turgid and dark-green, with a white or red midrib and petiole appropriate to the variety. Loss of quality of Swiss chard is associated with yellowing or browning and wilting. Leaves of similar size are harvested and banded together and packed loose in containers. Plastic films can be used to reduce water loss from the leaves.

Swiss chard should be stored at 32°F with 95 to 98% RH. The storage life can be up to two weeks. Hydro-cooling or vacuum cooling can be used, but room cooling is common. Swiss chard is not sensitive to chilling injury. Controlled atmosphere storage can increase the storage life, but it is not used commercially.

Swiss chard produces very low levels of ethylene, but it is highly sensitive to exogenous ethylene. Exposure results in more rapid yellowing and senescence.

The leaves of Swiss chard are very delicate and lose water easily if not in plastic liners. Ice or refrigerated displays are recommended at the retail outlet level. Mist if the environment is dry. Use small display areas and restock frequently with refrigerated produce.

3.31 Leek

Leaves of leeks should be firm and smooth, free of blemishes, green and the base of the stalk white without discoloration. The cut bottoms should be flat as rounded bottoms may indicate prolonged storage. Loss of quality is associated with yellowing, wilting and decay, and elongation and curvature of the leeks.

Hydro-cooling, icing, and vacuum cooling can be used to pre-cool leeks. The leeks should be stored at 32°F with 95 to 100% RH, and leeks can be stored in crushed ice. Storage periods under these conditions can be five to six weeks. Controlled atmosphere storage can retard yellowing and decay development, but it is not used commercially.

Leeks produce very low levels of ethylene, but they are moderately sensitive to exposure; ethylene can induce softening, yellowing, and decay.

For retail outlet display, leeks should be stored in refrigerated displays at 32°F or with ice.

3.32 Lettuce

High quality lettuce should be clean, free of browning, crisp and turgid, and bright color. Leaves of all harvested lettuces should be free from insect, decay, or mechanical damage. Loss of quality is associated with wilting, yellowing and browning of the leaves. Romaine, Boston/Bibb, and leaf lettuce should be harvested when heads are mature, and they are not too loose or tight. The lettuce should have brightly colored outer leaves. Crisphead lettuce is harvested when the full head can be slightly suppressed with moderate hand pressure. Loose heads are immature, while overly hard heads are past maturity. Soft heads are easily damaged, while hard and extra hard heads are more prone to develop russet spotting, pink rib and other physiological disorders. Three to four wrapper leaves should be left to protect the heads. Over-mature crisphead and Romaine lettuces tend to lack flavor and have increased postharvest problems. Non-crisphead varieties are more susceptible to damage during harvest and transport, and therefore have a shorter shelf life than crisphead varieties. Both crisphead and leafy lettuce types should be stored at 32°F and at least 98 to 100% RH. Rapid cooling will improve market quality and shelf life. Recommended cooling methods are vacuum cooling and forced air cooling. Ice made with potable water may be used in packages to supply moisture and remove heat. Lettuce is not sensitive to chilling injury.

The storage life of head lettuce can be up to four weeks but is much shorter for Romaine lettuce. A storage temperature of 41°F will decrease storage potential by 50%. Use of polyethylene films or film liners will help maintain high RH, but these must be perforated to prevent injurious gas atmospheres around the leaves. Controlled atmosphere storage will increase the storage life of lettuce but this technology is not used in New York.

Ethylene production of lettuce is very low, but exposure to ethylene can cause russet spotting and yellowing of the leaves.

At the retail outlet market, lettuce should be refrigerated, iced or misted with water. Avoid placement near fruits and vegetables that produce ethylene. Packing lettuce in cellophane or plastic bags prevents wilting.

3.33 Melons

Muskmelons (Cucumis melo) are divided into smooth skin (Honeydew, Crenshaw, Casaba) and netted skin (Cantaloupe, Persian). In New York the use of plastic mulch and plastic or cloth tunnels allow seedling planting in the spring, before the danger of frost has past. This gives the melons time to ripen before the weather turns cool. High quality melons should be well-shaped, spherical and uniform, with a smooth stem end and no peduncle (stem attachment), which would indicate a premature harvest. There should be no scars, sunburn or surface defects, no evidence of rough handling and it should appear to have a firm internal cavity with no loose seeds or accumulation of liquid.

When the stem separates completely from the fruit (full slip), it is considered fully developed with maximum flavor. Its quality will start to deteriorate unless the melon is cooled or consumed quickly. Fruit for the local market may be harvested at the full slip stage but if the melons will be shipped elsewhere, they are usually harvested at one-half slip or three quarter slip to reduce damage. It is important to pick frequently to get the best quality melons. Honeydew melons do not slip from the vine so it is important to check for when the tendrils near the stem become brown and dry, the fruit surface becomes rough to the touch and the fruit color becomes dull. This would indicate the ideal time to pick a fully mature melon.

Melons are often pre-cooled by forced air or sometimes by hydro-cooling and packed in cartons to be shipped. Full slip melons can be held for 14 days at 36-41°F with 85-95% RH without deteriorating, and even longer for less mature melons. Casaba melons have low ethylene production and sensitivity while Crenshaw, Honeydew and Persian melons are moderate producers with high sensitivity to ethylene. Cantaloupes are high ethylene producers but have moderate sensitivity. Effects of ethylene are loss of firmness, yellowing and an increase in volatiles.

Long distance shipment of melons benefits from controlled atmosphere storage with high carbon dioxide which retards decay development, color change and softening.

Whole melons are usually displayed at room temperature in retail markets, either in bins or on shelves. If sliced, guidelines for safe handling must be followed so that Salmonella found on the rind does not contaminate the fruit. The rind of the whole melon should be scrubbed with potable water and rinsed with clean water. Clean and sanitized knives and cutting boards must be used. The rind should be removed from cut melons at retail where the rind of one piece could touch the flesh of another. Over wrapping of quartered or halved melons is permitted. Cut melons must be refrigerated at or below 41°F at all times. If the cut melons are maintained at 41°F with ice, the container with the cut melons should be below the ice, otherwise, the appropriate temperature will not be maintained.

3.34 Mushroom

High quality mushrooms have a uniform, well-rounded cap with a smooth glossy surface and fully intact veil. The cap should be white or dark brown. Loss of quality is associated with open caps, absence of a stipe, and the presence of disease, spots, insect injury and decay. Water loss is associated with stipe blackening and veil opening.

Mushrooms should be pre-cooled to 32°F immediately after harvest by room cooling or forced air cooling, and stored at 32°F with 95% RH. Mushrooms are not sensitive to chilling injury, and they can be stored for seven to nine days at low temperatures. Controlled atmosphere storage has moderate benefits, but it is not commonly used.

Mushrooms should be packed in cartons with a perforated over-wrap of polyethylene film to reduce water loss, but condensation of water inside packages must be avoided.

Mushrooms produce very low levels of ethylene, exposure to ethylene causes browning of the caps.

For retail outlet display, mushrooms should be kept on refrigerated shelves. Storage close to ethylene producing products should be avoided. Mushrooms should also be kept separate from green onions as they absorb odor.

In the Northeast there is increasing interest in forest mushrooms such as pompom (Hericum erinaceous) and Lion's mane (H. americanum). Little information about storage of these species is known, but it is likely that storage conditions will be similar to those recommended for button mushrooms. Commercial experience has shown that these species have much better quality maintenance if stored in perforated polyethylene films.

3.35 Onion (dry)

High quality onions should have mature bulbs with good firmness and compactness of fleshy scales. Bulbs should have well shaped thin necks and no soft or moldy spots. Bulbs should be free of mechanical or insect damage, decay, sunscald injury, greening of fleshy scales, sprouting, bruising, doubles and abnormally large necks.

For long term storage, onions should be harvested when 50 to 80% of the tops have fallen over and the bulbs are mature with a thin neck. Bulbs harvested when the neck is completely dry have a shorter storage life. Onions intended for storage must be dried well and cured in the field, in sheds, or in storage, to promote drying of the neck and outer bulb scales. Field-cured onions must be protected from the sun to prevent sunscald injury. Bulbs can be covered with cloth bags or arranged in the field with tops of one row of bulbs cover the next row of bulbs.

Curing is carried out using forced-air ventilation that is controlled thermostatically by an air proportioning system. Airflow should be uniform throughout the storage facility to maintain consistent temperature. At a weight loss of about 5%, the tight neck and dry scales form an effective barrier to further reduce water loss and susceptibility to pathogens. Neck rot is the most prevalent disease for onions, occurring if bulbs are not cured completely after harvest. Exposure of bulbs to light after curing causes greening of outer scales.

Pungent, dry onion bulbs should be precooled to 32°F immediately after drying. Rapid pre-cooling inhibits rooting and sprouting more effectively than gradual cooling (e.g. 2.8°F per day). The optimum storage temperature for onions is 32°F at 65 to 75% RH. High temperatures induce sprouting, high RH induce root growth, while high temperatures and RH increases decay and loss of quality. Mild or sweet onions have a shorter storage period than pungent types and can be kept in refrigerated rooms or common storage.

Onions are often stored in common storage, using cool ambient air to maintain low temperatures and RH. Storage periods are shorter in common storage than refrigerated storage, however, because of losses due to sprouting and decay. Onions in cold storage should be kept in crates and containers with good ventilation. Storage in sacks is limited because of insufficient air movement.

Onions enter a state of rest after harvest for a period of four to six weeks, depending on variety and weather conditions before harvest. Breaking of dormancy, or spouting, is inhibited at 32°F, but released rapidly at 50 to 59°F. The sprouting inhibitor, maleic hydrazide, used commonly by conventional growers before harvest, is not available to organic growers.

Controlled atmosphere storage is not used in New York for pungent onions, but may extend the storage period of sweet onions. Onions produce very low levels of ethylene and they are not very sensitive to the gas. However, low levels of ethylene may retard sprouting, while high amounts may induce sprouting.

Onions should be shaded during retail outlet display. The bulbs can be sold in bulk or small packages, preferably at 41°F. This temperature retards sprouting. Pungent onions should be separated from sweet onions and they should not be stored with fruits and vegetables that tend to absorb odors (Table 2.3).

3.36 Onion (green) and shallot

High quality green onions *(Allium cepa)* and shallots *(Allium cepa var. ascalonicum)* should be turgid with no seed stems. The tops should be green, the bulb trimmed and there should be overall freedom from defect and decay. Both can be pre-cooled with package icing, hydro-cooling or water spray vacuum cooling. Both last about 3 weeks when stored at 32-36°F with 95-100% RH. Green onion odor is absorbed by figs, grapes, mushrooms, rhubarb and corn so care must be taken when multiple crops are stored together.

Green onions can be stored for 6-8 weeks under controlled atmospheres but there are no recommended conditions for shallots. Both are low ethylene producers but shallots have low sensitivity to ethylene while green onions are highly sensitive.

Green onions and shallots benefit from misting when displayed or being packaged in perforated polyethylene film to reduce moisture loss.

3.37 Parsley

High quality parsley should be green and turgid with no defects, seed stems or decay. Loss of quality is associated with wilting, yellowing and decay.

Pre-cooling can be carried out by icing, forced air, hydro-cooling or vacuum cooling. Parsley should be stored at 32°F with 95 to 100% RH. Parsley is not sensitive to chilling injury. Storage life can be one to two months under these conditions. Packing the parsley in perforated polyethylene bags helps maintain freshness. Parsley responds to controlled atmosphere storage, but the effects of modifying the atmosphere are more evident at higher storage temperatures where the storage life is shorter.

Parsley produces little ethylene, but is highly sensitive to ethylene in the atmosphere. Effects of ethylene on yellowing are reduced by use of the proper storage temperature.

Parsley is often sold in unsealed bunches on ice or with misting at retail displays.

3.38 Parsnip

High quality parsnips are firm, reasonably clean and their surface is relatively smooth, without secondary rootlets or deep ridges. They are topped after harvesting, but not down into the crown. The parsnip is biennial but the crop is grown as an annual. It grows best in cool growing climates. Sweetness is important and can be enhanced by exposure to frost before harvest. Early harvested parsnips can become sweeter in short-term cold storage. Roots are harvested when the diameter at the shoulder is 1-3 inches. Parsnips can be kept in the ground over the winter but must be harvested before any new growth appears.

Parsnips, like carrots, should be hydro-cooled or package-iced. Rapid cooling to below 41°F immediately after harvest minimizes decay and moisture loss during long term storage. Parsnips store well for 4 to 6 months at 32 to 34°F with 98% RH. Parsnips are not stored in controlled atmospheres. They are similar to carrots in that they produce very little ethylene but exposure to low levels of the gas causes bitterness.

Surface browning is associated with bruising and abrasion injury during harvest, although there are cultivars that are resistant. Surface browning increases with time in storage and waxing to reduce moisture loss will increase browning.

Retail display should include water sprinklers or top icing for non-packaged parsnips. Packaged parsnips should be in a cold display case with no ice or water sprinklers.

3.39 Pea

Peas can be of the traditional shelling type where only the seeds are eaten, or the edible pod types, snow/sugar peas or sugar snap/snap peas. High quality peas are uniformly bright green, fully turgid and free from defects and mechanical damage. Stems and calyxes should be green.

Peas deteriorate rapidly, including loss of sugars and flavor, and should be cooled immediately after harvest. Peas should be pre-cooled using forced air cooling, hydro-cooling or vacuum cooling. All pea types are best stored at 32°F with 92 to 98% RH. Under these conditions, storage periods of one to two weeks can be achieved. Garden peas store better unshelled than shelled, possibly because shelling damages the peas, although it has been suggested that pea pods actually act as "modified atmosphere packages" with lower oxygen and higher carbon dioxide around the intact peas.

Little is known about the effects of controlled atmosphere storage. Peas produce very low levels of ethylene, but are moderately sensitive to ethylene after harvest. Exposure to ethylene results in yellowing and increased decay. The calyx is more sensitive than the pod. The negative effects of ethylene are enhanced at warmer storage temperatures.

For retail outlet display, peas should be refrigerated or packed with ice for longer storage life. Surface moisture should be avoided unless the peas are kept at less than 35 to 36°F. Smaller displays encourage rapid product turnover. Retaining stems on the fruit reduces moisture loss and disease occurrence.

3.40 Peach and nectarine

High quality peaches and nectarines have high soluble solids concentrations as measured by a refractometer, and they should have appropriate firmness as measured by a penetrometer. Fruits with firmness of 6 to 8 lb-force on the cheek (8 mm probe) are acceptable to consumers, but fruit of 2 to 3 lb-force are considered ready-to-eat. They should be free from bruising, blemishes and decay. The fruit can be easily bruised during harvest, especially if they are tree ripe. Susceptibility to bruising also varies by variety.

Peaches and nectarines should be stored at 32°F with 90 to 95% RH. In New York, peaches are typically cooled in cold rooms, but forced air and hydro-cooling is more effective. Where appropriate, the fruit can be cooled to 41 to 50°F provided that packing is carried out the next day. Otherwise, fruit should be cooled completely. Controlled atmosphere storage helps maintain flesh firmness and ground color, but it is not used in New York.

Peaches and nectarines are susceptible to chilling injury (loss of flavor, wooliness, mealiness, reddening around the stone), but these symptoms develop faster and more intensely at 36 to 45°F than at 32°F. Although variety specific, it may take 1 to 2 weeks to develop symptoms at 36 to 45°F compared to 3 or more weeks at 32°F. In general, nectarines are less susceptible to chilling injury than peaches, but nectarine susceptibility to injury is also affected by variety. More mature peaches and nectarines tend to be less susceptible to injury.

Peaches and nectarines are climacteric and produce ethylene during ripening.

For retail outlet display, fruit with less than 6 lb-force (8 mm probe) should be displayed cold, while firmer fruit can be displayed at warmer temperatures.

3.41 Pear

Pears are divided into summer and winter pears. The pears are harvested at the firm stage of maturity based on flesh firmness, but require a period of time in cold storage to develop the capacity to ripen to the softness, juiciness and flavor appropriate to the variety. High quality pears also must have the visual appearance specific to the variety as well as freedom from blemishes. Summer pears such as Bartlett have shorter cold storage requirements for proper ripening than winter pears.

Pears are climacteric fruit but do not produce ethylene until removed to warmer temperatures after the cold storage requirement has been met. Unripe pears are somewhat sensitive to ethylene, depending on the variety. Apples and pears are usually never mixed, although in New York mixed rooms have been used by processors for short term storage.

Cooling, typically room cooling, should be prompt. Care should be taken to load rooms in a manner that will allow good air circulation around the bins. Negative effects of slow cooling on the storage life are magnified as the storage period increases. The recommended storage temperature for most pear varieties is 30 to 32°F with 90 to 95% RH. If fruit are stored in cartons as is common in the west, polyliners are effective in reducing water loss.

Conventional growers use postharvest chemicals that are not permitted for use by organic growers. These include fungicides that are sometimes applied to reduce decay.

Controlled atmosphere storage increases the storage period and quality of pears but it is not used commonly in New York.

These limitations reinforce the need for preharvest management of disease pressure, careful handling, use of clean picking buckets and bins, attention to rapid cooling of fruit, and cleanliness in the packing shed. Varieties that are susceptible to scald development should not be stored in air for more than two to three months. Sample fruit periodically while in cold storage, including a couple days at ambient temperatures to follow changes in quality over time. Cut the fruit to look for development of external and internal disorders.

For retail outlet display, refrigeration is best, but because of the longer shelf life of pears, is not commonly used. Ensure turnover of product by keeping displays small, keep out of direct sunlight and in cooler areas of the market. Return fruit to a cooler overnight if possible.

3.42 Pepper

High quality sweet bell peppers and chili peppers have uniform shape, size and color typical of the variety. The flesh should be firm, relatively thick with bright skin color, and free from defects such as cracks, decay, and sunburn. Loss of quality is associated with shriveling, dullness and pitting. Cull injured or poorly shaped fruit.

After harvest, fresh market peppers can be pre-cooled to 45°F using forced air, hydro-cooling or vacuum cooling. Peppers are susceptible to chilling injury and should be stored at no lower than 45°F with 90 to 95% RH. Some varieties are susceptible to chilling injury at 45°F, so monitor fruit during storage. Peppers ripen faster and are susceptible to bacterial soft rot if stored above 55°F. Peppers derive only slight benefit from controlled atmosphere storage.

Peppers are non-climacteric fruits and produce very low levels of ethylene, but they may be affected negatively by exposure to ethylene. Peppers should be stored separately from ethylene-producing fruit.

For retail outlet display, sweet bell peppers and chili peppers should be refrigerated at 45°F. The fruit should not be misted or top iced.

3.43 Plums

High quality plums have a smooth skin with a sweet flesh. Loss of quality is associated with over-softening and susceptibility to bruising, and presence of external defects. The fruit can be easily bruised during harvest, especially if they are tree ripe. Fruit with firmness of about 2 to 3 lb-force are ready to eat.

Plums should be stored at 32°F with 90 to 95% RH. Plums can be passively cooled in cold rooms, but forced air and hydro-cooling is more effective. Controlled atmosphere storage helps maintain flesh firmness and ground color of some varieties, but it is not used in New York.

Plums are susceptible to chilling injury (flesh translucency, flesh internal browning, flesh mealiness, flesh bleeding, failure to ripen and flavor loss). As with peaches and nectarines, these symptoms develop faster and more intensely at 36 to 45°F than at 32°F. The symptoms become more severe after removal of fruit from cold storage to ambient temperatures.

Plums are climacteric and produce ethylene during ripening.

For retail outlet display, fruit with less than 5 lb-force (8 mm probe) should be displayed cold, while firmer fruit can be displayed at warmer temperatures.

3.44 Potato

High quality potatoes should be turgid, well shaped, uniform, brightly colored, with no residual mechanical damage, greening, sprouts physiological defects, or disease. The storage life of potatoes can vary according to variety, quality at harvest, quality of storage facilities, handling, appropriate curing, and control of sprouting. Potatoes can be washed after storage and just prior to sale so storage loss from bacterial soft rot spread via the wash water is minimized. There should be no adhering soil on potatoes grown in quarantined areas because of the possible presence of soil-borne pests such as the Golden Nematode *(Heterodera rostochiensis).*

Common maturity indices for mature potatoes include the ability to resist abrasion (skinning) during harvest, which is closely associated with vine senescence. Immature potatoes are more susceptible to bruising and skinning, which leads to shriveling or decay. Early crop potatoes are more perishable than later harvested ones and they are usually marketed without storage. Sugar content is also used as a maturity index for processing varieties. The sugar content reaches a minimum value that is associated with maximum starch content.

Death of the foliage signals the end of the growth cycle and generally coincides with thickening of the tuber periderm (skin). Vine killing is usually employed 2 to 3 weeks before harvest and is routinely carried out by conventional farmers with the use of herbicides. However, none of the herbicides approved for certified organic farmers are labeled for vine kill. Organic options for vine killing include cutting and beating down foliage with equipment such as a flail mower. Flame weeding of the vines would not be allowed since NOP Standards restrict this practice specifically to weed control. Burning of crop residue is also prohibited, except to suppress the spread of disease, or to stimulate seed germination. Natural senescence can be induced by reducing water applications in some cultivars. Frost damage to the vines can also be useful, but like water supply, is affected greatly by seasonal events. If plants show symptoms of late blight or ring rot, or if potatoes left to mature in the ground are exposed to a frost event and then exposed to additional frosts, they should be cooled without curing and marketed immediately. Discard any tubers damaged by insects or disease.

Potatoes are dug and lifted from the soil and either left on the ground to cure before being collected, or transferred quickly to trailers after separating soil and plant material. Decay is a major cause of postharvest losses for potatoes, and mechanical injuries such as bruising, scrapes and cuts during harvest provide inoculation sources for bacteria and fungi. Therefore, careful harvest and handling practices are critical to ensure minimal bruising and damage. Harvest in wet cold conditions should be avoided as potatoes bruise easier at lower temperatures, and wet conditions facilitate infection of damaged areas. Curing is used to stimulate suberization or wound healing, making less susceptible to damage and disease.

Suberization is the primary means of reducing water and quality loss and minimizing disease development during storage. The time needed for wound healing can vary according to temperature conditions. In New York, temperatures of 50°F to 60°F with high RH should be provided for 1 to 3 weeks at the beginning of the storage period. Lower and higher temperatures can reduce the rate of curing. Although harvest temperatures can be lower than the recommended curing temperatures, the respiration of the potatoes in storage will increase temperatures and raise the RH. Temperature and RH control during this "sweating" or curing time is managed by forced air ventilation.

If potatoes are cured in the field, they can be damaged by sun exposure that results in localized cell death known as sunburn or sunscald. Light exposure can also trigger greening as a result of chlorophyll synthesis, resulting in production of toxic glycoalkaloids.

After curing, the storage temperature should be lowered 2-4°F per day until the desired temperature and RH are reached. Tablestock and seed potatoes should be stored at 40°F, 45°F for Andover, Marcy, Reba or Snowden, or 50°F for chipstock varieties such as Atlantic. The low temperatures for tablestock and seed potatoes help suppress sprouting, but potatoes for processing must be stored at no less than 45°F to minimize conversion of starches to glucose and other sugars. Many chipping varieties accumulate sugar if stored at temperatures less than 50°F, resulting in the flesh turning brown when chipped. Potatoes should be stored in dark environments to prevent greening.

Adequate ventilation of potatoes during storage is essential to maintain dry surfaces and thereby avoid ideal growing conditions for growth of microbes. Also, bacterial soft rot can occur in lenticels of wet tubers even without mechanical damage. Desired storage temperature is best achieved with forced-air ventilation that is controlled thermostatically by an air proportioning system. Airflow should be uniform throughout the storage facility to maintain consistent temperature and oxygen levels. Flow rates can range from 0.5 to 4/5 cu. ft./cwt/min, for maintenance of temperature, but higher rates may be needed if severe rot potential exists in order to dry the potatoes. However, excessive flow rates will dehydrate potatoes, especially at low RH.

Organic growers must manage sprouting by storing at 38-40°F, using reduced storage periods or sprout suppressors (Table 3.3; Frazier et al., 2004). Temperatures lower than 38°F may encourage sprouting in storage. Use of the sprout inhibitor, chlorpropham (CIPC), is prohibited. Most potato varieties are dormant for two to three months after harvest and therefore sold before sprouting occurs. Sprout suppressors used in conjunction with good storage management may help extend the storage season. Sprout suppressors are applied before the sprouts are one eighth of an inch long, and require repeated applications.

Controlled atmosphere storage has little beneficial effect on potato storage and is not recommended. Potatoes produce very low levels of ethylene unless they are injured, but they are not very sensitive to the gas. However, low levels of ethylene may retard sprouting, while high amounts may induce sprouting.

Potatoes should be washed, but allowed to dry before retail outlet display. Storage in paper bags will prevent exposure to light and consequent greening. Potato displays should be replaced regularly to ensure product turn-over, and any greening potatoes culled. New potatoes that are displayed in bulk can be misted or sprinkled with water.

Table 3.3 Sprout Suppressors

Class of Compounds Product Name (active ingredient)	Rate/A Product	PHI (days)	REI (days)	Efficacy	Comments
Volatile Oils					
Certified organic peppermint oil[1]	10 lbs oil/1000cwt potatoes/month	0	0	1 / 1	25(b) pesticide. Wick application method most effective; apply 50 ppm every two weeks, 75 ppm every three weeks, or a daily application of 4 ppm.
Certified organic clove oil[1]	5.2 lbs/1000 cwt	0	0	1 / 1	25(b) pesticide. Apply as thermal aerosol; repeat applications of 1.9 lbs/1000cwt necessary at 2-3 week intervals.

[1]Check with your certifier before use. If potatoes are sold as a food crop, Section 205.606 National Organic Standards applies; since non-organically produced clove and peppermint oils are not on this approved products list, certified organic clove and peppermint oils are required. If potatoes are sold as seed potatoes, certified organic oil is not required.

3.45 Radish

Radish roots should be uniform and of similar shape, smooth, with firm but tender texture, free of growth or harvest damage, disease or insects. Bunched radish tops should appear fresh, turgid, free of freezing or other serious injury, seed stalk, discoloration, disease, decay or insects. Radishes should be picked when at least 5/8 inches in equatorial diameter, but ideally 1.5 inches. Just the roots can be stored, or both roots and tops. They store best at 32°F with 95-100% RH and should last 1-2 months under these conditions. They produce very little ethylene and have low sensitivity, primarily resulting in bunched tops getting yellow after prolonged exposure in storage. Radishes can develop freezing injury where roots appear water-soaked and glossy and shoots become water-soaked, wilted and turn black if the temperature drops to 30°F in storage.

Controlled atmospheres are slightly beneficial by helping to retard regrowth of shoots and rootlets in 'topped and tailed' roots. Prompt cooling, chlorination and refrigeration is effective in controlling bacterial black spot and bacterial soft rot.

Radishes will look fresh when displayed if the roots are previously held in water. Otherwise a plastic bag or wrap will discourage moisture loss.

3.46 Rhubarb

High quality rhubarb stalks should be straight and crisp, free of blemishes and decay. The major cause of quality loss after harvest is leaf blade breakdown and leaf blade rot. Therefore the leaf blades should be removed and discarded before packaging and marketing. However, a small portion of leaf blade will lessen the possibility of petiole splitting.

After pre-cooling, rhubarb should be stored at 32°F with 95 to 100% RH. Pre-cooling can be by room cooling or hydro-cooling. Whole, packed stalks can be stored for two to four weeks at 32°F with 95 to 100% RH, but cutting stalks to shorter lengths will markedly reduce the potential storage periods achievable. Controlled atmosphere storage is not used for rhubarb.

Ethylene production by rhubarb is low, but it is sensitive to the gas.

Rhubarb should be displayed under refrigeration, and kept away from ethylene producing fruits and vegetables.

3.47 Rutabaga (Swedes, Swedish turnips, turnip-rooted cabbage)

The rutabaga is a cool season crop that is able to withstand frost and mild freezing. A high quality rutabaga is a rounded, purple-topped root with a small neck and a taproot. It has a minimum of side roots, and is firm and heavy for its size. Lighter rutabagas may be woody, a defect that is encouraged by harvesting the winter crop after the weather has gotten hot. They should be harvested when sweet and fully mature. An immature rutabaga can be bitter. The flavor of a fall crop can be sweetened by harvesting after the first frost.

Roots should be rapidly cooled to 32°F and this is most commonly done through room cooling. The rutabaga can also be hydro-cooled, forced air cooled or package-iced to speed the cooling, and help control weight loss, decay and the development of 'storage burn', which is a brown surface burn. Rutabagas can be kept at 32°F for 4 to 6 months with 98 to 100% RH. Storage at 41°F with 90% RH for 6 months can result in 11% weight loss. Higher than recommended storage temperatures also promote rot diseases. Rutabagas destined for immediate sale are often waxed to protect against moisture loss and improve appearance. If in long-term storage, they should not be waxed since gas exchange is diminished and the appearance of the wax coating degrades after extended storage.

Rutabagas produce very little ethylene and are not sensitive to it. They are not stored in CA. Rutabagas are not chilling sensitive. They freeze at around 30°F with symptoms including small, water-soaked areas on the skin with injured flesh appearing tan or gray and giving off a fermented odor. Fruits and leafy vegetables should not be stored in the same room with rutabagas since strong odors can transfer.

Once in the marketplace, there must be no soil adhering to rutabagas grown in NYS because of the possible presence of soil-borne pests such as the Golden Nematode *(Heterodera rostochiensis)*. A permit to import to Canada and other countries is required.

Rutabagas should be put in refrigerated displays. They can be top-iced but should not be misted. They are suitable as a fresh-cut product and are either peeled, cubed or shredded and put in film bags. They will keep up to 21 days in modified atmospheres.

3.48 Sprouts, Alfalfa or Mung bean

High quality bean sprouts are usually harvested within 4 to 6 days of germination; high quality sprouts are intact, turgid and white, without dark streaks or other discoloration, bruising or mechanical damage. Symptoms of deterioration are discoloration, development of sliminess, decay and off-odor. Bean sprouts are susceptible to bacterial infection and have been associated with food safety concerns because of human pathogenic bacteria. Good worker hygiene and sanitary processes must be maintained at all stages of handling of sprouts along with low temperature storage.

Sprouts are highly perishable and should be cooled to 32°F with 95 to 100% RH. Spouts can be cooled using vacuum cooling, hydro-cooling or forced air cooling. The storage life of sprouts can be increased by use of modified atmosphere packaging.

The ethylene production of sprouts is small, but exogenous ethylene can affect growth of sprouts. At retail outlet displays, sprouts should be kept refrigerated at 32°F, or on ice. Do not use misting.

3.49 Squash, summer

Zucchini is the most widely grown and economically important summer squash. High quality summer squash are harvested young, when only a few inches long and while the skin is still shiny. Tenderness and lack of seeds are the most important quality attributes. Yellowness, a dull appearance, and loss of firmness are signs of senescence and water loss. Summer squashes have a soft skin and they are injured easily by scratches, bruising or scuffing. Damaged fruit should be discarded as breaks in the skin can result in faster water loss and increased decay.

Pre-cooling can be by room, forced air or hydro-cooling. Rapid cooling reduces water loss from the fruit. Summer squash are susceptible to chilling injury and the optimum storage regime is 41 to 50°F with 95% RH. However, the storage potential of summer squash is less than two weeks even under the best conditions. Controlled atmosphere storage has no benefit.

Summer squash produce low to moderate levels of ethylene. Exogenous ethylene can cause yellowing of green skinned varieties.

At retail outlet displays, summer squash can be refrigerated. They should not be allowed to come into contact with ice. Display squash in the shade if refrigeration is not available.

3.50 Squash, winter (Acorn, Buttercup, Butternut, Delicata, Hubbard, Pumpkin, Sweet dumpling, Spaghetti)

Winter squash should be fully mature with hard rinds, and except for some striped varieties, they should have solid external color. The flesh of winter squash is bright yellow or orange with a fine, moist texture. Over-mature flesh can become dry and stringy. Even though winter squash are a hard fruit, they still bruise if not handled carefully.

Delaying harvest increases the potential for decay. Also, sensory quality improves more in storage than on the plant. Removing the stem may reduce the incidence of rot but the stem scar can be a site for greater water loss.

Only mature fruit that is free of disease should be stored. The fruit should be harvested and placed under shelter before chilling or freezing can damage it, as winter squash are sensitive to chilling injury in the field and in storage. Fruits subjected to temperatures below 50°F for two weeks or more can be more susceptible to breakdown and decay.

Squashes are susceptible to chilling injury and they should be stored at 50 to 55°F with 50 to 75% RH. For long term storage, a higher RH of 70-75% helps to reduce water loss. Common storage is often used. The squash can be stored on racks, in bulk bins, or in baskets. Regardless of storage type, good air circulation is desirable to maintain dryness and maintain uniform temperature around the fruit throughout the storage period.

For best quality of winter squash other than acorn, they should be cured at 70°F for 10 days. Acorn squash should not be cured as they store poorly and should be sold within five to eight weeks of harvest. Greenhouses are a good place to cure winter squash.

Pumpkins and most winter squashes cannot be stored for more than two to three months, but good quality Hubbard and Butternut squashes can be stored for six months at 70 to 75% RH. Winter squash responds well to controlled atmosphere storage but decay incidence can be higher if RH is not managed properly.

Winter squashes produce very low levels of ethylene, but exposure to ethylene can cause skin color changes to orange-yellow and stem abscission.

For retail outlet display, winter squash can be left at ambient conditions. Fruit should be protected from low temperatures if left outside.

3.51 Strawberry

High quality strawberries are uniform in size, have a glossy bright red skin, and strong aroma and flavor. Strawberries are highly perishable, with loss of quality associated with development of dullness and dark red color, loss of flavor and decay. The skin of the strawberry is very delicate and easily bruised while picking, both by touching the berries during harvest and by generating impact bruises while being placed in containers and during transport.

In New York, pick-your-own operations are common, but retail demand is increasing. Maximizing the storage potential of the berry requires attention to pre-harvest disease control and sanitation, maturity selection, avoiding injury during harvest and packing, grading to eliminate injured and diseased berries, protection from warming, and prompt cooling.

Decreasing disease pressure before harvest is critical. In addition to the use of organically prescribed disease and pest control, plants should be grown with good airflow through the canopy, and berries should not touch damp soil. Cleanliness and sanitation in the planting is important. Touching of infected berries followed by touching of healthy berries will result in transfer of decay-causing organisms, so it is best to designate pickers to remove infected, damaged and over-ripe fruit separately. During harvest, any diseased, damaged or overripe berries should be kept separate from healthy berries and burned or buried. Removal of these berries, along with any berries dropped during harvest, reduces disease pressure from gray mold, leather rot and anthracnose, strawberry sap beetle and slugs.

Harvest of strawberries should be gentle with little pressure placed on the berry itself to avoid finger bruising. Harvest should be carried out as frequently as needed to avoid over-mature berries. Any overripe berries should be discarded if fruit will be stored. Strawberries are non-climacteric and while they will develop red color after harvest, they will not develop good flavor if picked while immature. However, mature berries have shorter storage potential than less fully mature berries. The berries should have a half to three-quarters pink or red color on the surface to meet US quality standards. If strawberry storage is required, berries should be harvested within a narrow maturity (color) range so that they will respond to postharvest treatments in a uniform manner. Mixed ripening is also unattractive in the marketplace; unripe berries are slow to ripen, while the over-ripe berries lose their glossy appearance and become susceptible to mold. This mold provides inoculum sources that will infect the other berries.

Berries can be graded and field packed into shallow containers for market, or graded on a post-harvest grading table. Postharvest grading allows an additional opportunity to grade out damaged berries and ensure uniform maturity. Even small skin lesions, and any fruit with cuts, finger bruises, torn or removed calyxes can be discarded.

Temperature management is the most important factor in minimizing strawberry deterioration and maximizing berry storage life. Strawberries should not be left in the field exposed to direct sunlight and containers should be shaded if not transported quickly. Low storage temperatures maintain berry quality while minimizing growth of decay causing pathogens. Rapid cooling within an hour of harvest is critical to maintain quality of strawberries after harvest, but the rapidity of cooling is more important with longer storage requirements.

Room cooling is commonly used in New York, but forced air cooling is highly recommended to maintain berry quality. Strawberries are not chilling sensitive and they should be stored at 32°F with 90 to 95% RH. We have shown (Shin et al., 2008) that reducing temperatures to only 50°F can be beneficial for storage of berries that are harvested at early maturity stages, but decay pressure is likely to be much greater at warmer temperatures. At 32°F, strawberries can be stored for a week or more, but the actual storage periods achievable are affected greatly by variety, berry maturity, and pre- and post-harvest conditions. Condensation, which can result in undesirable loss fruit 'glossiness', when fruit are warmed can be avoided by using plastic sheets (see section 2.4).

Controlled atmosphere storage using high carbon dioxide (10 to 15%) maintains berry firmness and inhibits decay. In California, modified atmosphere package systems are used, whereby pallets of strawberries encased in pallet shrouds are injected with carbon dioxide prior to shipment. Only limited use of tent based controlled atmosphere systems has been carried out in the northeast. Varieties can differ in their tolerances to elevated carbon dioxide.

Strawberries produce very low levels of ethylene and do not respond to the gas.

At retail outlets, strawberries should be displayed under refrigerated conditions. Covering the baskets with plastic film maintains a higher RH around the berries and reduces water loss and shriveling.

3.52 Sweet corn

High quality sweet corn has uniform size and color, whether yellow, white or bicolor, and has plump, tender and well developed kernels. The husk should be fresh, tight and green, free of insect injury, mechanical damage, and decay. All sweet corn varieties are highly perishable, with loss of sweetness, aroma and tenderness during storage. Kernel denting may occur with a moisture loss of 2 percent or less. Sweet corn has a high rate of respiration and therefore rapid cooling of the ears is important. If delays before transporting to the packing shed occur, use shade and if possible, water the ears well to maintain high moisture content.

At the packing shed, sweet corn should be trimmed uniformly to eliminate flag leaves and long shanks as they increase water loss from the ears. Any ears exhibiting signs of disease or mechanical or insect damage should be discarded along with any ears that lack adequate shuck coverage.

Pre-cooling to 32°F within an hour of harvest results in optimum quality retention, but is rarely achieved in commercial practice. Nevertheless, rapid cooling is the first step in quality management. Package and top icing is a rapid means of cooling the sweetcorn and helps keep the husk fresh. Hydrocooling and vacuum cooling are also highly effective.

Sweet corn should be stored at 32°F with 90 to 98% RH. Sweet corn is not susceptible to chilling injury. Traditional sweet corn varieties are usually kept only a few days, while the supersweet corn can be stored for up to two weeks if conditions are optimal. Controlled atmosphere storage is not usually used.

Sweet corn has very low ethylene production and exposure to high ethylene is usually not a problem.

At the retail outlet level, sweet corn should be kept refrigerated or on ice.

3.53 Sweet potato

Cultivars of sweet potato can vary from white to orange to purple, from sweet to non-sweet, from mild to intense in flavor and from firm to very soft. Roots continuously grow and can enlarge until their interiors become anaerobic and rot. Ideally, roots are harvested when they are 3.2 – 3.5 inches in diameter and weigh 18 to 20 ounces.

Immediately after harvest the roots should be cured for 4 to 7 days at 84 +/- 2°F, 90 to 97% RH with good ventilation. This curing period helps to heal wounds and reduce moisture loss and the incidence of decay in storage. The roots should then be moved to storage at 57 +/- 2°F with 90% RH. Sweet potatoes store well without sprouting for up to a year but will lose sensory quality with extended storage. Storage at 66°F or above results in sprouting after a few months, and storage at 55°F or lower, results in chilling injury.

Chilling injury symptoms include shriveling, surface pitting, fugal decay, internal tissue browning, abnormal wound periderm formation and hardcore formation. Hardcore only appears after cooking. Non-cured roots appear to be more susceptible.

Pithiness (reduced density, spongy roots) is another physiological disorder that is encouraged by sprouting in storage, low soil temperatures before harvest (41-50°F) and curing and storage conditions that promote a high metabolic rate.

Sweet potatoes produce very low or no ethylene. Ethylene exposure should be avoided since levels as low as 10 ppm result in increased discoloration and reduced β-amylase activity. So long as the storage is properly ventilated with an air flow of 36 ft^3 min^{-1} ton^{-1}, this should not be a problem.

A controlled atmosphere may have some benefit by increasing total sugars, reducing the rate of respiration and possibly offering some control of the sweet potato weevil. So far the cost outweighs the benefit. If the weevil is present, the roots should not be shipped to other areas of the country. In retail outlets, sweet potatoes are typically displayed unpackaged and at room temperature.

3.54 Tomato

High quality fruit have a turgid appearance, uniform color without signs of mechanical injuries, shriveling or decay. Fruit are sold singly or in clusters, and a fresh-looking green stem appearance can be an additional quality characteristic for consumers. Principal causes of postharvest losses are decay, external damage incurred during harvest and handling, and harvest at the improper maturity stage. No postharvest chemicals are applied to tomato and therefore proper harvest, handling and storage methods are the same for the organic and conventional grower. However, extra effort to minimize disease pressure before harvest is critical. Any decaying or damaged fruit should be discarded immediately.

Tomatoes can be harvested at the mature green stage through to red ripe depending on the market requirements. A fruit allowed to ripen on the vine will develop fuller quality characteristics such as sugars, vitamin C, aroma and flavor, but will have a short storage life. Different tomato varieties also have very different storage potential; most modern ones have longer storage potential because of the use of slow ripening mutants in breeding programs.

Immature green tomatoes with immature seeds and no gel in the locules will not ripen to acceptable quality. Mature green tomatoes should have seeds that are pushed aside when the tomato is sliced and all the locules have gel, or when red color is visible in the gel and pericarp tissues. Subsequent ripening stages are defined as:

Breaker—a definite break in color from green to tannish-yellow, pink or red on not more than 10% of the surface.

Turning—10% to 30% of the surface shows a definite color change to tannish-yellow, pink, or red, or a combination of colors.

Pink—more than 30% but less than 60% of the fruit is pink or red.

Light red—more than 60% but less than 90% of the fruit surface is red.

Red ripe—more than 90% of the fruit surface is red.

Tomato fruit are climacteric, ethylene production and increased respiration occurring at the breaker stage of maturity. After harvest, tomatoes are either kept at ambient temperatures to ripen, or cooled for storage. Room cooling is common, but forced air cooling is more uniform and produces a better quality fruit.

Optimum storage temperatures depend on the maturity stage of the fruit. Mature green tomatoes should be stored at 55°F with 90-95% RH as fruit are susceptible to chilling injury at lower temperatures and will ripen faster at warmer temperatures. Red ripe tomatoes can be stored for a few days at 45 to 50°F, RH 85-90%, but flavor and aroma may be compromised and the fruit susceptible to chilling injury. Varieties vary in susceptibility to chilling injury, which is manifested as pitting, non-uniform ripening and storage decays.

Controlled atmosphere storage can extend the storage life of tomatoes, but it is not commonly used. The exact oxygen and carbon dioxide atmospheres vary by variety and maturity stage, though 3% oxygen and 2% carbon dioxide appears to have wide applicability.

Retail outlet displays of tomatoes should be shaded, and the fruit should not be refrigerated or iced. Uniformity of size, grade, firmness and color is desirable as consumers tend to avoid packages with fruit of different colors, decay or external blemishes. Sometimes color mixing may be good for marketing, such as at farmer's markets, but should not be done if fruit are to be stored since different varieties and maturities may degrade at different rates.

3.55 Turnip

High quality turnips are firm and free of woodiness, pithiness, growth cracks, rot and injury. These small, white-fleshed roots that are typically purple on the top half, can be grown in warm soils (> 77°F), while large yellow-fleshed rutabagas are grown in cool soils. There are some yellow-flesh turnips. Roots should be at least 1.75 inches (4.4 cm) in diameter yet free from woodiness to be considered mature. Turnips are packaged either with tops 6 inches or greater, or 4 inches or less, or 0.75 inches or less. They are bunched as fresh roots and leaves, or topped and packed in mesh bags or vented plastic film.

Turnips can be pre-cooled in wash water, so long as the temperature of the water is not more than 18°F cooler than the temperature of the roots to prevent cracking. They can be stored for 4 to 5 months at 33-36°F with 90 to 95% RH. They do not get chilling injury but should not be frozen. Storage at 32°F may result in freezing damage while storage at > 41°F accelerates soft rot development and weight loss. They do not produce measurable ethylene and are not sensitive to it. CA is not used. Turnips can be put in refrigerated displays and misted to maintain high RH.

3.56 Watermelon

High quality watermelons are well formed, symmetrical and uniform in shape with a waxy, bright appearance. The rind should be free of scars, sunburn, and abrasions, with no bruising or other physical injury, and without decay. Because of their large size and propensity to crack or split under mechanical stress, watermelons should not be harvested in the early morning when they are most turgid. A short length of peduncle should be left attached to the fruit at harvest to deter stem end rot.

Watermelons are generally not pre-cooled. They develop chilling injury, expressed as rind browning and fading of flesh color, if stored at less than 50°F for more than a few days, and therefore watermelons should be stored at 50 to 59°F with approximately 90% RH. The fruit should be consumed within two or three weeks of harvest. Watermelons do not respond to controlled atmosphere storage.

Watermelons produce low levels of ethylene, but exposure of fruit to as little as 5ppm ethylene causes softening, rind thinning, flesh color fading, and over ripening.

At retail outlet outlets, whole watermelons are usually sold from unrefrigerated displays. If sliced, guidelines for safe handling must be followed so that Salmonella found on the rind does not contaminate the fruit. Sliced fruit is refrigerated and guidelines are listed under melons (section3.33).

APPENDIX 1. SUMMARY OF RESPIRATION PRODUCTION RATES

(modified from Gross et al., 2004)

Values shown are approximations or the average rates of a range; see individual sections on each commodity for more specific information and references. To get mL CO_2 $kg^{-1}h^{-1}$, divide the mg $kg^{-1}h^{-1}$ rate by 2.0 at 32°F, 1.9 at 50°F, and 1.8 at 68°F. To calculate heat production, multiply mg $kg^{-1}h^{-1}$ by 220 to get BTU per ton per day or by 61 to get kcal per metric ton per day.

Commodity	31°F (0°C)	41°F (5°C)	50°F (10°C)	59°F (15°C)	68°F (20°C)	77°F (25°C)
			(mg CO_2 kg^{-1} h^{-1})			
Apple (fall)	3	6	9	15	20	nd[1]
Apple (summer)	5	8	17	25	31	nd
Apricot	6	nd	16	nd	40	nd
Artichoke	30	43	71	110	193	nd
Asian Pear	5	nd	nd	nd	25	nd
Asparagus	60	105	215	235	270	nd
Basil	36	nd	71	nd	167	nd
Beans (Snap)	20	34	58	92	130	nd
Beans (Long)	40	46	92	202	220	nd
Beets	5	11	18	31	60	nd
Blackberry	19	36	62	75	115	nd
Blueberry	6	11	29	48	70	101
Bok Choy	6	11	20	39	56	nd
Broccoli	21	34	81	170	300	nd
Brussels Sprouts	40	70	147	200	276	nd
Cabbage	5	11	18	28	42	62
Carrot (topped)	15	20	31	40	25	nd
Cauliflower	17	21	34	46	79	92
Celeriac	7	13	23	35	45	nd
Celery	15	20	31	40	71	nd
Cherry, Sweet	8	22	28	46	65	nd
Chervil	12	nd	80	nd	170	nd
Chicory	3	6	13	21	37	nd
Chinese Cabbage	10	12	18	26	39	nd
Chinese Chive	54	nd	99	nd	432	nd
Chive	22	nd	110	nd	540	nd
Coriander	22	30	nd	nd	nd	nd
Cranberry	4	5	8	nd	16	nd

Cucumber	nd	nd	26	29	31	37
Currant, Black	16	28	42	96	142	nd
Dill	22	nd	103	324	nd	nd
Eggplant (American)	nd	nd	nd	69 [2]	nd	nd
Eggplant (Japanese)	nd	nd	nd	131 [2]	nd	nd
Eggplant (White Egg)	nd	nd	nd	113 [2]	nd	nd
Endive/Escarole	45	52	73	100	133	200
Fennel	19 [3]	nd	nd	nd	32	nd
Garlic (Bulbs)	8	16	24	22	20	nd
Garlic (Fresh Peeled)	24	35	85	nd	nd	nd
Ginseng	6	nd	15	33	nd	95
Gooseberry	7	12	23	52	81	nd
Grape, American	3	5	8	16	33	39
Grape, Muscadine	10 [3]	13	nd	nd	51	nd
Grape, Table	3	7	13	nd	27	nd
Honey Dew Melon	nd	8	14	24	30	33
Horseradish	8	14	25	32	40	nd
Jerusalem Artichoke	10	12	19	50	nd	nd
Kohlrabi	10	16	31	46	nd	nd
Leek	15	25	60	96	110	115
Lettuce (Head)	12	17	31	39	56	82
Lettuce (Leaf)	23	30	39	63	101	147
Marjoram	28	nd	68	nd	nd	nd
Mint	20	nd	76	nd	252	nd
Mushroom	35	70	97	nd	264	nd
Nectarine (ripe)	5	nd	20	nd	87	nd
Netted Melon	6	10	15	37	55	67
Okra	21 [2]	40	91	146	261	345
Onion	3	5	7	7	8	nd
Oregano	22	nd	101	nd	176	nd
Parsley	30	60	114	150	199	274
Parsnip	12	13	22	37	nd	nd
Pea (Garden)	38	64	86	175	271	313
Pea (Edible Pod)	39	64	89	176	273	nd
Peach (ripe)	5	nd	20	nd	87	nd
Pepper	nd	7	12	27	34	nd
Plum (ripe)	3	nd	10	nd	20	nd
Potato (cured)	nd	12	16	17	22	nd
Radicchio	8	13 [5]	23 [6]	nd	nd	45
Radish (Topped)	16	20	34	74	130	172
Radish (Bunched with tops)	6	10	16	32	51	75
Raspberry	17 [3]	23	35	42	125	nd

Rhubarb	11	15	25	40	49	nd
Rutabaga	5	10	14	26	37	nd
Sage	36	nd	103	nd	157	nd
Salad Greens (Rocket Salad)	42	113	nd	nd	nd	nd
Salad Greens (Lamb's Lettuce)	12	67 [6]	81	nd	139	nd
Salsify	25	43	49	nd	193	nd
Spinach	21	45	110	179	230	nd
Sprouts (mung bean)	23	42	96	nd	nd	nd
Squash, Summer	25	32	67	153	164	nd
Squash, Winter	nd	nd	99 [2]	nd	nd	nd
Strawberry	16	nd	75	nd	150	nd
Sweet Corn	41	63	105	159	261	359
Swiss Chard	19 [3]	nd	nd	nd	29	nd
Tarragon	40	nd	99	nd	234	nd
Thyme	38	nd	82	nd	203	nd
Tomatillo (mature green)	nd	13	16	nd	32	nd
Tomato	nd	nd	15	22	35	43
Turnip	8	10	16	23	25	nd
Watermelon	nd	4	8	nd	21	nd

[1] nd = Not determined.
[2] At 54.5°F.
[3] At 35.6°F.
[4] Although not accurately measured, very low is considered to be < 0.05 µL CO_2 $kg^{-1}h^{-1}$.
[5] At 42.8°F. [6] At 45.5°F.

APPENDIX 2. SUMMARY TABLE OF OPTIMAL HANDLING CONDITIONS FOR FRESH PRODUCE

(Modified from Cantwell, 2002)

Crop	Storage temperature (°F)	Relative humidity (%)	Ethylene production*	Ethylene sensitivity[t]	Approximate storage life
Apple					
Not chilling sensitive	32	90-95	VH	H	3-6 months
Chilling sensitive	36-38	90-95	VH	H	1-2 months
Apricot	32	90-95	M	M	1-3 weeks
Artichoke, Globe	32	95-100	VL	L	2-3 weeks
Asian pear	34	90-95	H	H	4-6 months
Asparagus; green, white	35	95-99	VL	M	2-3 weeks
Beans					
Dry	40-50	40-50			6-10 months
Fava, broad	32	90-95			1-2 weeks
Lima	41-43	95	L	M	5-7 days
Long	40-45	90-95	L	M	7-10 days
Snap; wax; green	41-46	95-100	L	M	7-10 days
Beet, bunched	32	98	VL	L	10-14 days
Beet, topped	33-36	98	VL	L	4 months
Berries					
Blackberry	32	90-95	L	L	3-6 days
Blueberry	32	90-95	L	L	10-18 days
Cranberry	37-41	90-95	L	L	6-16 weeks
Dewberry	32	90-95	L	L	2-3 days
Elderberry	32	90-95	L	L	5-14 days
Gooseberry	32	90-95	L	L	3-4 weeks
Loganberry	32	90-95	L	L	2-3 days
Raspberry	32	90-95	L	L	3-6 days
Strawberry	32	90-95	L	L	7-10 days
Broccoli	32	95-100	VL	H	2-3 weeks
Brussels sprouts	32	95-100	VL	H	3-5 weeks
Cabbage					
Chinese, Napa	32	95–100	VL	M-H	2–3 months
common, early crop	32	98–100	VL	H	3–6 weeks
common, late crop	32	98–100	VL	H	5–6 months
Carrots					
topped	32-34	98-100	VL	H	6-8 months
bunched, immature	32	98-100	VL	H	10-14 days
Cauliflower	32	95-98	VL	H	3-4 weeks
Celery	32	98-100	VL	M	2-3 months
Cherries, sour	32	90-95	VL	L	3-7 days
Cherries, sweet	30-32	90-95	VL	L	2-3 weeks
Corn, sweet and baby	32	90-98	VL	L	5-14 days

Cucumber, slicing	50-55	95	L	H	10-14 days
Cucumber, pickling	40	95-100	L	H	7 days
Currants	32	90-95	L	L	1-4 weeks
Eggplant	50-54	90-95	L	M	1-2 weeks
Garlic	32	60-70	VL	L	6-7 months
Grape	32	90-95	VL	L	1-6 months
Herbs					
Basil	50	90	VL	H	7 days
Chives	32	95-100	L	M	
Cilantro	32-34	95-100	VL	H	2 weeks
Dill	32	95-100	VL	H	1-2 weeks
Epazote	32-41	90-95	VL	M	1-2 weeks
Mint	32	95-100	VL	H	2-3 weeks
Oregano	32-41	90-95	VL	M	1-2 weeks
Parsley	32	95-100	VL	H	1-2 months
Perilla, shiso	50	95	VL	M	7 days
Sage	32	90-95			2-3 weeks
Thyme	32	90-95			2-3 weeks
Leafy greens					
cool-season; spinach, Swiss chard, collards, kale, rape, mustard, turnip	32	95-98	VL	H	10-14 days
warm-season	45-50	95-100	VL	H	5-7 days
Leek	32	95-100	VL	M	5-6 weeks
Lettuce	32	98-100	VL	H	2-3 weeks
Melons					
Cantaloupe and netted	36-41	95	H	M	2-3 weeks
Casaba	45-50	85-90	L	L	3-4 weeks
Crenshaw	45-50	85-90	M	H	2-3 weeks
Honeydew, orange-flesh	41-50	85-90	M	H	3-4 weeks
Persian	45-50	85-90	M	H	2-3 weeks
Mushrooms	32	95	VL	M	7-9 days
Onions					
Mature bulbs, dry	32	65-75	VL	L	1-8 months
Green onions	32	95-100	L	H	3 weeks
Parsnip	32	95-100	VL	H	4-6 months
Peach and nectarine	32	90-95	M	M	2-4 weeks
Pear, European	32	90-95	H	H	2-7 months
Peas in pods; snow, snap & sugar	32	92-98	VL	M	1-2 weeks
Peppers					
Bell, paprika	45-50	90-95	L	L	2-3 weeks
Hot peppers, chilies	41-50	85-95	L	M	2-3 weeks

Plums and prunes	32	90-95	M	M	2-5 weeks
Potato					
early crop	50-59	90-95	VL	M	10-14 days
late crop	40-54	95-98	VL	M	5-10 months
Pumpkin	54-59	60-70	L	M	2-3 months
Radish	32	95-100	VL	L	1-2 months
Rhubarb	32	95-100	VL	L	2-4 weeks
Rutabaga	32	98-100	VL	L	4-6 months
Shallots	32-36	65-70	L	L	
Sprouts from seeds	32	95-100			5-9 days
Alfalfa sprouts	32	95-100			7 days
Bean sprouts	32	95-100			7-9 days
Radish sprouts	32	95-100			5-7 days
Squash					
Summer (soft rind), zucchini	41-50	95	L	M	1-2 weeks
Winter (hard rind) acorn, buttercup, butternut, Hubbard	50-55	50-75	L	M	2-3 months
Sweet potato, yam	55-59	85-95	VL	L	4-7 months
Tomato					
mature green	55	90-95	VL	H	2-5 weeks
firm-ripe	45-50	85-90	H	L	1-3 weeks
Watermelon	50-59	90	VL	H	2-3 weeks

*Ethylene production rate: VL = very low (<0.1 µl/kg*hr at 68°F) L = low (0.1 – 1.0 µl/kg*hr) M = moderate (1.0 – 10.0 µl/kg*hr) H = high (10 – 100 µl/kg*hr) VH = very high (>100 µl/kg*hr)

[t]Ethylene sensitivity (detrimental effects include yellowing, softening, increased decay, abscission, browning)
L = low sensitivity M = moderately sensitive H = highly sensitive

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