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Postharvest Handling of Vegetables

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The nutritional value of vegetables as a vital source of essential minerals, vitamins, and dietary fiber has been well recognized. In addition to these constituents, vegetables also supply fair amounts of carbohydrates, protein, and energy and add color, flavor, and aroma to consumers' diets.

Vegetables are living tissues that are subject to continuous changes after harvest. Because of their characteristics (high-moisture content, large size, rapid rate of metabolism), they can deteriorate rapidly after removal from the plant.

Vegetables have their maximum potential for high quality when harvested. The postharvest treatments they receive determine whether this potential is realized or is lost. It is incorrect to say that quality always decreases after harvest. A mature green tomato has less visual appeal and nutritive quality when harvested than it has days later after it has ripened. However, the degree of quality it attained upon ripening was dictated by its condition when harvested and the treatment it received after harvest. Postharvest practices are designed to take full advantage of a commodity's quality potential and to reduce the rate of quality loss.

Not only must a vegetable be well grown but it also must be harvested at the right stage of maturity, carefully handled and packed, and delivered to fresh market in prime condition. Expedited operations are thus required by growers, handlers, marketing specialists, wholesalers, and retailers to move produce from the farm to the consumer.

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CLASSIFICATION

Vegetables can be classified in a number of ways. A most useful method is to group crops by plant parts because commodities within these groups usually have similar postharvest characteristics (Table 10.1).

Table 10.1. Classification of Vegetables by Plant Parts

Plant Part	Examples
A. Entire plant	Sprouts, potted plants
B. Root	
1. Swollen taproot	Carrots, turnips, radishes, chicory, beets, celeriac
2. Root tuber	Sweet potatoes, cassavas, yams
C. Bulbs	Onions, garlic
D. Stem tuber	Potatoes, Jerusalem artichokes
E. Stem	Asparagus, kohlrabi
F. Leaf	
1. Blade	Leaf lettuce, spinach, chard, endive
2. Petiole	Celery, rhubarb
3. Buds	Lettuce, brussels sprouts, cabbage
4. Shoots	Green onions, leeks
G. Floral parts	Artichokes, broccoli, cauliflower
H. Fruits	
1. Immature	
a. fleshy	Green peppers, summer squashes, eggplants, cucumbers
b. non-fleshy	Snap beans, lima beans, peas, fava beans, sweet corn, okra, cowpeas
2. Mature	
a. fleshy	Tomatoes, red peppers, pumpkins, winter squashes, watermelons
b. non-fleshy	Dry peas, dry beans

Leafy and Succulent Vegetables

These vegetables have a relatively low monetary value per unit weight. Most are also of low density so that they take up a lot of volume per unit weight. These two characteristics require that inexpensive packaging, handling, and transportation be used with these crops. With the exception of cabbage, leafy and succulent vegetables are traditionally marketed quickly after harvest.

Although these vegetables are temperate-zone or cool-season crops and thus, with the exception of asparagus, are not subject to chilling injury (a physiological disorder characterized by a variety of symptoms, which occurs when a commodity is subjected to temperatures above freezing but below a minimum threshold temperature value), most of them are more perishable than underground or fruit vegetables. They have a high water content and a large surface-to-volume ratio—characteristics that contribute to their susceptibility to water loss and physical damage.

Underground Vegetables

Because these crops are surrounded by soil during their growth and development and are exposed to soil-borne contamination during harvest and handling, they are subject to bacterial and fungal diseases. Extracting these large, bulky crops from the soil is often accomplished mechanically, which often produces many harvest-related injuries.

Initial storage conditions should encourage wound-healing to limit infection and water loss. Water loss is often minimal because of their large size; however, it can be severe in early harvested crops or in those crops that do not develop an effective barrier to water loss. Many of these crops are storage organs, and renewed growth can be a potential source of loss during long-term storage.

Potatoes are the most important vegetable within this group, both in the world and in the United States.

Fruit Vegetables

Many vegetables are classified botanically as fruits, i.e., as the products of ripening ovaries and their associated tissues.

Most fruit vegetables are warm-season crops (tomatoes are the leading fresh market vegetable in the United States) and are subjected to chilling injury. Exceptions are sweet corn and cool-season crops like fresh peas and fava beans. Most fruit vegetables are not adapted to long-term storage. The exceptions are hard-rind (winter) squashes, pumpkins, and dry legumes.

Fruit vegetables picked immature are more susceptible to water loss than those picked mature because of their poorly developed cuticle. Physical damage is a major source of losses in quantity and quality during postharvest handling and marketing.

FACTORS INVOLVED IN DETERIORATION

Biological Factors

Respiration. Respiration is the overall process by which stored plant reserves (carbohydrates, fats, and proteins) are broken down to simple end products with the release of energy in the form of heat. Oxygen is used in this process, and carbon dioxide is released by the commodity. This heat, called vital heat, is always a part of the refrigeration load that must be considered in handling vegetables in cold storage.

Some vegetables have high respiration rates and require considerably more refrigeration than more slowly respiring crops to keep them at specified temperatures. Asparagus, for example, respires approximately 10 times faster than tomatoes.

The rate of respiration is governed by temperature. Head lettuce respires about three times as fast at 50°F as at 32°F. The faster a commodity respires, the greater the quantity of heat generated. The rate of deterioration (perishability) of harvested commodities is generally proportional to their respiration rate. The storage life of crops like broccoli, lettuce, peas, sweet corn, spinach, and watercress, which have relatively high rates of respiration, is short; and that of onions, potatoes, and sweet potatoes, which have low respiration rates, is long.

Cultural and marketing practices can significantly affect respiration and consequently perishability. Root crops marketed with tops have a higher respiration rate than that of the roots alone (e.g., carrots, radishes). Potatoes harvested immature (new potatoes) respire twice as fast as those harvested mature. Cured potatoes and sweet potatoes have a lower respiration rate than non-cured ones.

Ethylene Production. Ethylene is a natural product of plant metabolism and is produced by all tissues of higher plants. Ethylene plays an important role, often deleterious, increasing the rate of senescence and reducing shelf life. Sometimes ethylene is beneficial, improving the quality of the product by faster and more uniform ripening prior to retail distribution.

Ethylene is physiologically active in trace amounts (less than 0.1 ppm). Generally, ethylene production rates increase with maturity at harvest, physical injuries, disease incidence, increased temperature up to 86°F, and water stress. Ethylene is exempted from the requirement of a residue tolerance when used as a plant regulator either before or after harvest.

Compositional Changes. Many changes in composition may continue in vegetable crops after harvest, and these can be desirable or undesirable. Loss of chlorophyll (green color) is desirable in some fruit vegetables, but undesirable in leafy vegetables. Development of red, yellow, and orange colors is desirable in tomatoes, squashes, pumpkins, carrots, and some peppers and muskmelons.

Conversion of starch to sugar can occur at low temperatures (32° to 41°F) and can be desirable (parsnips, sweet potatoes) or undesirable (potatoes). On the other hand, sugar to starch conversion is undesirable in peas and sweet corn.

The breakdown of polysaccharides can result in a softening of fruit vegetables and a consequent increase in susceptibility to mechanical injuries. Increased lignin content is responsible for toughening of asparagus and root vegetables. Loss of vitamin content (mainly through water loss), especially ascorbic acid (vitamin C), is detrimental to nutritional quality.

Transpiration or Water Loss. Loss of water from harvested vegetables is a major cause of deterioration in storage. Most fruit and vegetables contain between 80 and 95 percent water by weight, some of which may be lost by evaporation. This loss of water is known as *transpiration*. Transpiration rate is influenced by internal or commodity factors (morphological and anatomical characteristics, surface-to-volume ratio, surface injuries, and maturity stage), and external or environmental factors (temperature, relative humidity, air velocity, and atmospheric pressure). The rate of transpiration, which must be minimized to avoid loss in salable weight and to avoid wilting and shrivelling of produce, can be controlled by good handling conditions at recommended humidity and temperature.

A moisture loss of 3 to 8 percent is enough to cause a marked loss of quality for many vegetables. Roots stored with the tops attached lose water much faster than those with the tops removed. The vitamin C content of green vegetables decreases more readily when they are stored under conditions favorable to wilting.

Condition of Crop. Commodities should be in excellent condition and have excellent quality if maximum storage life is desired. The physical condition of stored vegetables does not improve in storage. Vegetables should be as free as possible from skin breaks, bruises, and other forms of deterioration. Not only are mechanical injuries unsightly, but they also accelerate water loss, provide good avenues for entrance of decay organisms, and stimulate respiration and ethylene production by the commodity, which results in faster deterioration.

Growth and Development. Sprouting of potatoes, onions, garlic, and root crops greatly reduces their utilization value and accelerates deterioration. Sprouting can often be inhibited by preharvest application (two to four weeks before harvest) of maleic hydrazide (MH-30). Rooting of onions and root crops is also undesirable. Asparagus spears continue to grow after harvest; elongation and curvature (if the spears are held horizontally) are accompanied with increased toughness and decreased palatability. Seed germination inside tomatoes and peppers reduces quality.

Environmental Factors

Temperature. Temperature is the single most important environmental factor that influences the deterioration rate of harvested vegetables. For each increase in 18°F above optimum, the rate of deterioration increases by two- to three-fold. Temperature influences respiration and ethylene production rates, metabolism, moisture loss, compositional changes, development of physiological disorders, growth rate of pathogens, and undesirable growth, such as sprouting of underground crops. For maximum storage life, the minimum safe temperatures for individual or groups of vegetables should be maintained.

Relative Humidity. Relative humidity can influence water loss, incidence of some physiological disorders, uniformity of fruit ripening, and decay development. For most vegetables the optimum relative humidity is about 90 to 100 percent. If the humidity of the air in storage rooms is too low, wilting or shriveling will occur. High humidity is beneficial for wound healing and curing of certain crops.

The relative humidities recommended are those that retard moisture loss and do not favor growth of microorganisms. Condensation of moisture on the commodity (sweating) during storage is probably more important than is the relative humidity of the ambient air in enhancing decay.

Atmospheric Composition. Reduction of oxygen and elevation of carbon dioxide in the atmosphere surrounding a crop, whether intentional (modified or controlled atmosphere storage) or unintentional, can either delay or accelerate deterioration of vegetables. The magnitude of these effects depends on commodity, cultivar, physiological age, maturity, O_2 and CO_2 levels, temperature, and duration of holding.

About 1 to 3 percent O_2 is the lowest limit tolerated by most vegetables. Below this, anaerobic respiration may result in the development of off-flavors and off-odors. Vegetables with a wide variety of plant parts differ greatly in their CO_2 tolerance. Differences in susceptibility to elevated CO_2 and reduced O_2 among commodities or cultivars of a given commodity may be due to structural (anatomical, natural barriers within the plant parts) differences rather than metabolic differences. While lettuce is damaged by 1 to 2 percent CO_2, spinach tolerates 20 percent CO_2. Broccoli tolerates 15 percent CO_2, but cauliflower is damaged by 5 percent CO_2.

Ethylene. The most important sources of ethylene as an air pollutant during postharvest handling are internal combustion engines, ripening rooms, and ripening fruits. Other sources include decomposing produce, fluorescent ballasts, cigarette smoke, rubber materials exposed to heat or UV light, and virus-infected plants.

Since ethylene found in the environment can reduce the life of vegetables sensitive to it, techniques to remove or avoid its effects are of considerable importance during postharvest handling, storage, and transportation.

Light Greening due to exposure to light is a problem with potatoes, onions, garlic, and Belgian endive. The amount of chlorophyll that develops depends upon the intensity and quality of light, duration of exposure, cultivar, and crop maturity. Greening is a serious defect in potatoes because it is often associated with the formation of solanine, a bitter and toxic compound.

Sanitation. Maintenance of sanitary conditions is essential for minimizing development of and contamination by decay organisms during postharvest handling operations. Harvesting equipment, field bins, trucks, packinghouse lines, and storage rooms should be maintained clean, and rotted produce should be disposed of promptly.

Air purification is a recommended practice in storage rooms where odors or volatiles may contribute to off-flavors and hasten deterioration.

MATURATION AND MATURITY INDICES

Horticultural maturity can be defined as "that stage at which a commodity has reached a sufficient stage of development that after harvesting and postharvest handling (including ripening), its quality will be at least the minimum acceptable."

A given commodity may be horticulturally mature at any stage of development. In most vegetables optimum horticultural maturity coincides with optimum eating quality. Yet, for many vegetables, the optimum eating quality is reached before full maturity (i.e., full development), e.g., leafy vegetables, immature fruits (cucumbers, sweet corn, green beans, peas), etc. In this case, the problem frequently is delayed harvest, which results in overmaturity and consequently lower quality. Fruit vegetables consumed ripe attain their best quality when ripened on the plant. Immaturity in this group results in inferior quality.

The maturity at harvest has an important bearing on the way in which commodities are handled, transported, and marketed and on their storage life and final quality.

Maturity indices for selected vegetables that have been proposed or are presently in use are shown in Table 10.2.

Table 10.2. Maturity Indices for Selected Vegetables

Index	Examples
Heat units during fruit development	Peas, sweet corn
Development of abscission layer	Muskmelons
Drying of foliage	Potatoes
Drying of tops	Garlic, onions
Surface morphology and structure	Tomatoes—cuticle development Muskmelons—skin netting
Size	Most vegetables
Color (external)	Most vegetables
Specific gravity	Watermelons, potatoes
Shape compactness	Cauliflower, broccoli
Solidity	Cabbage, lettuce, brussels sprouts
Internal color structure	Tomatoes—formation of jelly-like material
Tenderness	Peas
Toughness	Asparagus

HARVESTING

When to Harvest

The time of harvest is almost always a compromise. On the one hand, it is desirable to have the commodity at a stage of development (maturity) that will ensure the maximum quality to the ultimate consumer. On the other hand, the commodity must be harvested when it can tolerate the rigors of harvesting, handling, packing, storage, and transportation.

In many vegetables, tenderness and flavor are best before the crop has reached a size that is profitable to the grower and before the commodity has sufficient mechanical rigidity to withstand the rigors of marketing.

Timing of harvest (based on maturity indices) is complicated by the great differences that occur in the rate of development and maturation of individual plants, or organs on the same plant. This variability in maturation and ripening is especially important when once-over mechanical harvesting is used.

Economic considerations, price and demand for a crop, are often even more important factors that affect the decision to harvest.

Hand vs Mechanical Harvest

Even in the United States, most fresh vegetables are harvested by hand. Only the unique combination of eyes, intelligence, and hands can permit rapid harvest of delicate and perishable materials with minimum loss and bruising. Pickers can be trained to select only those vegetables that are of the correct maturity and to leave produce that is immature, overmature, blemished, or diseased in the field. This saves in the cost of transportation and later grading of the produce and reduces the danger of spreading infection during the handling and packing operations.

With some commodities, mechanical aids can be used in hand harvesting. Belt conveyors are used for some vegetable crops, such as lettuce and melons, to move the harvested commodity to a central loading or in-field loading device. Lights have been used to a limited extent for night harvest of melons.

Mechanical harvest can be used with commodities that can be harvested at one time and are not sensitive to mechanical injury (e.g., some roots and tubers, sweet corn, peas, and snap beans), and with vegetables designed for immediate processing (e.g., pickling cucumbers and processing tomatoes). Although mechanical harvest has the potential for rapid harvest and reduces problems associated with hiring and managing hand labor, it is not presently used for most fresh vegetables because machines are rarely capable of selective harvest; whatever can be shaken, pulled, or beaten off the plant is harvested. Mechanization has increased the efficiency of harvesting, but in many cases it has also increased damage to vegetables.

Temperature Protection

Temperature protection in the field involves shading the harvested vegetables to minimize high temperature exposure and warming of the crops. This may mean moving harvested produce to the shade of plants and bushes while awaiting transport. If natural shade is not available, then portable shading may be needed. Inverting empty containers over the top of stacks of containers can provide some field protection. During periods of very high field temperatures, it may be desirable to avoid harvesting in mid-day.

PREPARATION FOR FRESH MARKET

The purposes of preparing for market are: (1) to eliminate unwanted material, (2) to select items of similar grade, and by this, (3) to improve the value of the marketed portion of the crop. The preparation of vegetables for marketing may be done mostly in the field (Figure 10.1) or in packing sheds or facilities.

Figure 10.1. Harvesting and field packing of crisphead lettuce.

Some advantages of field packing are: (1) less material to transport and dispose; (2) fewer handling steps, which results in less damage to the commodity and consequently better quality; and (3) smaller initial cost. Disadvantages of field packing include: (1) less control over quality, (2) more dependence on weather than packinghouse operations, (3) large machines needed in the field, and (4) cooling of produce inside field cartons is more difficult than bulk cooling.

In more typical operations, the crop is transported in bins or gondolas to a facility to be packed and graded.

Packinghouse Operations

Preparation for marketing begins with harvesting (maturity selection and some quality control) and, depending upon the commodity, may include some or all of the following subsequent operations:

Receiving. The receiving area should be covered to keep the product cool and to retard deterioration. The crop is then unloaded from field containers onto a conveyor or into a wet dump for conveying to the packinghouse. This can be done with dry dumps, water dumps, or water flumes. Dry dumps can cause considerable product damage. Sanitation with chlorinated agents is important in water dumps and flumes to prevent bacterial or fungal contamination. A conveyor belt then moves the crop to the eliminator for removal of undersized and decaying products, as well as noncrop materials, e.g., leaves, twigs, and stones.

Cleaning. Washing and/or brushing removes soil, spray residues, and other foreign materials from the product surface. The wash water may or may not be chlorinated. Recycled water should always be chlorinated. Air dryers or sponge rollers are then used to remove excess water from product surfaces.

Pre-sizing. When needed, pre-sizers are usually located immediately after the dump and designed to eliminate commodities below a minimum acceptable size.

Trimming. In crops such as lettuce, celery, cauliflower, asparagus, and dry onions, trimming removes unwanted leaves, stems, or roots prior to grading, packaging, and packing (Figure 10.2).

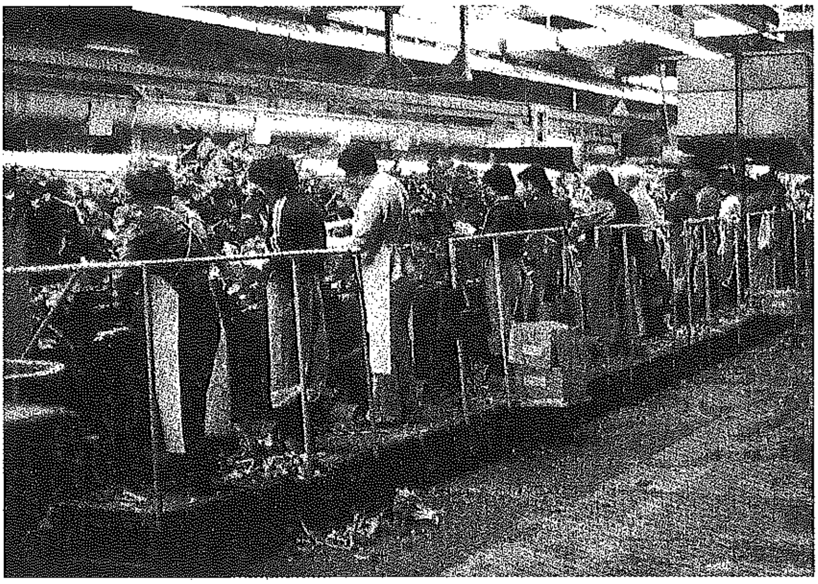

Figure 10.2. A modern broccoli grading and packinghouse.

Sorting. Sorting eliminates defects. Most products are selected based on maturity, shape, color, or some other physical parameter. Some commodities are machine-sorted.

Waxing. The process of covering the surfaces of product units with a coating of food-grade wax reduces water loss through epidermal openings, replaces natural waxes removed during washing and/or brushing, and covers injuries. Wax is generally applied to fruit vegetables such as tomatoes, peppers, and cucumbers, but it may also be used on root crops such as rutabagas. Waxing is also used to improve the cosmetic appearance of the commodity. A fungicide may be incorporated into the wax.

Sizing. Product units are separated into physical sizes (weight, volume, length, diameter, or other parameters). This is mostly done by mechanical or electronic sizers, although many vegetables are still manually sized.

Curing. Some products such as garlic, dry onions, sweet potatoes, and new-crop potatoes are cured after harvesting and prior to storage or marketing. Onions and garlic are cured to dry their necks and outer scales. Sweet potatoes and potatoes are cured to develop suberized layers and wound periderms over cut, broken, or skinned surfaces. Curing helps heal harvesting injuries, reduces water loss, and prevents entry of decay-causing organisms during storage. Curing may be done in the field (garlic, onions), in curing rooms (sweet potatoes), or during transit (new-crop potatoes).

Grading. Products are separated according to market quality (grades) on the basis of color, shape, maturity, or other physical parameters. Currently, there are many attempts to automate separation of a given commodity into various grades and to eliminate defective units. The availability of low-cost microcomputers and solid-state imaging systems has made computer-aided video inspection on the packing line a practical reality. Solid-state video cameras or light-reflectance systems can be used for detection of external defects, while x-ray or light transmittance systems can be used for detecting internal defects.

Packaging. Individual product units are enclosed in individual packages (wraps, bags, sleeves, trays, or other units) that are subsequently packed in master containers. Most materials used for consumer unit packaging are flexible plastic films. Paper bags are also used. Some packaging involves enclosing a single product unit (a head of lettuce or cauliflower, celery), while in other packaging, several product units are enclosed in a single consumer unit (sweet corn, potatoes, radishes, brussels sprouts, carrots). Packaging is done both automatically and manually at the shipping point or destination market, or both.

Packing. A given count or weight of similar-sized product units is assembled into shipping containers. Counts, arrangements, and weights are often specified in and regulated by the various grade standards and industry codes. Product units can be packed mechanically or by hand. Liners and pads may assist the operation but increase the materials costs. Shipping containers may be bags, cartons, crates, lugs, or bulk bins. Some vegetables are shipped unpacked to markets in bulk trucks or railroad cars.

The purposes of packing are: (1) efficient handling of products; (2) protection of the commodity from physical injury, contamination, and pilferage; and (3) identification of the product, producer, and shipper. When designing packages for horticultural crops, one should consider important factors such as container ventilation to facilitate air flow and achieve heat removal during precooling and refrigerated storage and transport, protection from injuries and water loss, compatibility with existing marketing systems, and cost.

Ripening Initiation. Ethylene gas is commonly applied at the shipping point to stimulate faster and more uniform ripening of mature green tomatoes and honeydews. Satisfactory ripening occurs within the range of 59° to 77°F, with the rate of ripening increasing with the temperature within this range. Commodities should be treated with ethylene concentrations of about 100 ppm for 18 to 48 hours. The relative humidity in the ripening room should be maintained between 90 and 95 percent. Adequate air circulation and ventilation should be provided to ensure good distribution of ethylene within the ripening room and to prevent the accumulation of CO_2, which reduces the effectiveness of ethylene.

COOLING VEGETABLES

Precooling

Cooling vegetable crops immediately after harvest is the best way to maintain high quality. Precooling entails the rapid removal of field heat to lower the temperature of the commodity to the recommended storage temperature before it is stored. Precooling is usually done in a facility that is separate from the cold storage room. The precooling facility is characterized by having a very large refrigeration capacity and the capacity to move the cooling medium rapidly past the commodity.

The packing method will dictate how, and sometimes when, the product is presented for cooling. Packaging materials and design will affect access of the coolant to the product, and pallet stacking patterns will influence coolant flow through and around containers.

Precooling Methods

The technique selected for cooling a particular produce item depends on a wide range of factors, including the rate of cooling desired, the surface-to-volume ratio, the susceptibility to water damage or fungal infection, and the practical requirements of the packaging and handling system. Economic considerations may dictate which cooling method is used.

Room Cooling. This is the traditional technique. Field bins or packed commodities are placed in a cold room and allowed to cool. Typically, cold air is discharged into the room near the ceiling, moves horizontally across the ceiling, and then sweeps past the produce containers to return to the heat exchangers. Room cooling is relatively inexpensive compared to other methods, but too slow for most vegetables.

The efficiency of room cooling can be improved by the use of ceiling jets or fans to increase air velocities. Cabbage and artichokes are primarily cooled with this method, although all vegetables can be room cooled. Room cooling allows produce to be cooled in the same location where it will be stored.

Forced-Air Cooling (Pressure Cooling). This is a much more efficient and rapid method than room cooling because it provides for cold air movement through, rather than around, containers. The system, which creates a slight pressure gradient to cause air to flow through container vents, achieves rapid cooling as a result of the intimate contact between cold air and warm product. With proper design, fast, uniform cooling can be achieved through stacks of pallet bins or unitized pallet loads of containers. It is widely used for fruit vegetables, tubers, onions, garlic, and cauliflower.

Hydrocooling. Hydrocooling is an extremely efficient method for cooling because of the high heat capacity and thermal conductivity of water, which makes it a better cooling medium than air (Figure 10.3).

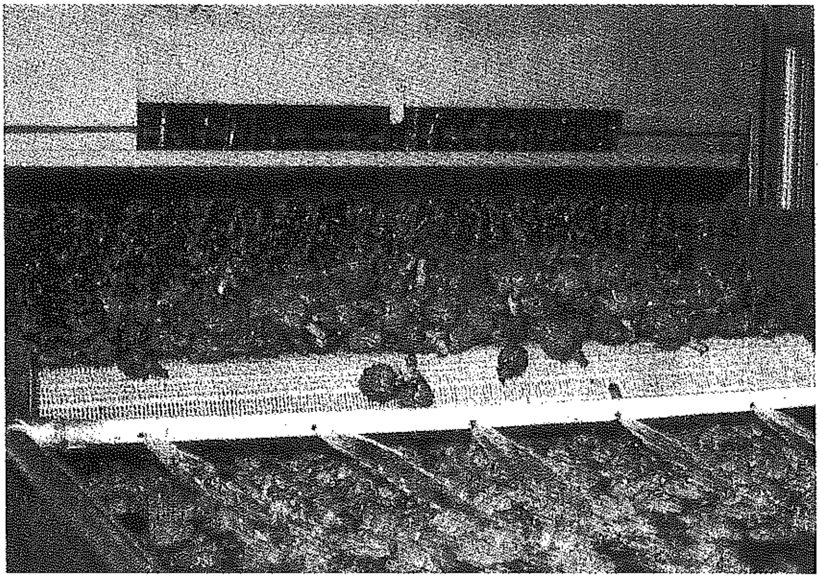

Figure 10.3. Hydrocooling and washing of artichokes.

Two types of hydrocoolers in common use are immersion and spray. In the first type, the product is submerged in cold water. This can create problems because of water intrusion into the commodity. Water can enter the crop because of hydrostatic pressure when it is submerged to a depth of more than a few inches. In a spray-type hydrocooler, cold water is sprayed over the crop. In either type, the water must be clean and usually chlorinated to prevent the spread of pathogens.

Hydrocooling is widely used to cool vegetables in bins or in bulk before packing; these vegetables include lettuce, celery, spinach, some green onions, leeks, artichokes, muskmelons, sweet corn, and most temperate-zone crops. Its use is limited for packed commodities because the containers must withstand water soaking. The product must be tolerant of wetting.

Package Icing. Some vegetables are cooled by filling packed containers with predetermined quantities of ice. Package ice may be finely crushed ice, flake-ice, or a slurry of ice and water at 32°F, called liquid ice. With certain products, for example, broccoli, liquid ice is sprayed into the packed boxes (wax-impregnated) to achieve better ice-product contact (Figure 10.4). Package icing requires the use of more expensive, water-tolerant shipping containers.

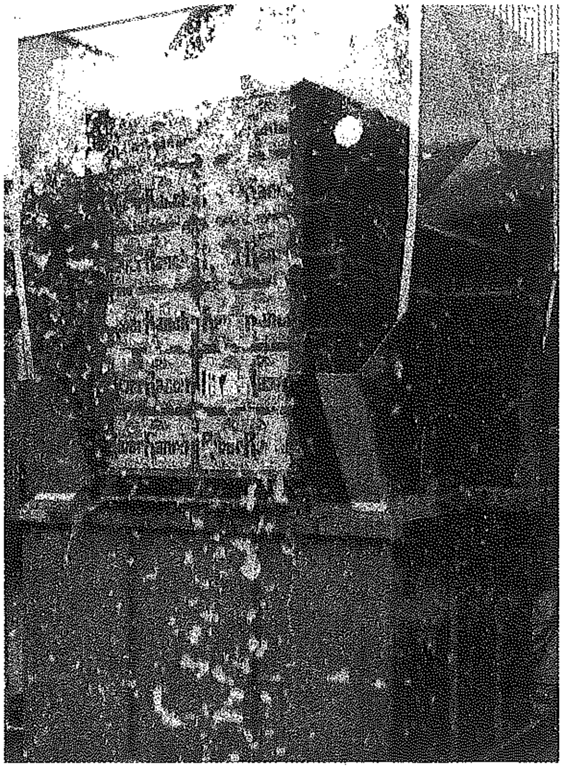

Figure 10.4. Liquid icing a pallet of broccoli.

Package icing is less efficient than forced-air or hydrocooling but is still useful for some root and stem vegetables, brussels sprouts, and green onions. It is limited to commodities that can tolerate water–ice contact. Top icing and icing in bulk inside rail cars have been used with muskmelons, and carrots, and some other root crops.

Vacuum Cooling. Vegetables that have a favorable surface-to-mass ratio, such as leafy vegetables, can be rapidly cooled by this method. It has the advantage that it cools the product throughout the container and throughout the bulk of a well-insulated item such as iceberg lettuce. It is also used to cool cauliflower, celery, and some sweet corn, carrots, and bell peppers. Its use with carrots and peppers is primarily to dry the surface and stems, respectively, to inhibit postharvest decay.

Cooling is achieved by reducing the atmospheric pressure inside a large, steel chamber containing the product. This reduction in atmospheric pressure causes loss of water vapor from the commodities, resulting in cooling. Vacuum cooling causes about 1 percent product weight loss (mostly water) for each 11°F of product cooling. A patented process called Hydro-Vac®, which adds water in the form of a fine spray during the vacuum-cooling cycle, reduces water loss, and is used in some operations, especially with celery.

STORAGE OF VEGETABLES

The orderly marketing of vegetable crops often requires some storage to balance day-to-day fluctuations between product harvest and sales, and may include some long-term storage to extend the processing and marketing season of some commodities. Table 10.3 shows recommended storage conditions and shelf-life expectancy for various vegetables.

Table 10.3. Recommended Storage Conditions for Selected Vegetables[a]

Vegetable	Temperature		Relative Humidity	Storage Life[b]
	(°C)	(°F)	(%)	
Asparagus	0–2	32–35	95	2–3 weeks
Beans—snap	5–8	41–46	90–95	7–10 days
—lima	3–5	37–41	90–95	5–7 days
Broccoli	0	32	90–95	10–14 days
Brussels sprouts	0	32	90–95	3–5 weeks
Cabbage—head	0	32	95–98	1–6 months
—Chinese	0	32	98–100	2–3 months
Carrots	0	32	95–100	1–3 months
Cauliflower	0	32	95–100	3–4 weeks
Celery	0	32	98–100	1–2 months
Cucumbers	10–13	50–55	95	10–14 days
Eggplants	10–12	50–54	90–95	1 week

(Continued)

Table 10.3 (Continued)

Vegetable	Temperature		Relative Humidity	Storage Life[b]
	(°C)	(°F)	(%)	
Garlic	0	32	65–70	6–7 months
Honeydews	7	45	90–95	2–3 weeks
Lettuce	0	32	98–100	2–3 weeks
Mushrooms	0	32	90–95	3–5 days
Muskmelons	8–10	46–50	90–95	7–14 days
Onions—dry	0	32	65–70	1–7 months
—green	0	32	95–100	3–4 weeks
Peas	0	32	95–98	1–2 weeks
Peppers	8–12	46–54	90–95	2–3 weeks
Potatoes	4	39	90–95	4–8 months
Spinach	0	32	95–98	10–14 days
Squashes—summer	7–10	45–50	95	1–2 weeks
—winter	10–12	50–54	60	1–3 months
Sweet corn	0	32	95–98	5–8 days
Tomatoes—mature green	12–14	54–57	90–95	1–3 weeks
—fully ripe	8–10	46–50	90–95	4–7 days
Watermelons	8–12	46–54	90	2–3 weeks

[a] Source: USDA. 1986. Agriculture Handbook No. 66.

[b] These values represent only approximate values and will vary depending on the cultivar and the atmospheric conditions that are present.

Room Cooling and Cold Storage: Two Different Operations

Refrigeration capacity for fast cooling and that for cold storage are quite different. It takes much more refrigeration to cool a commodity than to cold store it. High relative humidity is essential to prevent excessive water loss during cold storage but is not as important during the relatively short cooling period.

Most cold storage facilities use mechanical refrigeration to control storage temperature. This system is based on a liquid absorbing heat as it changes to a gas. The simplest method for doing this is to release liquid nitrogen into the storage environment. This requires a constant supply of refrigerant. This system is used only to a limited extent with highway vans where high nitrogen concentrations and low O_2 levels may also be of value. The more common mechanical refrigeration systems use one of the new types of "environmentally friendly" freons, such as SUVA® (DuPont, Wilmington, DE), as refrigerants. The vapor is recaptured by a compressor and heat exchanger, allowing the refrigerant to be continuously recycled.

Alternate Storage Methods

In places where mechanical refrigeration is prohibitively expensive to install and maintain, a range of other techniques is available for storing vegetables. Some of these less sophisticated techniques are still widely used.

Field Storage. Vegetables such as cabbage, potatoes, and most root crops can be stored in the field in trenches, pits, mounds, or clamps. When freezing weather approaches, a well-drained place is selected. The vegetables may be placed in piles surrounded by straw and covered with just enough soil to prevent freezing injury. Ventilation can be provided by a flue placed in the center of the pile, extending it above the cover and running perforated channels across the pile.

Common or Unrefrigerated Storage. These structures can include specially constructed buildings that are often heavily insulated, rooms dug into the ground, cellars, abandoned mines, or human-made caves. These facilities are best used for commodities that can be stored for long periods, such as potatoes, onions, winter squashes, and some root crops. These structures are only effective in climates where the ambient temperatures during the storage period are low enough to maintain product quality for a reasonable length of time.

Night Air Storage. In warmer climates a modification of common storage can be used if there is a substantial difference between the day and night temperature during the storage season. The technique used is termed "night air ventilation." The produce is placed in a common store that is well insulated and supplied with a ventilation system to enable air to be drawn into the store and distributed through the produce during the coolest part of the night. This technique is sometimes used to remove field heat and cool produce before refrigerated storage. It could also be used to maintain produce at the proper storage temperature when the nights are cold.

Nighttime cooling is commonly used for unrefrigerated storage of potatoes, sweet potatoes, onions, hard-rind squashes, and pumpkins.

High Altitude Storage. High altitude can also be a source of cold. As a rule of thumb, air temperature decreases by 5.5°F for every 1,000 feet increase in altitude. Consequently, it may be possible to store some commodities at high elevations in mountainous areas. Air temperature has the potential of being more than 27°F cooler at high altitudes than at sea level.

TRANSPORTATION

Transportation methods used for moving fresh vegetables from shipping points to destination markets include railroads, trucks, ships, airplanes, and combinations of these, e.g., trailers on flat cars (TOFC), also called "piggy-backs." Over-the-road truck transport now accounts for more than 70 percent of the movement of vegetables in the United States.

Modes of Transportation

Water Transportation. Water transport is much more energy-efficient than other modes of transportation. For international trade in commodities such as onions and potatoes, sea transportation under refrigerated or ventilated conditions is still the preferred method.

By far the largest portion of vegetables transported by sea now travel in seagoing intermodal "marine" containers (Figure 10.5). These containers are well insulated and may or may not have their own refrigeration capacity. The

Figure 10.5. Refrigerated marine containers being loaded into a ship.

containers are 20 to 40 feet in length. Although many feature top air delivery, there is a trend towards containers with bottom air delivery, where the circulation system works with, rather than against, the natural convective flow of air through the load of product.

Other vessels, many of which ply between Australia, New Zealand, or South Africa and the countries in Europe, are designed to supply cool air to the containers from a centralized refrigerated system on the vessels.

Rail Transportation. In the latter part of the 19th century, ice refrigeration systems were developed for transport of perishables by rail. Ice-bunker cars needed frequent replenishing, and icing stations were developed along major railways. Ice was often harvested from lakes and streams during the winter. Some ice-bunker cars are still operational. Air is circulated through ice bunkers at either end of the car and over the product by electric fans powered from the locomotive. Disadvantages include the need for replenishing the ice and the volume utilized by the ice bunkers.

Diesel-powered refrigerated rail cars are primarily used for long haul (more than 2,000 miles) domestic and Canadian shipments of generally only one commodity, and sometimes two or three. These cars have a large load space (more than 4,000 cubic feet) and weight capacity (more than 100,000 pounds).

In general, rail cars are heavily insulated and fairly airtight, so a major problem can be providing enough air exchanges to prevent injurious atmospheric modifications in route. Many of the mechanically refrigerated cars, last made in the United States in the early 1970s, are inadequately serviced, and cannot maintain proper product temperatures throughout. Transportation times range from 6 to 10 days on transcontinental shipments in the United States.

Piggy-back trailer or flat car (TOFC) transportation of vegetables has been of considerable interest to shippers in recent years. This system uses road-trailers loaded at the railhead onto flat cars and then reconnected to a tractor unit at the destination. The flexibility of containerized truck transportation and the economy of rail transport are thus combined.

Road Transportation. Over-the-road refrigerated truck trailers are now the dominant mode in the distribution of perishables. Most refrigerated trucks are now of the tractor-trailer type, where a separate power train cab (the tractor) hauls a refrigerated road trailer (Figure 10.6). These trailers are of standard dimensions, have a load space of 2,000 to 3,500 cubic feet, and

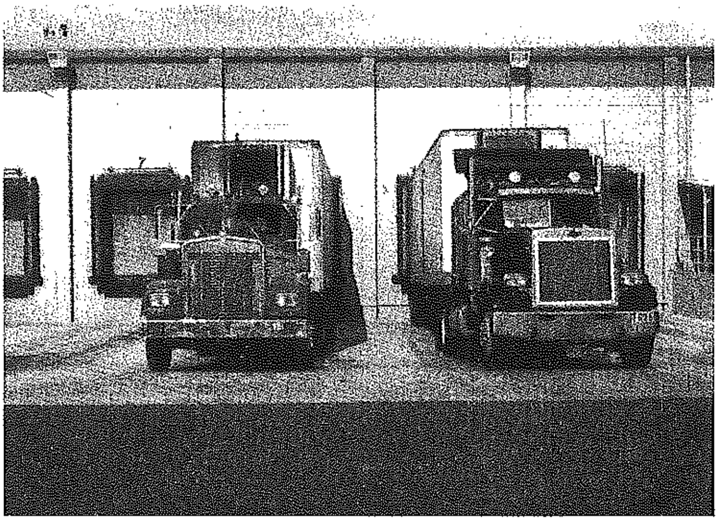

Figure 10.6. Refrigerated highway trucks awaiting loading of produce at a refrigerated distribution center's dock.

carry up to 45,000 pounds of produce. Gross weight of the truck is limited by highway load limit regulations to 72,000 to 80,000 pounds.

The refrigeration unit is diesel-powered, and the air circulation pattern is usually lengthwise, front to rear over the top of the load, down the end of the load, and back through and/or under the load. The air circulation capacity is designed for maintaining product temperatures, not for cooling. New containers incorporate a design in which air circulation is from the bottom, along deeper floor sections, to the top.

Trailers are less insulated than rail cars, allowing more conduction of energy across walls, roof, floor, and doors. Recent studies have shown that a very substantial portion of the heat load in summer shipments by truck is the radiant heat from the road surface, whose temperature can be as much as 14°F higher than the air temperature.

Air Transportation. Due to its very high cost, air shipment is limited to highly perishable and valuable commodities, such as flowers, berries, and tropical fruits.

Factors Affecting Temperature Management During Transit

Refrigeration and Air Circulation System. To be effective at maintaining temperatures, a refrigeration system needs forced-air delivery and air-return channels large enough to enable the fans to operate near peak performance. Anything that interferes with this air circulation will reduce cooling efficiency and temperature maintenance.

A thick layer of top ice, 6 inches or greater, over a load of vegetables prevents cold air from cooling the product. Only the top layer of the product which is in contact with the ice is kept cool. In tight loads of produce, the lower layers can warm.

Condition and Features of the Transit Vehicle. Intact sidewalls and insulation, clean floors and drains, refrigeration units properly serviced and maintained (including frequent calibration of thermostats), intact air delivery chute(s), and tight, undamaged doors and seals are essential to proper temperature maintenance.

Shipping Container Design and Construction. Inadequately vented containers, primarily cartons and large polyethylene bags, prevent sufficient air movement around products for effective temperature management, especially in solid, tight loads. Partial collapse of weak containers results in the formation of a solid load mass, which completely prevents air circulation through the loads.

Load Patterns and Sizes. Loads must have open-air channels through and around them that are either vertical or horizontal. Loads should be assembled to assure that their rigidity and conformation will be maintained in transit, which is generally achieved by unitizing load units on pallets or slip sheets.

The use of incentive freight rates, in which per package freight cost decreases as load weight increases, has created serious transit temperature maintenance problems in recent years. Incentive rates have resulted in such increases in load size, weight, and tightness that adequate transit temperature maintenance is difficult. In hot or very cold weather, loads should be palletized and pallets loaded away from the sidewalls and floor to prevent excessive warming or freezing in wall or bottom layers of products.

Mixed Loads. Maintaining optimum product temperatures in mixed loads is difficult, especially in loads containing several commodities. Vegetables are generally packed in containers of different sizes and shapes, which are often loaded in different patterns in various parts of a transit vehicle. In mixed loads certain product compatibility factors must be considered. They are:

1. *Temperature compatibility*—Differences in optimum and minimum safe temperatures for products shipped together must be considered. Chilling-sensitive commodities (e.g., tomatoes, bell peppers, summer squashes) should not be shipped with products whose optimum temperature is 32°F (e.g., leafy vegetables, many fruits).

2. *Ethylene production and sensitivity*—Care must be taken not to ship commodities that produce large amounts of ethylene (e.g., apples, pears, avocadoes, bananas, certain muskmelons, tomatoes) with commodities that are very sensitive to ethylene (broccoli, carrots, iceberg lettuce).

3. *Product odors*—Some products produce odors (e.g., garlic, onions) that can be absorbed by other products, causing the latter to have an objectionable aroma and less market appeal.

4. *Moisture*—Some products benefit from package ice or high levels of humidity in their ambient atmosphere (e.g., leafy vegetables, sweet corn), while other commodities benefit from intermediate to low humidity levels (e.g., garlic, dry onions).

Often used are compromise transit temperature settings that are designed to protect the most perishable or most valuable commodity in a load.

Thermostats and Recording Thermometers. Accurate temperature control is provided only if thermostats are accurately calibrated and are in an air stream that is representative of the temperature in the air supply load. Thermostats should be calibrated periodically. It is important to make sure the air-return passage is not blocked and adequate air can circulate through and/or around the load. It is the temperature of the commodity that is important, not the temperature of the air circulating around the containers.

Modified Atmospheres

Some vegetables benefit from the maintenance of modified atmospheres in transit vehicles, while other do not. Successful use of modified atmospheres is largely dependent upon the tightness of transit vehicles. In general, some rail cars and newer marine container vans can maintain modified atmospheres. Older or damaged rail cars are usually no longer tight enough.

Over-the-road trucks and TOFC trailers are generally not tight enough or do not remain tight to maintain modified atmospheres. In these vehicles, modified atmospheres can be established and maintained within pallet covers (polyethylene bags) secured to the pallet bases. Some newer trailers have the capability of maintaining desired atmospheres by using liquid nitrogen tanks, which are carried in a special compartment.

Accidental or undesirable atmospheric modification can result when air passages, such as floor drains, become plugged with debris or ice, which results in depletion of the internal oxygen supply by the product's respiration. This is a common problem during the winter with rail shipments of broccoli and brussels sprouts. These crops are commonly shipped with package ice and under top ice. During the winter, water from the melting ice can freeze at drains and seal all vents from the rail car. This problem can be overcome by providing open-air channels to the outside.

QUALITY OF VEGETABLES

Quality is defined as " . . . degree of excellence, relative nature, attribute, trait, or faculty" (*Oxford Dictionary*). Quality of fresh vegetables is a combination of characteristics, attributes, and properties that give a commodity value to humans for food. The connotation is that the important attributes of quality vary according to the individual(s) defining the term.

1. Growers are interested in disease resistance, high yield, uniform maturity, desirable size, and ease of harvest. Postharvest characteristics have not been one of their main interests.

2. Shippers and handlers are concerned with shipping quality and market quality. Hard fruit that can endure inexpensive handling and transport and still maintain high market quality is desirable.

3. Consumers care about appearance, price, and table quality, including texture, flavor, color, and nutritive value.

An effective quality control system throughout the handling steps between harvest and retail display is essential to providing a consistently good-quality supply of fresh vegetables to the consumer and to protecting the reputation of a given marketing label.

Quality Factors

A wide range of characteristics of vegetables is used to determine their quality. Important features differ according to the commodity being tested. These include:

Appearance (visual):	Size: dimensions, weight, volume
	Shape: diameter, length, compactness
	Color: uniformity, intensity
	Gloss: nature of surface wax
	Defects (external, internal): sprouting, rooting, elongation, curvature, seed germination, floret opening, growth cracks, shrivelling, wilting, bruises, cuts, scars, scabs, sunburn, decay, chilling/freezing injury symptoms, and nutritional-related defects
Texture (feel):	External smoothness and softness
	Internal texture: fibrous, tough, juicy, succulent
Flavor (taste and smell):	Sweetness, sourness, bitterness
	Off-flavors and aroma
Nutritive value:	Carbohydrates, fiber, proteins, lipids, vitamins, minerals
Safety:	Naturally occurring toxicants
	Chemical residues, heavy metals

Grade Standards

The objective of the grade standards and their application is to provide quality control of fresh produce. There are federal, state, industry, and international types of standards.

The first U.S. grade standard (for potatoes) was developed in 1917. There are now more than 150 U.S. grade standards covering 80 different fruits and vegetables. These standards are normally applied voluntarily, except when required under certain state and local regulations, by industry-marketing orders, or for export produce.

The U.S. grade standards include a range of grade names, of which the most important are U.S. Fancy, U.S. No. 1, U.S. No. 2, and U.S. No. 3. The U.S. Department of Agriculture is gradually phasing out an assortment of other grade names such as U.S. Extra No. 1, U.S. Extra Fancy, U.S. Combination, and U.S. Commercial.

The European Economic Community grade standards include the following quality classes: Extra class = superior quality, Class I = good quality, and Class II = marketable quality. These classes are generally equivalent to U.S. Fancy, U.S. No. 1, and U.S. No. 2, respectively.

Application of the Grade Standards

The grade standards are applied by USDA inspectors or the county agricultural commissioners for state standards. In large packinghouses, the inspectors may be permanently assigned. Sometimes the inspectors are seasonal employees hired during peak production for a given crop or location. In other cases inspection may be at the shipping point, or at the terminal market.

Representative samples, or a prescribed number of boxes or packages, are removed at random from a given lot and inspected. Inspectors are trained in the application of the standards, visual aids (color charts, diagrams, photographs, etc.) are used wherever feasible and practical, and objective methods are used whenever possible.

When the inspection is completed, inspection certificates are issued by the inspector denoting the grade standard to which the product conforms. Tolerances (allowances for product outside the grade quality) are set as a certain percentage of the product in the sample.

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