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# Postharvest Handling Systems: Fresh-Cut Fruits and Vegetables

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Fresh-cut products have grown rapidly during the past decade, extending from the foodservice sector to the retail shelf. These fruit and vegetable products are prepared and handled to maintain their fresh state while providing convenience to the user. Although more expensive than bulk produce on a weight basis, successful fresh-cut products are often more cost-effective for the user due to reduced waste. Minimal processing at central facilities greatly reduces the number of on-site employees involved in fresh produce preparation. Preparation of fresh-cut products involves cleaning, washing, trimming, coring, slicing, shredding, and other related steps, many of which increase the perishability of the produce items. Other terms used to refer to fresh-cut products are "minimally processed," "lightly processed," "partially processed," "fresh-processed," and "pre-prepared."

Examples of fresh-cut vegetables include peeled and sliced potatoes, shredded lettuce and cabbage, mixed salads (fig. 36.1), washed and trimmed spinach, peeled "baby" carrots (fig. 36.2), cauliflower and broccoli florets, and cleaned and diced onions. These products are expected to have a shelf life of 10 to 14 days and represent about 70% of the total volume of fresh-cut items available commercially. Other important vegetable items include peeled garlic (fig. 36.3), fresh salsas, vegetable snacks such as carrots and celery, sliced mushrooms, sliced and diced tomatoes and peppers, and fresh or microwaveable vegetable trays. More recent fresh-cut vegetable products include salad meals or "home replacement meals," which contain meat and other food items. Fresh-cut fruit products include peeled and cored pineapple; peeled citrus fruits (fig. 36.4) and segments; apple (fig. 36.5), peach, mango, and melon (fig. 36.6) slices; and fruit salads. Expected shelf life of these products is generally much less than for the vegetable products. Sales of fresh-cut products currently account for 8 to 10% of the fresh fruits and vegetables marketed through foodservice and retail channels in the United States (see chapter 2).

Whereas most food processing techniques stabilize the products and lengthen their storage and shelf life, minimal processing of fruits and vegetables increases their perishability. Although the industry began as a salvage operation to utilize off-grade and second-harvest products, it was soon recognized that high-quality raw materials were required because of the increased perishability caused by product preparation. Due to this and the need for strict sanitation, preparation and handling of these products require an integration of production, postharvest, and food science technologies and marketing expertise.

## FRESH-CUT PRODUCT PHYSIOLOGY AND SHELF LIFE IMPLICATIONS

Fresh-cut products generally have higher respiration rates than the corresponding intact products. Higher respiration rates indicate a more active metabolism and, usually, a faster deterioration rate. Higher respiration rates can also result in more rapid loss of acids, sugars, and other components that determine flavor quality and nutritive value. The increased $O_2$ demand due to the higher respiration rates of fresh-cut products dictates that packaging films with sufficient permeability to $O_2$ are required to prevent fermentation and off-odors. The physical damage or wounding caused by preparation increases respiration and ethylene production within minutes, with associated increases in rates of other biochemical reactions responsible for changes in color

**Figure 36.1**

Retail bags of mixed "European" salads from five major U.S. processors.


**Figure 36.2**

Baby carrots packaged in polyethylene bags for retail. Carrots in the bag on the left show surface drying or "white blush."

**Figure 36.3**

Peeled garlic cloves for foodservice distribution.


**Figure 36.4**

Peeled orange fruits in rigid tray with film lid.


**Figure 36.5**

Apple slices treated with browning inhibitors in a Fresh Hold package.


**Figure 36.6**

Melon chunks and single-serving mixed fruit salads.

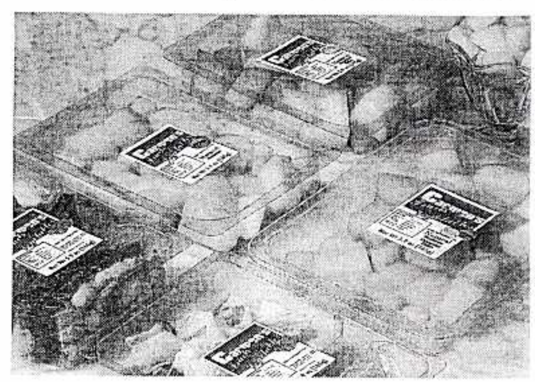


**Figure 36.7**

Respiration rates of intact and shredded cabbage stored at four temperatures.

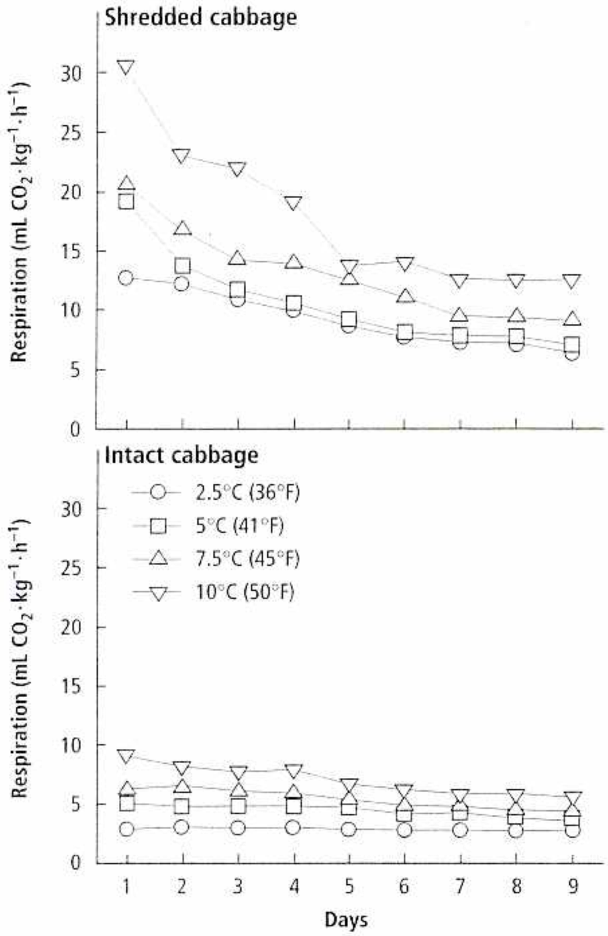



**Table 36.1.** Respiration rates of leaves of kale stored at various temperatures for 5 days

| | Respiration rate (mL $CO_2 \cdot kg^{-1} \cdot h^{-1}$) | | | |
|---|---|---|---|---|
| Product | 0°C (32°F) | 5°C (41°F) | 10°C (50°F) | 15°C (59°F) |
| Full-sized leaves | 8 | 12 | 29 | 33 |
| Small leaves | 14 | 21 | 42 | 57 |
| Chopped (pieces 2 by 2 cm [¾ by ¾ in] cut from full-sized leaves) | 15 | 23 | 46 | 53 |
| Shredded (pieces 0.3 cm [1/10 in] from full-sized leaves) | 17 | 18 | 59 | 68 |

(including browning), flavor, texture, and nutritional quality (sugar, acid, and vitamin content). The degree of processing and the quality of the equipment (e.g., blade sharpness), significantly affect the wounding response.

Strict temperature control is required to minimize the increased respiration and metabolic rates of fresh-cut products. The importance of temperature is illustrated with data from intact and shredded cabbage stored at different temperatures (fig. 36.7). Young leaf tissue will have higher respiration rates than mature fully developed leaves, as shown with data on kale leaves (table 36.1). Salad-size (2 by 2 cm, or 0.75 by 0.75 in) pieces from mature kale leaves have respiration rates almost double those of the intact leaves, but their rates are similar to rates of the small leaves; shredding mature leaves approximately doubled respiration rates. Different parts of a vegetable may have very different respiration rates, as illustrated by data from broccoli (fig. 36.8). These differences in respiration rates have implications for the quality and shelf life of mixed medleys and salad mixes. The quality of an entire fresh-cut item is only as good as that of its most perishable component. In mixed salads, it is important to ensure that components included for their color or flavor qualities be as fresh as possible and similar in shelf life to the major salad components. These considerations also apply to a product such as cleaned and washed spinach, where differences in leaf age or physical damage may yield a mixed product of variable perishability.

The greater the degree of processing, the higher the induced rates of respiration. Intact garlic bulbs have relatively low respiration rates, but they have high respiration rates when cloves are peeled or chopped, especially if stored at temperatures above 5°C (41°F) (table 36.2). The respiration rates of iceberg and romaine lettuces cut as salad pieces (2 to 3 cm  2 to 3 cm, or 0.75 to 1.18 in by 0.75 to 1.18 in) are only 20 to 40% higher than rates of the respective intact heads. The respiration rates of shredded lettuce and shredded cabbage are 200 to 300% greater than those of the intact heads and remain high throughout the storage period (see fig. 36.7). The relationship between respiration rates and changes in quality at different temperatures can be illustrated by data from intact and sliced mushrooms (fig. 36.9). Respiration rates and deterioration rates can be minimized by quickly cooling the product and storing at 5°C (41°F) or below.

Cutting carrots into large segments does not significantly change their respiration rate but does make them much more sensitive to ethylene. Unpeeled segments and slices of

**Figure 36.8**

Respiration rates of florets, stem, and intact heads of broccoli.

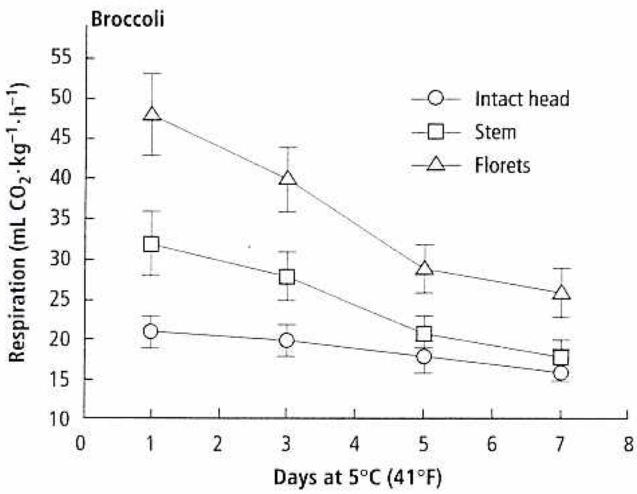



**Table 36.2.** Average respiration rates of intact, peeled, and chopped cloves of garlic stored 5 days

| | Respiration rate (mL $CO_2 \cdot kg^{-1} \cdot h^{-1}$) | | | |
|---|---|---|---|---|
| Product | 0°C (32°F) | 5°C (41°F) | 10°C (50°F) | 15°C (59°F) |
| Intact | 4 | 6 | 8 | 13 |
| Peeled cloves | 12 | 20 | 57 | 69 |
| Chopped cloves | 16 | 22 | 73 | 107 |

carrots exposed to ethylene become bitter due to the synthesis of isocoumarin. However, the peeled "baby" carrots do not produce this bitter compound even if exposed to ethylene because isocoumarin is formed predominantly in the peel tissue.

Fresh-cut fruits generally have a more complicated physiology than fresh-cut vegetables. Stage of ripeness at the time of processing may alter the physiological responses to cutting. In cantaloupe, respiration rates of pieces from fruit harvested at different stages of ripeness are similar. Ethylene production rates, however, are much higher in pieces from riper fruits (three-quarters or full slip) than less-ripe fruit (one-quarter to one-half slip). Piece size also greatly affects the physiological response of the fresh-cut fruits. Cantaloupe cut into very small pieces (0.2 mm, or 0.008 in) had a large increase in ethylene production, whereas large pieces (1 by 2 cm, or 0.4 by 0.75 in) were not different in their physiology from the intact fruit. Respiration rates of sliced peaches, bananas, kiwifruit and tomatoes average about 65% higher than rates of the corresponding intact fruits at 0° to 10°C (32° to 50°F). Examples of fruit responses to fresh-cut processing are summarized in table 36.3.

Although temperature is the principal controlling factor for respiration rates, modified

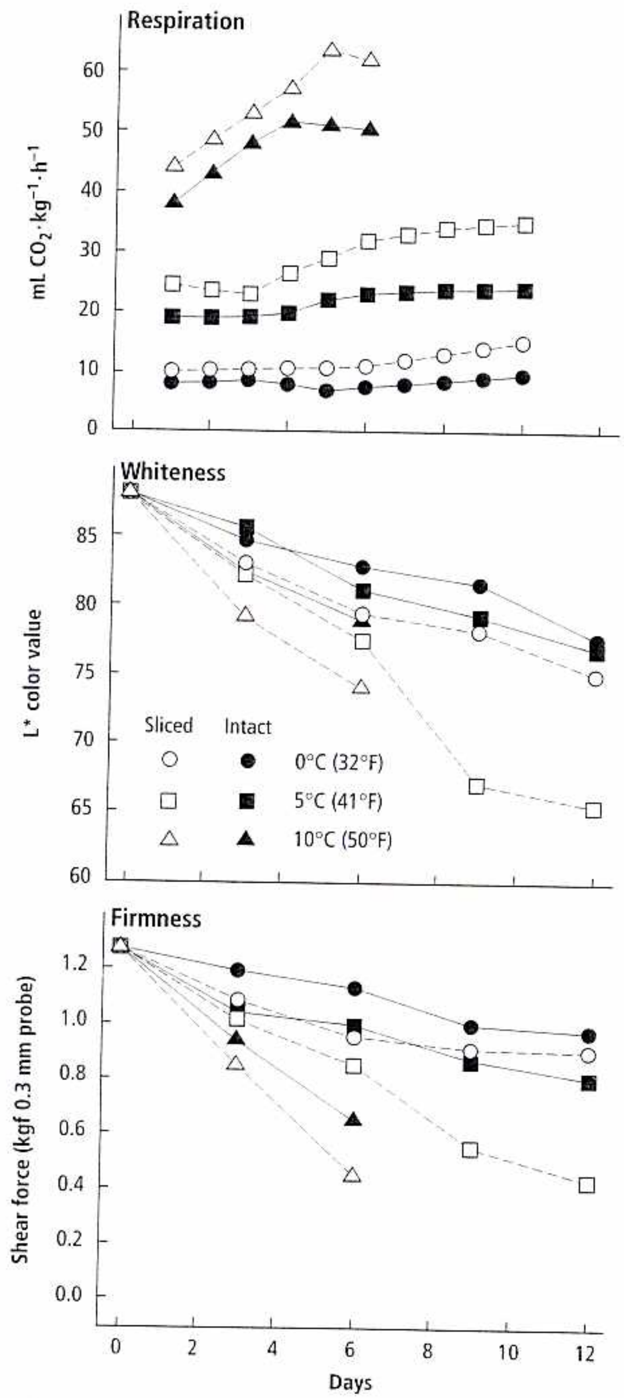
**Table 36.3.** Responses of fresh-cut fruit pieces compared to the physiology of intact fruit (compiled by Cantwell, 1998)

| Fruit | Stage of ripeness | Temperature °C | Temperature °F | Piece size | Respiration compared to intact fruit | Ethylene production compared to intact fruit |
|---|---|---|---|---|---|---|
| Apple | Ripe | 2 | 36 | Wedge | Increase | — |
| Banana | Unripe | 20 | 68 | 0.4 cm | — | Increase 4× |
| | Ripening | 20 | 68 | 0.4 cm | Increase | Increase |
| | Ripe | 20 | 68 | 4 cm | Same | Same |
| Cantaloupe | Ripe | 20 | 68 | 0.2 mm | — | Increase 10× |
| | Ripening | 2 | 36 | 2- × 1-cm cylinder | Same | Same |
| | Ripe | 2 | 36 | 2- × 1-cm cylinder | Same | Same |
| | Ripening | 10 | 50 | 2- × 1-cm cylinder | Same | Same |
| | Ripening | 20 | 68 | 2- × 1-cm cylinder | Increase 2× | Same |
| Kiwifruit | Ripe | 20 | 68 | 1 cm | Increase | Increase 8× |
| Pear | Ripening | 2 | 36 | 1-cm wedge | Same | Same |
| | | 20 | 68 | 1-cm wedge | Increase | Reduced |
| Strawberry | Ripe | 2 | 36 | Quarters | Same | Same, none |
| | | 20 | 68 | Quarters | Increase | Increase 4× |
| Tomato | Mature-green | 20 | 68 | 1 cm | Same | Same |
| | MG+$C_2H_4$ | 20 | 68 | 0.7-cm slice | Same | Same |
| | Ripening | 20 | 68 | 1 cm | Increase | Increase 5× |
| | Ripe | 20 | 68 | 1 cm | Same | Same |

atmospheres also reduce rates (see chapter 14). Limited information is available regarding respiration rates of fresh-cut products under CA or MA. An atmosphere of 5% $O_2$ and 5% $CO_2$ only slightly reduces the respiration rates of fresh-cut carrots, leek, and onion but slightly increases the rates of cut potatoes (Mattila et al. 1995). CA of 1 to 2% $O_2$ and 10% $CO_2$ reduced respiration rates of minimally processed strawberries, peaches, and honeydew by 25 to 50% at 5°C (41°F) (Qi and Watada 1997). These same atmospheres also substantially reduced ethylene production rates and softening of the fruit tissues.

**Figure 36.9**

Respiration rates, color, and firmness changes of intact and sliced white mushrooms.




Control of the wound response is the key to providing a fresh-cut product of good quality. Low temperatures minimize differences in respiration and ethylene production rates between the fresh-cut and the intact product. Low temperatures are also essential to retard microbial growth and decay on cut surfaces. Variety, production conditions, stage of maturity, piece size, and storage conditions all contribute to variations in fresh-cut product physiology.

## PROCEDURES FOR PREPARATION OF FRESH-CUT VEGETABLES

Minimally processed products may be prepared at the source of production or at regional and local processors, depending on the perishability of the fresh-cut item relative to the intact product and also depending on the quality required for the designated use of the product. Table 36.4 summarizes some considerations in relation to location of processing. Fresh-cut vegetable processing has shifted from destination (local) to source processors and regional processors as improvements in equipment, MA packaging, and temperature management have become available. Other than pineapple, processing and marketing of fresh-cut fruits has remained at the regional or local level.

An example of the operations involved in minimal processing is shown in figure 36.10 for lettuce. In the past, fresh-cut lettuce operations often salvaged lettuce remaining in the fields after harvesting for fresh market. It is now recognized that first-cut lettuce of optimal maturity (heads firm but not hard) should be used to maximize processed product quality. After reception and emptying of the bins, all operations are done in cold, clean processing rooms. After trimming and coring, piece size may be reduced with rotating knives or by tearing into salad-size pieces. Damage to cells near cut surfaces influences the shelf life and quality of the product. For example, shredded lettuce cut by a sharp knife with a slicing motion has a storage life

**Table 36.4.** Advantages, disadvantages, and requirements of fresh-cut vegetable products prepared at different locations

| Location of processing | Characteristics and requirements |
|---|---|
| Source of production | Raw product processed fresh when it is of the highest quality. |
| | Processed product requires a minimum of 14 days postprocessing shelf-life. |
| | Good temperature management critical. Economy of scale. |
| | Avoid long-distance transport of unusable product. |
| | Vacuum- and gas-flushing common; differentially permeable films. |
| Regional | Raw product processed when of good quality, typically 3 to 7 days after harvest. |
| | Reduced need to maximize shelf life; about 7 days postprocessing life required. |
| | Good temperature management vital. |
| | Several deliveries weekly to end users. |
| | Can better respond to short-term demands. |
| | Vacuum- and gas-flushing common; differentially permeable films. |
| Local | Raw product quality may vary greatly, since processed 7 to 14 days after harvest. |
| | Relatively short postprocessing life required or expected. |
| | Good temperature management required but is often deficient. |
| | Small quantities processed and delivered. |
| | More labor-intensive; discard large amounts of unusable product. |
| | Simpler and less costly packaging; less use of vacuum or gas-flushing techniques. |

approximately twice that of lettuce cut with a chopping action. Shelf life of lettuce is less if a dull knife is used rather than a sharp knife. A common defect in commercially prepared fresh-cut melon is translucency or glassiness, and dull cutting equipment increases the incidence of this defect.

Washing the product immediately after cutting removes sugars and other nutrients at the cut surfaces that favor microbial growth and tissue discoloration. The wash water is usually cold and also provides rapid cooling. Because of differences in composition, some products such as cabbage are known as "dirty" products because they release a lot more organic nutrients with processing. It is therefore desirable to maintain separate processing lines or thoroughly clean the line before another product follows cabbage. Cut tissues take up water in the washing and cooling flumes, as illustrated with spinach (fig. 36.11); continuous and strict water disinfection is necessary. Excess moisture must be completely removed after washing and cooling. Centrifugation is generally used aft passing the product over a vibration screen. Forced-air tunnels over the conveyor line ar used to a limited extent but may be especial useful for fresh-cut fruits and other delicate products. Ideally, the drying process should remove at least the same amount of moistur that the product retained during processing. For lettuce products, removal of slightly mo moisture (i.e., slight desiccation of the product) may favor longer postprocessing life.

Centrifuged or dried product may be packaged in preformed bags on equipment that pulls a vacuum before sealing (i.e., shredded lettuce in 3- to 5-lb foodservice bags) or into bags on a form-fill-seal machir in which product is fed through a stainless steel tube around which the bag is formed from plastic film rollstock (e.g., retail salad mixes). In this case, nitrogen gas flushing is often done immediately before sealing to drop $O_2$ levels and rapidly establish a beneficial MA in the bag. The sealed bags then drop onto a conveyor that passes through a metal detector and are boxed and palletized usually in an adjoining cold room. To ensur a continuous cold chain, palletized product should be loaded onto only precooled traile at enclosed refrigerated docks.

Peeled "baby" carrots are a popular fresh-cut vegetable that is also produced in large volumes. Varieties and growing conditions have been developed to produce a long, tender carrot that is mechanically harvested an cut into 5-cm (2-in) segments. The segment may be stored to ensure a continuous suppl to the processing line. Segments are flumed through course and fine abraders to remove the peel and cell wall debris, and then washed, diameter-sized, and packaged. Low-density polyethylene (LDPE) bags with a fe small holes are often used to maintain high humidity and free moisture (no MA), and the bags are packed into waxed carton boxe that may be top-iced to ensure low temperature during distribution. Whitening of the carrot surface is a common defect that result from drying of the abraded and exposed cell walls (see fig. 36.2). Edible surface coatings, hygroscopic coatings, free water in the bag, and other treatments have been applied to

**Figure 36.10**

Preparation of minimally processed lettuce products.

Harvest
Lettuce from first harvest results in better quality
Overmature lettuce browns more after cutting
Trim outer leaves

↓

Field-pack and local transport
Plastic bins or totes or fiberboard boxes or bins; avoid wood bins
Transport on flatbed trucks; if distances far, transport in refrigerated trailer

↓

Vacuum or forced-air cooling
Field temperatures and delay determine need to cool
Vacuum and forced-air cooling most common

↓

Reception, dump, trim, and core
Revision and selection of heads on conveyer
Further trimming to remove damaged outer leaves
Manual removal of stem tissue with manual coring device

↓

Chop/shred/tear
Continuous-feed cutter for salad pieces (3 by 3 cm, or 1.75 by 1.75 in.) or shreds (<0.5 cm, or 0.2 in.)
Manual cutting for some lettuce types (romaine)
Very sharp knives reduce damage and subsequent browning

↓

Wash and Cool
Water containing disinfectant, usually chlorine
Residence time from 15–30 sec
Processing aids to reduce browning may be used

↓

Centrifugation or other drying technique
Vibration screen removes large volumes of water
Centrifugation and air tunnels remove moisture so surface of product dry
Basket centrifuges of different sizes depending on product

↓

Combine different products for salad mixes
Or "color" items may be added after washing and centrifuged together

↓

Package in plastic film bags
Centrifuged product dumped onto conveyor feeding filler
Manual or automated form-fill-seal machines
Vacuum- or gas-flushing with nitrogen
Check for leakers in pressurized water chamber

↓

Box, palletize, and store temporarily
Pass bags through a metal detector
On conveyor to boxing and palletizing area
Temporary storage <5°C (<41°F); 0°C (32°F) is optimum

↓

Transport to food service outlets and/or retail markets
Pre-cooled clean trucks; thermostat at <5°C (41°F)
Load at enclosed docks to maintain cold chain

reduce this visual defect. However, a dry surface is less conducive to microbial growth, and the pieces can later be rehydrated rapidly in chilled water.

Items such as broccoli and cauliflower florets require manual trimming of the florets. The broccoli stems may also be trimmed and cut for slaw and various other products. In the handling of cauliflower it is extremely important to reduce damage to the florets during harvest as well as during the fresh-cut operations. Bacterial growth on the damaged surface can be a common defect, especially if the cauliflower florets are not held at low temperature (fig. 36.12).

Key factors for maintaining quality and shelf life of fresh-cut vegetable products include

- using high-quality raw product
- using strict sanitation procedures
- minimizing mechanical damage by using sharp knives
- rinsing and sanitizing cut surfaces
- drying to remove excess water
- packaging with an appropriate atmosphere
- scrupulous control of product temperature at 0° to 5°C (32° to 41°F) during storage, transportation, and handling

Selected characteristics, including respiration rates, quality defects, and beneficial atmospheres of many fresh-cut vegetables are summarized in table 36.5.

## PROCEDURES FOR PREPARATION OF FRESH-CUT FRUITS

Preparation of fresh-cut fruit products is complicated by the inherent nature of fruits in which softening and other ripening processes continue after harvest. Finding the right balance between flavor quality and firmness is a key consideration for adequate shelf life of fresh-cut fruit products. Fruit varieties often change during the production season, and fruits may be stored for relatively long periods of time before processing. Defining the best storage and conditioning procedures for fruits destined for fresh-cut processing is also a challenge.

For fresh-cut fruit products, the exterior

**Table 36.5.** Physiology and storage characteristics of fresh-cut products (all products should be stored at 0° to 5°C)

| Commodity | Fresh-cut product | Respiration rate in air at 5°C (mL $CO_2 \cdot kg^{-1} \cdot h^{-1}$)* | Common quality defects (other than microbial growth) | Beneficial atmosphere† | |
|---|---|---|---|---|---|
| | | | | % $O_2$ | % $CO_2$ |
| Apple | Sliced | 3–7 (2°C) | Browning | <1 | — |
| Asparagus tips | Trimmed spears | 40 | Browning, softening | 10–20 | 10–15 |
| Beans, snap | Cut | 15–18 | Browning | 2–5 | 3–12 |
| Beets | Cubed | 6 | Leakage; color loss | 5 | 5 |
| Broccoli | Florets | 20–35 | Yellowing, off-odors | 3–10 | 5–10 |
| Cabbage | Shredded | 13–20 | Browning | 3–7 | 5–15 |
| Carrots | Sticks, shredded | 7–10; 12–15 | Surface drying ("white blush"); leakage | 0.5–5 | 10 |
| Cauliflower | Florets | — | Discoloration; off-odors | 5–10 | <5‡ |
| Celery | Sticks | 2–3 (2.5°C) | Browning, surface drying | — | — |
| Cucumber | Sliced | 5 | Leakage | — | — |
| Garlic | Peeled clove | 20 | Sprout growth, discoloration | 3 | 5–10‡ |
| Jicama | Sticks | 5–10 | Browning; texture loss | 3 | 10‡ |
| Kiwifruit | Sliced | 1–3 (0°C) | Juice leakage; texture loss | 2–4 | 5–10 |
| Leek | Sliced, 2 mm | 25 | Discoloration | 5 | 5 |
| Lettuce, iceberg | Chopped, shredded, | 6; 10 | Browning of cut edges | <0.5–3 | 10–15 |
| Lettuce, other than iceberg | Chopped | 10–13 | Browning of cut edges | 1–3 | 5–10 |
| Melons | | | | | |
| Cantaloupe | Cubed | 5–8 | Leakage; softening; glassiness (translucency) | 3–5 | 5–15 |
| Honeydew | Cubed | 2–4 | Leakage; softening; glassiness (translucency) | 2–3 | 5–15 |
| Watermelon | Cubed | 2–4 | Leakage; softening | 3–5 | 5–15 |
| Mushrooms | Sliced, 5 mm | 20–45 | Browning | 3 | 10** |
| Onion, bulb | Sliced, diced | 8–12 | Texture, juice loss, discoloration | 2–5 | 10–15 |
| Onion, green | Chopped | 25–30 | Discoloration, growth; leakage | — | — |
| Orange | Peeled; sectioned | 3 | Juice leakage; off-flavors | 14–21 | 7–10 |
| Peach | Sliced | 6 | Browning; mechanical damage | 1–2 | 5–12 |
| Pear | Sliced | 6–8 (2.5°C) | Browning; mechanical damage | 0.5 | <10 |
| Peppers | Sliced; diced | 3; 6 | Texture loss, browning | 3 | 5–10 |
| Persimmon | Sliced | — | Glassiness (translucency); darkening | 2 | 12 |
| Pineapple | Cubed | 3–7 | Leakage; discoloration | 3 | 10‡ |
| Pomegranate | Arils | 2 | Color loss; juice leakage | 21 | 15–20 |
| Potato | Sticks, peeled | 4–8 | Browning, drying | 1–3 | 6–9 |
| Rutabaga | Cubed | 10 | Discoloration, drying | 5 | 5 |
| Spinach | Cleaned, cut | 6–12 | Off-odors; rapid deterioration of small pieces | 1–3 | 8–10 |
| Squash, summer | Cubed, sliced 5 mm | 12–24 | Browning; leakage | 1 | — |
| Strawberry | Sliced; topped | 12; 6 | Loss of texture, juice, color | 1–2 | 5–10 |
| Tomato | Sliced | 3 | Leakage | 3 | 3 |

* *Source:* Adapted from Mirjami et al. 1995; Watada et al. 1996; Avena-Bustillos et al. 1997.

† *Source:* Adapted from Gorny 1997.

‡ Unpublished results.

** Not used because of *C. botulinum* risk.

**Figure 36.11**

Water uptake by young (6-cm, [2.4-in]) and mature (12-cm [4.7-in]) spinach leaves in relation to the number of cut surfaces.

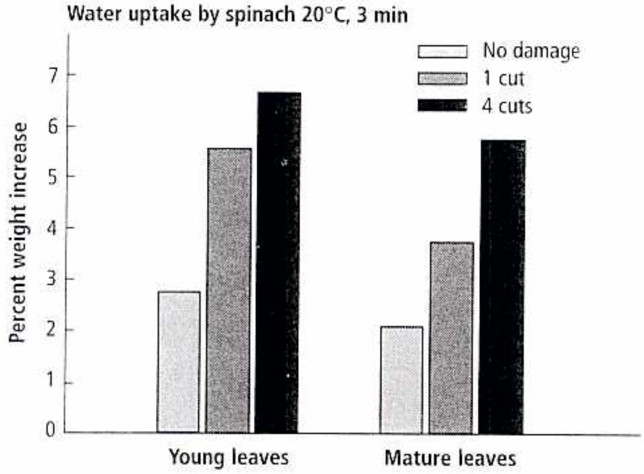



**Figure 36.12**

Cauliflower florets with physical damage stored at 6 days in air at 3 temperatures.

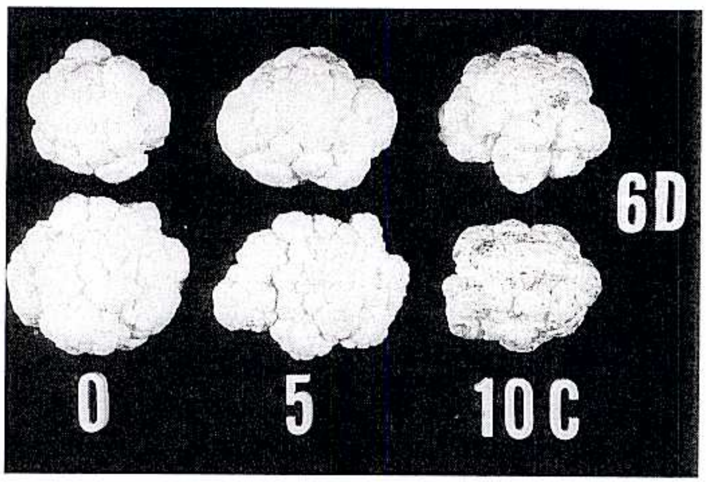
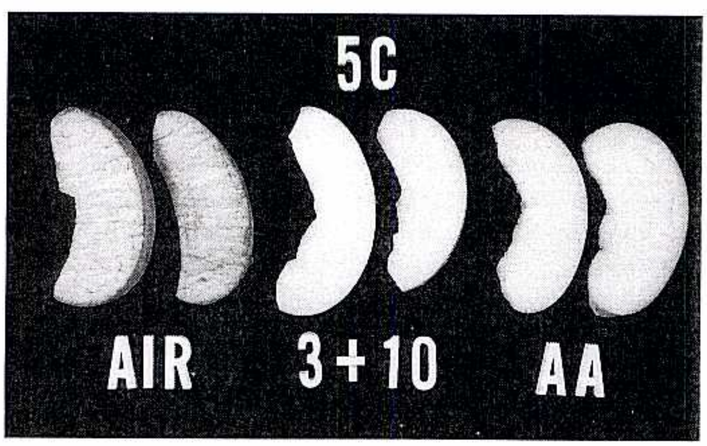



**Figure 36.13**

Control of browning of Granny Smith apple slices by CA (3% $O_2$ and 10% $CO_2$) and a 1% ascorbic acid dip. Pieces were stored at 5°C (41°F) for 2 weeks.




surface is disinfected; the fruit is peeled and sectioned and then may be passed through a cutter/slicer or cut by hand. Depending on the fruit, pieces may be washed after cutting. Fresh-cut soft fruit products need to be packaged in rigid containers, usually lidded with a plastic film that permits development of MA. Loss of fluid from juicy fresh-cut fruits, such as melons, during storage and handling is a common problem.

Selected characteristics, including respiration rates, quality defects, and beneficial atmospheres, of many fresh-cut fruits are summarized in table 36.5.

The visual acceptance and shelf life of many fruit products depend on the use of treatments to retard browning beyond that achieved by the use of low temperatures and MA. Many fruits (e.g., apples, peach, pear) and some vegetables (e.g., potatoes, artichoke) have high levels of preformed phenolic compounds. After cutting, very rapid surface browning will occur. Apple and peach varieties can vary greatly in browning potential of cut pieces. The use of antioxidants such as ascorbic acid (fig. 36.13) and erythorbic acid, and the use of acidifying and chelating agents (citric acid, EDTA), and combinations of these can be useful to reduce browning problems. Rinses with hypochlorite solutions may also retard browning. Sulfites are very effective but are not permitted for use on fresh-cut products in the United States. Calcium salts can also be useful to retard browning and maintain firmness, as illustrated with data on pear slices (fig. 36.14). Dips into calcium chloride or calcium lactate (which has less effect on flavor) solutions have been shown to improve the firmness of fresh-cut cantaloupe. Table 36.6 lists requirements and considerations for efficient minimal processing of vegetables and fruits.

## STORAGE TEMPERATURE

Low temperatures are necessary to reduce respiration rates, retard microbial growth, and retard deterioration such as browning and softening in fresh-cut products, as illustrated for diced onions, broccoli florets, and peppers (figs. 36.15, 36.16, and 36.17, see color well). In general, all fresh-cut items should be stored at 0° to 5°C (32° to 41°F) to maintain their quality, safety, and shelf life.

**Figure 36.14**

Effects of a 1% calcium chloride dip on color and firmness of pear slices. (Gorny and Kader in Cantwell 1998)

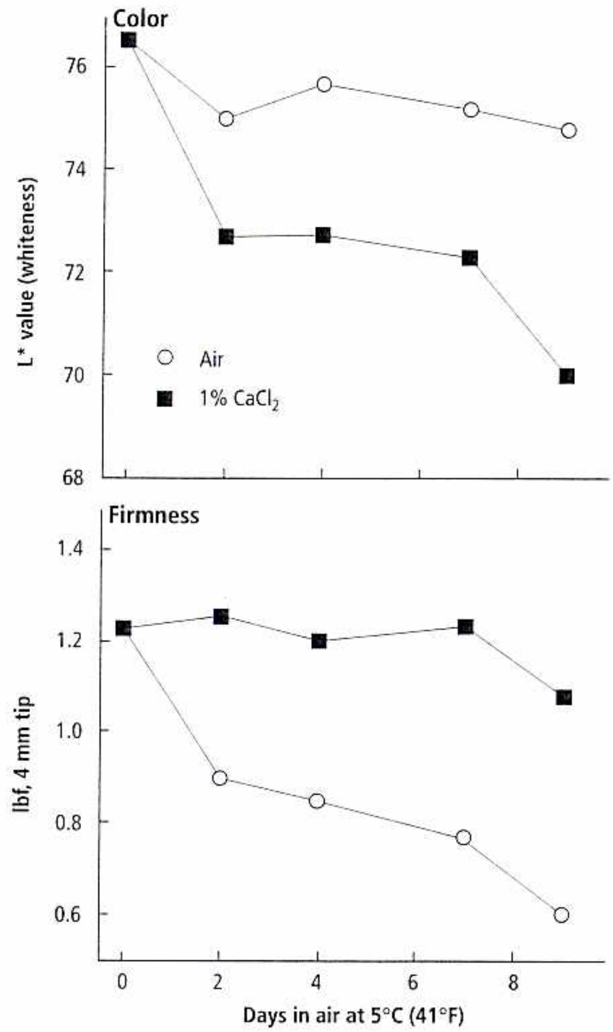



**Figure 36.15**

Diced yellow onion quality after 20 days in air storage at three temperatures.

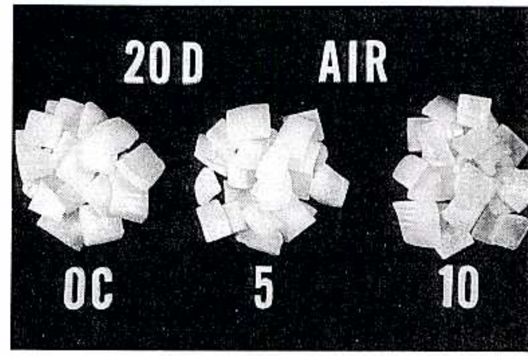



**Figure 36.16**

Visual quality of broccoli florets stored in air or CA (2% $O_2$ and 10% $CO_2$) at three temperatures.

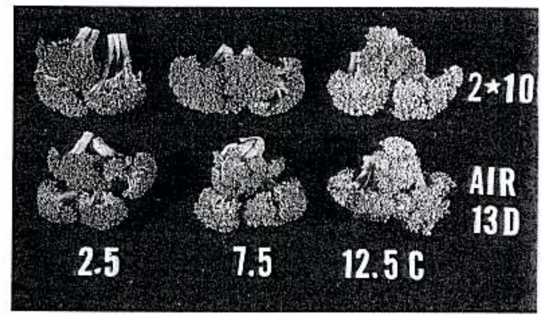
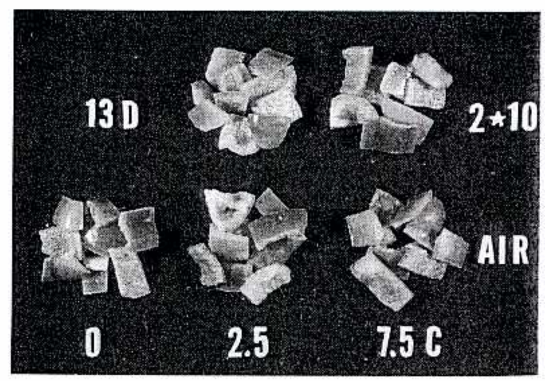



**Figure 36.17**

Visual quality of diced green peppers stored in air or CA ($2\% O_2 + 10\% CO_2$) at three temperatures. The pepper dices kept in air (lower right) have yellowed more than those kept in CA.




The recommendation to store fresh-cut products as close to 0°C (32°F) as possible also generally applies to items prepared from chilling-sensitive produce such as peppers, honeydew melons, jicama, and tomatoes. Fresh-cut products are usually taken directly from cold rooms and used without transfer to warmer temperatures, conditions that favor the development of chilling injury symptoms on intact sensitive products. For fresh-cut squash, cucumber, and watermelon, there are reports that storage at 2° to 3°C (36° to 38°F) may result in better shelf life than storage at 0°C (32°F). However, for chilling-sensitive commodities in general, low temperatures retard the rate of deterioration of the fresh-cut products more than they induce chilling injury. In addition, microbial safety concerns dictate that fresh-cut products always need to be kept as cold as possible.

## MODIFIED ATMOSPHERES AND PACKAGING

For many fresh-cut products, MA packaging is a necessary supplement to low-temperature storage to further reduce rates of deterioration.

**Table 36.6.** Basic requirements for preparation of minimally processed fruits and vegetables

| |
|---|
| • High-quality raw material<br>Variety selection<br>Production practices<br>Harvest and storage conditions |
| • Strict hygiene and good manufacturing practices<br>Use of HACCP principles<br>Sanitation of processing line, product, and workers |
| • Low temperatures during processing |
| • Careful cleaning and/or washing before and after peeling<br>Good-quality water (sensory, microbiological, pH) |
| • Use of mild processing aids in wash water for disinfection or prevention of browning and texture loss<br>Chlorine, ozone, other disinfectants<br>Antioxidant chemicals such as ascorbic acid, citric acid, etc.<br>Calcium salts to reduce textural changes |
| • Minimize damage during peeling, cutting, slicing, and shredding operations<br>Sharp knives and blades on cutters<br>Elimination of defective and damaged pieces |
| • Gentle draining, spin- or air-drying to remove excess moisture |
| • Correct packaging materials and packaging methods<br>Selection of plastic films to ensure adequate $O_2$ levels to avoid fermentation |
| • Correct temperature during distribution and handling<br>Keep all minimally processed products at 0°–5°C (32°–41°F) |

*Source:* Adapted from Ahvenainen 1996.

Film packaging also reduces water loss from the cut surfaces. There have been many recent improvements and innovations in plastic films and packaging equipment specifically aimed at fresh-cut products.

There are many examples of the benefit of MA on fresh-cut products. Data from fresh-cut cantaloupe stored at 5°C (41°F) provides one example of the potential benefit of CA on shelf life (fig. 36.18). In this case, high-$CO_2$ atmospheres in air or low $O_2$ gave similar results and were effective in retarding microbial growth, softening, color change, and off-odors.

For fresh-cut lettuce, discoloration of the cut surfaces is a major quality defect (fig. 36.19). Cutting stimulates enzymes involved in phenolic metabolism, which in turn leads to the formation of undesirable brown pigments. To ensure that packaged salad products have no brown edges, very low $O_2$ (<0.5%) and high $CO_2$ (>7%) atmospheres are used in commercial production (fig. 36.20). These conditions may lead to increases in acetaldehyde and ethanol concentrations, indicating a shift from aerobic to anaerobic or fermentative metabolism. These changes are greater in the iceberg salads than in romaine salads and are correlated with the development of off-odors.

Although modified atmosphere packaging (MAP) maintains visual quality by retarding browning, off-odors increase and lettuce crispness decreases during storage of the salad products. With current packaging technology, it is possible to have product of good visual quality even at temperature-abuse conditions (fig. 36.21). Although product stored at temperatures of 20°C (68°F) are unlikely, short periods near 10°C (50°F) can readily occur. The visual quality of the product is only slightly reduced by holding at 10°C (50°F), but atmosphere composition, production of fermentative volatiles, and off-odor development are notably different from product stored at 0°C (32°F). These data underscore the importance of low-temperature storage in conjunction with appropriate MAP conditions. Figures 36.16 and 36.17 for diced peppers and broccoli florets also show that CA cannot compensate for improper storage temperatures.

In the case of lettuce, the atmospheres effective in retarding cut edge browning are very different from the atmospheres recommended for intact lettuce heads (lettuce heads develop the disorder brown stain when exposed to $CO_2$ >2%). Green bell peppers provide another example in which MA conditions beneficial for the fresh-cut product differ substantially from those recommended for the intact product. As more research is conducted on fresh-cut products we can expect more examples in which temperature and atmosphere requirements will be very different from those recommended for the intact products. Current recommendations of beneficial atmospheres for fresh-cut fruits and vegetables and their common quality defects are summarized in table 36.5.

Packaging technology is indispensable for most fresh-cut products. The selection of the plastic film packaging material involves achieving a balance between the $O_2$ demand of the product ($O_2$ consumption by respiration) and the permeability of the film to $O_2$ and $CO_2$. In practice, films are often selected on the basis of the $O_2$ transmission rate (OTR, expressed in units of ml/m$^2$-day-atm). Several product factors need to be considered in

**Figure 36.18**

Changes in quality of cantaloupe melon pieces stored at 5°C (41°F) under different controlled atmospheres. (Portela et al. 1997)

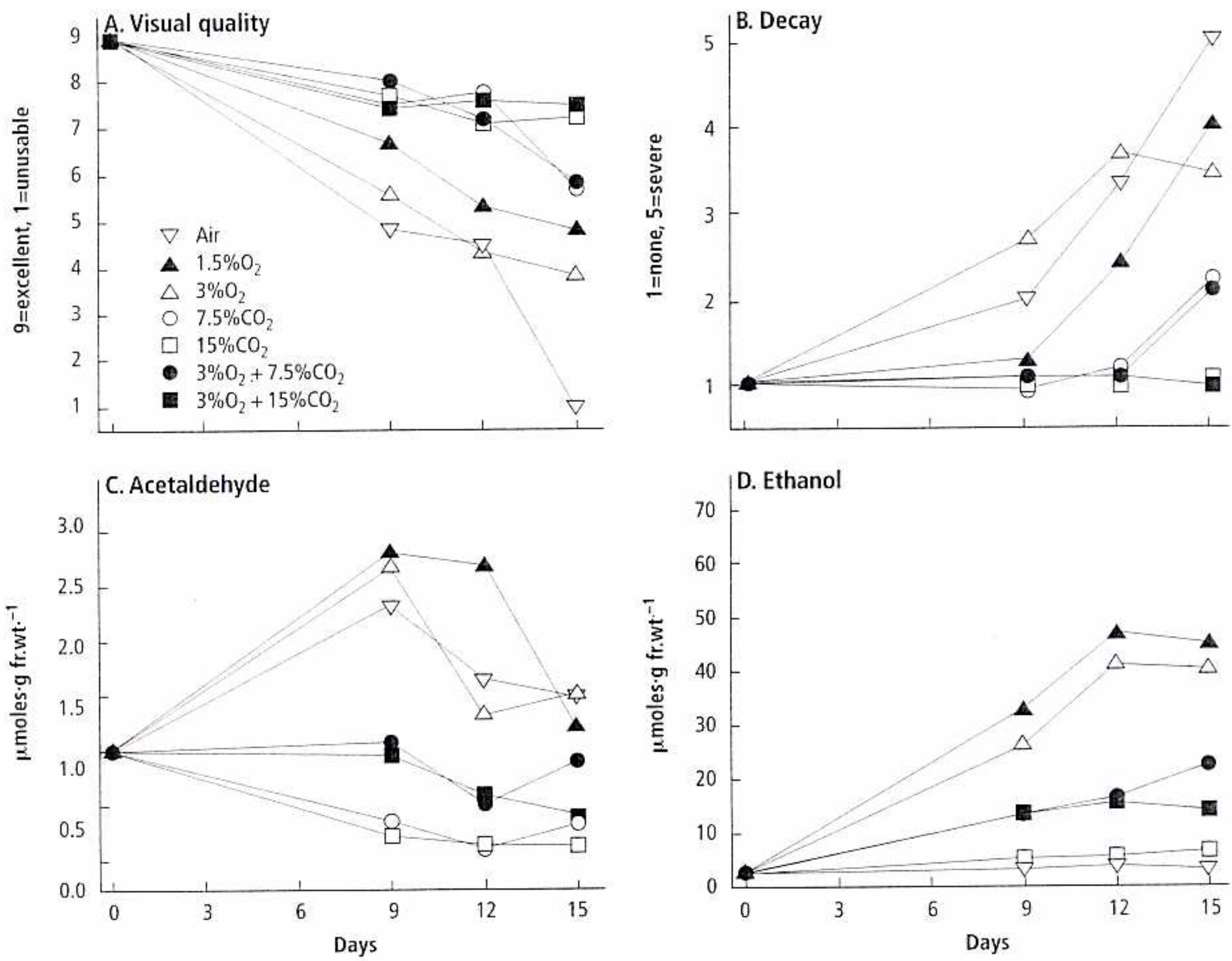
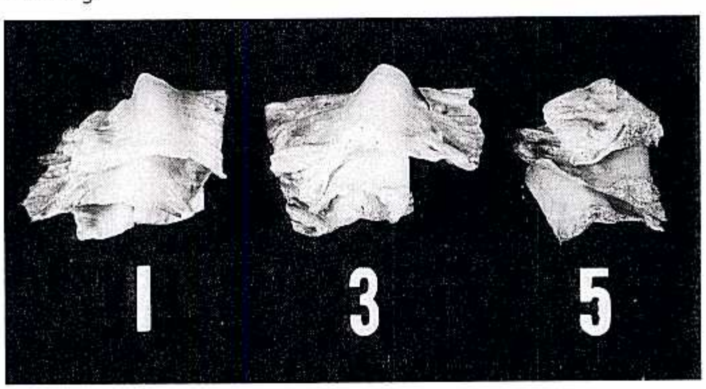



**Figure 36.19**

Romaine lettuce pieces showing none (1), moderate (3), and severe (5) browning.

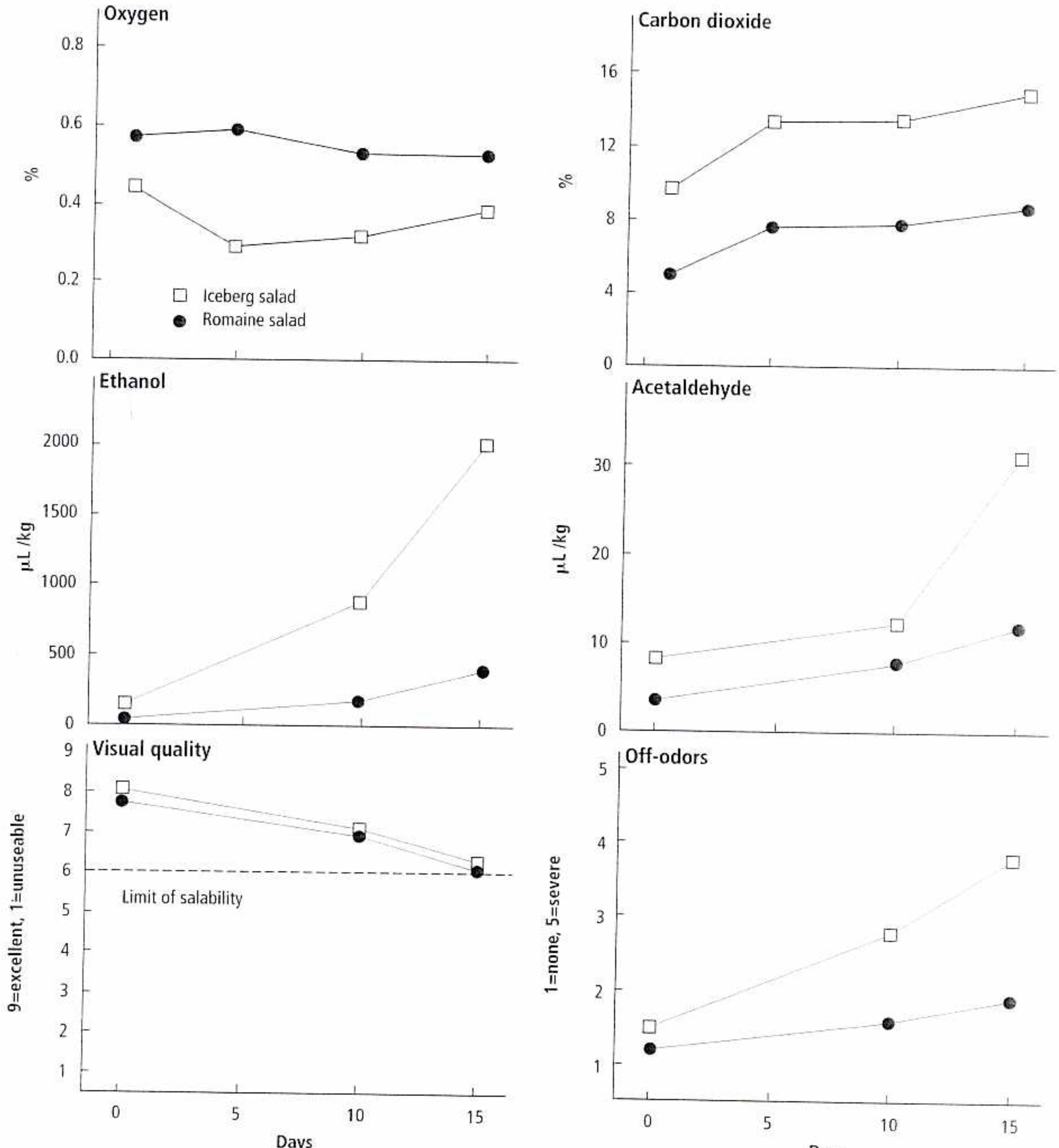



selecting film packaging: the rate of respiration of the product, the specific cut, the quantity of product, and the desirable equilibrium concentrations of $O_2$ and $CO_2$. Plastic film characteristics that need to be considered include the permeability of a given thickness of the plastic film to $O_2$, $CO_2$, and water at a given temperature; total surface area of the sealed package; and the free volume inside the package.

Many types of films are commercially available for fresh-cut packaging, including polyethylene (PE), polypropylene (PP), blends of PE and ethylene vinyl acetate (EVA), and coextruded polymers or laminates of several plastics. Besides the permeability characteristics described above, film must also satisfy other requirements (see Zagory 1995). They must have strength an be resistant to tears and splits (oriented PP or polystyrene), punctures (low-density PE), and stretching (oriented PP or polyetl ylene terephthalate); slip to work on bagging machines (acrylic coatings or stearate additives); have flex resistance, clarity, printability, and in some cases, resealabilit

**Figure 36.20**

Average changes in gas composition, fermentative volatiles, visual quality, and off-odors of commercial iceberg (garden salad) and romaine (Caesar salad) from five major processors. (López-Gálvez et al. 1997)




(ziplock or sticky seals). Consumer tactile appeal and ease of opening are also important considerations.

Film selection is a compromise between the strengths and weakness of the different materials. Many currently used films are coextrusion or laminates of several kinds of plastics, each providing a specific benefit. Recent advancements in controlling the chain length of plastic polymers have resulted in high-OTR films with superior strength, good clarity, and rapid sealing. Rapid sealing is extremely important for high-volume form-fill-seal packaging equipment. Bags are usually checked periodically on the processing line for seal integrity (in a water-filled

**Figure 36.21**

Effect of storage temperature on the gas composition and quality parameters of iceberg lettuce salads packaged for retail market.

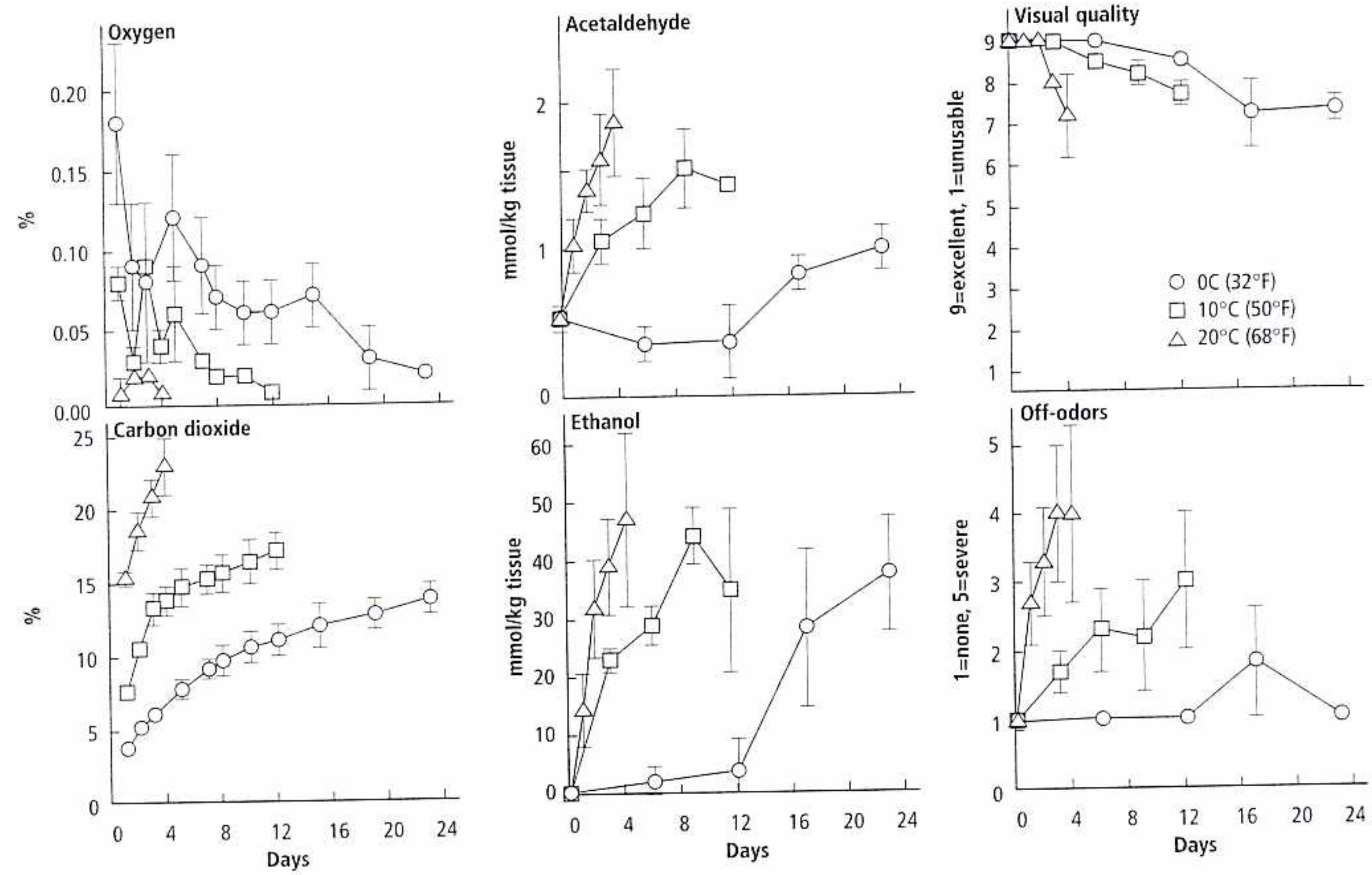



**Table 36.7.** Effect of small holes on atmospheres in bags of commercial products stored at 0° or 10°C (32° or 50°F) (holes made in bags with a hot, 25-gauge needle)

| Product | Bag perforations and storage temperature | Day 3 % $O_2$ | Day 3 % $CO_2$ | Day 5 % $O_2$ | Day 5 % $CO_2$ |
|---|---|---|---|---|---|
| Coleslaw, retail bag | Control 0°C | 1.36 | 3.7 | 1.07 | 3.8 |
| | Control 10°C | 0.22 | 5.5 | 0.28 | 5.1 |
| | 1 hole 10°C | 3.07 | 7.0 | 4.97 | 6.7 |
| | 4 holes 10°C | 10.73 | 4.3 | 15.70 | 3.9 |
| Garden salad, foodservice bag | Control 0°C | 0.69 | 9.2 | 0.17 | 8.8 |
| | Control 10°C | 0.06 | 12.1 | 0.02 | 11.7 |
| | 1 hole 10°C | 1.46 | 10.0 | 1.03 | 9.7 |
| | 4 holes 10°C | 4.80 | 8.0 | 10.57 | 7.8 |
| Garden salad with romaine, retail bag | Control 0°C | 0.03 | 10.6 | 0.03 | 10.6 |
| | Control 10°C | 0.01 | 12.8 | 0.01 | 13.0 |
| | 1 hole 10°C | 3.97 | 10.6 | 4.80 | 10.0 |
| | 4 holes 10°C | 6.60 | 5.2 | 14.97 | 5.0 |

pressurized chamber) or "leakers." There can be considerable variability in $O_2$ concentrations even in well-sealed salad bags, perhaps due to slight variations in film uniformity during the manufacturing process. An example of how a poor seal or pinholes in a package affect $O_2$ concentrations but have less effect on $CO_2$ concentrations is shown in table 36.7.

Other packaging options include rigid impermeable trays covered with a permeable film or membrane patch. Microperforated films (e.g., FreshHold, fig. 36.5) provide ver small holes (40 to 200 μm) and allow elevated levels of $O_2$ in combination with intermediate $CO_2$ concentrations. With temperature fluctuations, the permeability of most common films changes very little in comparison to the dramatic increases in respiration rates ($O_2$ demand) at warmer temperatures. With lack of $O_2$, anaerobic metabolism occurs resulting in off-odors and other quality prob lems (see fig. 36.21). "Intelligent films," "customized films," or "sense and respond," film technologies are being developed to address the problems caused by fluctuating temperatures. One company employs "temperature-activated pores" that open and allo an increase in the OTR under temperature abuse situations. Antifog films capable of di persing water droplets to avoid condensation, incorporation of antimicrobials in film and use of time-temperature indicators on or incorporated into plastic films are also under development.

## MICROBIOLOGICAL ASPECTS

The major groups of microorganisms involved in the spoilage or contamination of fresh produce are bacteria and fungi, although viruses (e.g., *Hepatitis*) and parasites (e.g., *Giardia*) can also be of concern. With minimally processed products, the increase in cut-damaged surfaces and availability of cell nutrients provide conditions that favor microbial growth. Furthermore, the increased handling during preparation of these convenience products provides greater opportunity for contamination with human pathogens such as *E. coli*, *Listeria*, *Yersinia*, and *Salmonella* spp.

There are several microbiological concerns specific to fresh-cut products: they are generally consumed raw with no critical kill step for pathogens, temperature abuse may occur during distribution and display, and some microorganisms of concern may grow under low temperatures and modified atmospheres. Because of these potential hazards, the microbiological quality and safety of minimally processed fruits and vegetables is a high priority. The International Fresh-Cut Produce Association has prepared specific voluntary guidelines for fresh fruit and vegetable processing operations to maintain high levels of microbiological safety (Gorny, 2001). Implementation of Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Points (HACCP) principles are integral parts of these guidelines.

Microbial growth on minimally processed products is controlled principally by good sanitation and temperature management. Sanitation of all equipment and use of chlorinated water are standard approaches. The large volumes of water used in fresh-cut operations are often recycled, filtered, and sanitized with chlorinated compounds (hypochlorites, chlorine gas, chlorine dioxide). The purpose of adding chlorine to the process water is to disinfect the water, which in turn prevents contamination of the produce. Vigorous washing of product with clean water may remove as many organisms as washing with chlorinated water. Continuous monitoring of active chlorine levels is considered essential to ensure consistent microbial quality of the washed product. Moisture increases microbial growth; therefore, removal of excess water after washing and cooling by centrifugation or other methods is critical. Combination treatments may be very effective. For example, irradiation of cut lettuce after a chlorinated water wash resulted in very low microbial levels during storage. The use of common sanitizers, potentiators of common disinfectants, and alternative sanitizers (e.g., ozone) are active areas of research (see chapter 24).

Clean product can become recontaminated, especially after passing through operations where debris can accumulate, such as cutters and package-filling equipment. This problem is illustrated by data in table 36.8, in which swabs from the package filler showed a much higher bacterial count than swabs from equipment in the immediately preceding operations.

Changes in the environmental conditions surrounding a product can result in significant changes in the microflora. The risk of pathogenic bacteria may increase with film packaging (high RH and very low $O_2$); with packaging of products of low salt content and high cellular pH (i.e., most vegetables); and with storage of packaged products at too high temperatures (>5°C, or 41°F). Food pathogens such as *Clostridium*, *Yersinia*, *Salmonella*, and *E. coli* spp. can potentially develop on minimally processed fruits and vegetables under such conditions. Low temperatures during and after processing generally retard microbial growth but may select for psychrotropic organisms such as pseudomonads and *Listeria* spp.

Microorganisms differ in their sensitivity to modified atmospheres. Low $O_2$ (1%) atmospheres generally have little effect on the

**Table 36.8.** Total microorganisms at various steps of a fresh, process lettuce line

| Operation | Number/in$^2$ |
|---|---|
| Bin dump | 92,000 |
| Coring belt | 210 |
| Cutter | 2,290 |
| Transfer belt | 40 |
| Cooling water | 5 |
| Centrifuge | 10 |
| Package filler | 3,350 |

*Source:* Adapted from Hurst 1990.

growth of fungi and bacteria. Concentrations of $CO_2$ at 5 to 10% are usually needed to have an effect on microbial growth. High $CO_2$ concentrations may indirectly affect microbial growth by retarding deterioration (softening, compositional changes) of the product. High $CO_2$ atmospheres may have a direct affect by lowering cellular pH and affecting the metabolism of the microorganisms. This is illustrated with data on fresh-cut melon stored under various $O_2$ and $CO_2$ concentrations (table 36.9). Gram-negative bacteria are very sensitive to $CO_2$. Anaerobic bacteria and lactic acid bacteria are quite resistant to $CO_2$. Fungi are generally very sensitive to $CO_2$ whereas yeasts are relatively resistant.

Packaging materials modify the humidity and atmosphere composition surrounding minimally processed products and may modify the microbial profile. MA may cause changes in the composition of the microflora on fresh-cut products. For example, the growth of common spoilage bacteria may be suppressed by MAP, but a pathogenic organism such as *Listeria monocytogenes*, which can grow at low temperatures under modified atmospheres, may not be.

Another issue is that MA can extend the visual shelf life of fresh-cut products by suppressing common spoilage organisms. An organism such as *Listeria*, which presents no spoilage symptoms, could develop to high levels by the end of visual shelf life in the MA-packaged product.

Products that are visually acceptable to consumers may have high microbial populations. The total microbial population, however, has no direct bearing on the safety of the product, as discussed in chapter 24. Tests for specific pathogens are needed to evaluate the microbial risk of a given product. This is one reason that no microbiological standards for fresh-cut products exist in the United States; food safety is based on prevention strategies through GMP and HACCP programs.

Although there is no kill step, several "hurdles" are used to maintain the microbiological quality of fresh-cut products. The combinations of cleanly cut products, strict sanitation procedures, appropriate MAP, and low temperatures during processing and distribution not only favor high sensory quality of the fresh-cut products but also serve to minimize microbiological risks (see table 36.6).

**Table 36.9.** Microbial counts of fresh-cut cantaloupe stored in air or CA at 10°C (50°F) and 5°C (41°F)

| Atmosphere | Day 0 APC/g* | Day 6 at 10 °C APC/g | Day 12 at 5 °C APC/g | Day 12 at 5 °C *Lactobacilli*/g |
|---|---|---|---|---|
| Air | $1.0 \times 10^7$ | $1.0 \times 10^8$ | $1.8 \times 10^{11}$ | $4.0 \times 10^7$ |
| 1.5% $O_2$ | | $3.9 \times 10^7$ | $1.9 \times 10^9$ | $9.9 \times 10^6$ |
| 3% $O_2$ | | $1.3 \times 10^7$ | $1.1 \times 10^{10}$ | $1.4 \times 10^7$ |
| 7.5% $CO_2$ | | $8.1 \times 10^6$ | $7.6 \times 10^6$ | $1.8 \times 10^5$ |
| 15% $CO_2$ | | $1.6 \times 10^6$ | $1.1 \times 10^6$ | $6.5 \times 10^5$ |
| 3% $O_2$ + 7.5% $CO_2$ | | 8.1 ×105 | $3.8 \times 10^5$ | $1.5 \times 10^5$ |
| 3% $O_2$ + 15% $CO_2$ | | 1.0 × 105 | $2.7 \times 10^5$ | $4.2 \times 10^4$ |

*Source:* Portela et al. 1997.

*Note:* *APC = Aerobic plate count at 29°C (84°F).

## RAW MATERIAL QUALITY

Consumers expect minimally processed products to be visually acceptable and appealing. Fresh-cut products must have a fresh appearance, be of consistent quality throughout the package, and be reasonably free of defects. Field defects such as tip burn on lettuce can reduce the quality of the processed product because the cut defective brown tissue will become distributed throughout the processed product. On melons, common defects such as sunburn and groundspot areas can seriously reduce the quality of the fresh-cut product. Pieces from sunburned and groundspot areas consistently have lower sugar content, less orange color, less aroma, and less firmness than pieces from sound areas. Areas of produce items with tipburn, sunburn, and other defects such as bruises should be removed from the processing line before cutting and mixing with good-quality product.

Improvements in processing equipment, packaging materials, and preparation procedures have greatly advanced the fresh-cut fruit and vegetable industry. Products of high visual quality are being produced, but in the future more emphasis will be placed on the aroma, flavor, and other sensory characteristics as well as on the nutritional qualities of fresh-cut products. This will be an even greater challenge for fresh-cut fruits, which inherently have more rapid quality losses than most fresh-cut vegetable products.

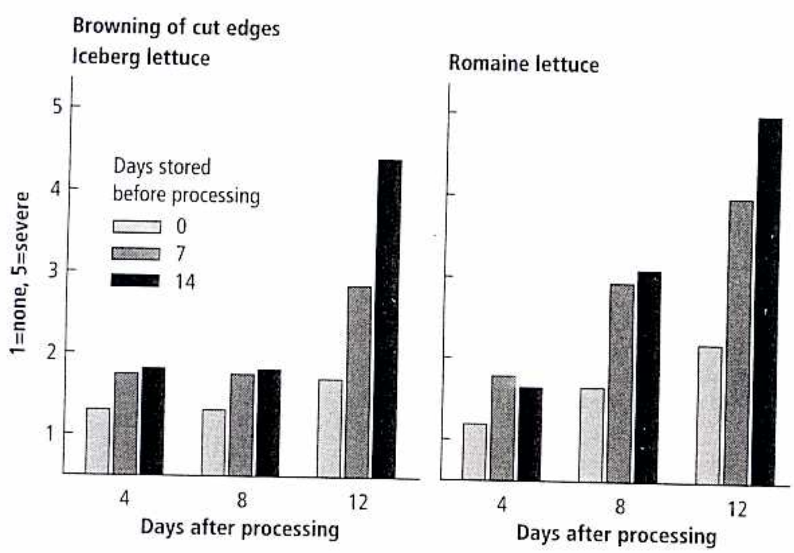
The development of varieties for different growing areas with "trait targeting" for fresh-cut quality will be increasingly important.

Until now, varieties for the fresh market have been evaluated for their potential usefulness in fresh-cut operations. But there are specific requirements for fresh-cut varieties that need to be met: varieties of lettuce, potato, apples, peaches, etc., with low browning potential; fruits with high sugar contents and firm texture; and varieties that facilitate cleaning, trimming, and cutting operations. Varieties with desirable characteristics will help in the production of fresh-cut products of consistently high quality throughout the year.

Many fresh-cut products are also handled in an "interrupted chain" in which the product may be stored before processing or may be processed to different degrees at different locations. Because of this variation in time and point of processing, it would be useful to be able to evaluate the quality of the raw material and predict the shelf life of the processed product. For example, iceberg lettuce can be stored 1 week but not more than 2 weeks before there are significant differences in browning rate of the salad product (fig 36.22). In the case of romaine lettuce, only 1 week storage was required to reduce the quality of the salad product. The variable quality of fresh-cut products such as peppers, tomatoes, jicama, squash, and beans may be related to preprocessing storage at chilling temperatures. Much California-grown product goes to regional processors, and a better understanding of the impact of preprocessing conditions on fresh-cut product quality and shelf life is needed.

**Figure 36.22**

Browning of cut edges of lettuce in relation to storage of the intact heads. Intact heads and the fresh-cut products were stored at 5°C (41°F).




## GRADES AND STANDARDS

There are no U.S. grade standards for fresh-cut fruits and vegetables separate from those applied to the original raw product. There are, however, quality and inspection guidelines to facilitate marketing (USDA 1994). In addition, industry guidelines for safe production and handling of fresh-cut products, and expectations by regulatory agencies, place them in the food processing realm (U.S. FDA 1998; Gorny 2001).

The terms *quality* and *shelf life*, as they apply to fresh-cut products, are not consistently defined or applied. Useful criteria, which encompass sensory, nutritional, and microbiological qualities, are needed for more accurate determinations of the shelf life of fresh-cut fruits and vegetables.

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