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Fresh-Cut Fruits and Vegetables: Aspects of Physiology, Preparation and Handling that Affect Quality

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Fresh-cut or minimally processed products are also referred to as "lightly processed," "partially processed," "fresh-processed," and "pre-prepared". Examples of minimally processed vegetables include peeled and sliced potatoes, shredded lettuce and cabbage, mixed salads, washed and trimmed spinach, “baby” carrots, cauliflower and broccoli florets, cleaned and diced onions. These products are expected to have a shelf-life of 10-14 days, and represent about 70% of the total volume of fresh-cut items available commercially. Other important vegetable items include peeled garlic, 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 and segments, slices of apple, peach, mango, and melon, and fruit salads. Expected shelf-life of these products is generally much less than for the vegetable products.

Whereas most food processing techniques stabilize the products and lengthen their storage and shelf life, fresh-cut 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 product perishability. 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. Also higher respiration rates can result in more rapid loss of acids, sugars and other components that determine flavor quality and nutritive value. The increased oxygen demand due to the higher respiration rates of fresh-cut products dictates that packaging films maintain sufficient permeability 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 (including browning), flavor, texture, and nutritional quality (sugar, acid, vitamin content). The degree of processing and the quality of the equipment (i.e. blade sharpness), significantly affect the wounding response.

Strict temperature control is required to minimize the increased respiration rates of fresh-cut products. This is illustrated with data from intact and shredded cabbage stored at different temperatures (F**ig. 1**). Young leaf tissue will have higher respiration rates than mature fully developed leaves (**Table 1**). Salad size (2 x 2 cm) pieces from mature leaves have respiration rates almost double those of the intact leaves, but 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 with data from broccoli **(Fig. 2).** These differences have implications for the quality and shelf-life of mixed medleys and salads 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 “color” or “flavor” components be as fresh as possible and similar in shelf-life to the major components. These considerations also apply to a product such as cleaned and washed spinach, where differences in leaf age or physical damage to leaves 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 high respiration rates when cloves are peeled or chopped, especially if stored at temperatures above 5°C (**Table 2).** The respiration rates of iceberg and romaine lettuces cut as salad pieces (2-3 x 2-3 cm) are only 20-40% higher than rates of the respective intact heads. The respiration rates of shredded lettuce and shredded cabbage are 200-300% greater than those of the intact heads and remain high throughout the storage period (**Fig. 1**). The relationship between respiration rates and changes in quality at different temperatures can be illustrated by data from intact and sliced mushrooms (**Fig.3**). 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 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.

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 melon, respiration rates of pieces from fruit harvested at different stages of ripeness were similar. Ethylene production rates, however, are much higher in pieces from riper fruits (¾ or full slip) than less ripe fruit (¼ to ½ slip). Piece size will also greatly affect the physiological response of the fresh-cut fruits. Cantaloupe cut into very small pieces (0.2 mm) had a large increase in ethylene production, whereas large pieces (1 x 2 cm) 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 0-10°C (32-50°F). Examples of fruit responses to cutting are summarized in **Table 3.**

Although temperature is the principle controlling factor for respiration rates, modified atmospheres will also reduce metabolic rates. Limited information is available regarding respiration rates of fresh-cut products under controlled or modified atmosphere conditions. An atmosphere of 5%O_2 + 5%CO_2 only slightly reduced the respiration rates of fresh-cut carrots, leek and onion, but increased slightly the rates of cut potatoes (Matilla et al., 1995). Controlled atmospheres of 1-2% O_2 + 10%CO_2 reduced respiration rates of minimally processed strawberries, peaches and honeydew by 25 to 50% at 5°C (Qi and Watada, 1997). These same atmospheres also reduced ethylene production and softening of the fruit tissues.

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 spoilage 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 on the quality required for the designated use of the product. **Table 32.4** summarizes some considerations in relation to location of processing. Vegetable processing has shifted from destination (local) to source processors and regional processors as improvements in equipment, modified atmosphere 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 fresh-cut processing is shown in F**ig. 4** 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 should be used for maximum processed product quality.   After reception and emptying of the bins, all operations are done in a large cold clean processing room(s). 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 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. Dull cutting equipment can also cause a water-soaked appearance (glassiness) in fresh-cut melon.

Washing and cooling the product immediately after cutting removes sugars and other nutrients at the cut surfaces that favor microbial growth and tissue discoloration. 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. Therefore it is desirable to maintain separate processing lines, or thoroughly clean the line before another product follows cabbage. Cut tissues take up flume water as illustrated with spinach (**Fig. 5**). Therefore continuous and strict water disinfection is necessary. Excess moisture must be completely removed after washing and cooling. Centrifugation is generally used, although vibration screens and forced air tunnels over the conveyor line can also be used. Ideally, the drying process should remove at least the same amount of moisture that the product retained during processing. For lettuce, removal of slightly more moisture (i.e., slight desiccation of the product) may favor longer post-processing life.

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

Peeled “baby” carrots are a popular fresh-cut vegetable also produced in large volumes.   Varieties and growing conditions have been developed to produce a long tender carrot which is mechanically harvested and cut into 2 inch segments. The segments may be stored to ensure a continuous supply 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. LDPE (low density polyethylene) bags with a few small holes are often used to maintain high humidity and free moisture (no modified atmosphere) , and the bags are packed into waxed carton boxes which may be top-iced to ensure low temperature during distribution. Whitening of the carrot surface is a common defect and results from drying of the abraded and exposed cell walls. Although edible surface coatings have been shown to reduce surface dehydration, a small amount of moisture in the bag generally prevents surface drying.

Items such as broccoli and cauliflower florets require manual removal of the florets. The broccoli stems may be trimmed and cut for “slaw” and various other products. In the handling of the 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 and is greatly retarded by proper low temperature storage.

Characteristics of many fresh-cut vegetables and recommended atmospheres are summarized in **Table 5**. 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.

Procedures for Preparation of Fresh-cut Fruits

Fresh-cut fruit preparation is complicated by the inherent properties of fruits that complete the ripening process after harvest. Finding the right balance between flavor quality and firmness is a key consider-ation for the 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 a challenge.

For fresh-cut fruit products, the exterior 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 or not be washed after cutting. Many soft fresh-cut fruit items need to be packaged in rigid containers, possibly lidded with a plastic film that permits development of a modified atmosphere. Loss of fluid from juicy fresh-cut fruits during storage and handling is a common problem. Characteristics of fresh-cut fruits and recommended modified atmospheres are summarized in **Table 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 modified atmospheres. Many fruits (i.e. apples, peach, pear) and some vegetables (i.e. potatoes, artichoke) have high levels of preformed phenolic compounds. Following 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 and erythorbic acid, and acidifying and chelating agents (citric acid, EDTA), and combinations can be useful to reduce browning problems. Rinses with hypoclorite solutions may also retard browning. Sulfites are very effective, but are not permitted for use on fresh-cut products in the U.S. Calcium salts can also be useful to retard browning as well as aid in maintaining firmness, as illustrated with data on pear slices (**Fig. 6**). Dips into calcium chloride or calcium lactate (has less effect on flavor) solutions have been shown to improve the firmness of fresh-cut cantaloupe melons also.

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. In general, all fresh-cut items should be stored at 0°C-5°C (32-41°F) to maintain their quality, safety and shelf-life. The recommendation to store fresh-cut products near 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 storage and used without transfer to warmer temperatures, conditions which favor the development of chilling injury symptoms on intact chilling sensitive products. For squash, cucumber and watermelon pieces, storage at a slightly higher temperature (2-3°C; 36-38°F) may result in better shelf-life than storage at 0°C (32°F). For chilling sensitive commodities, low temperatures generally retard the rate of deterioration of the fresh-cut products more than they induce physiological 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, modified atmosphere packaging is a necessary supplement to low temperature storage to further reduce rates of deterioration. 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 modified atmospheres on fresh-cut products. Data from fresh-cut cantaloupe melon stored at 5°C (41°F) provides one example of the potential benefit of controlled atmospheres on shelf-life (**Fig. 7**). In this case, high CO2 atmospheres in air or low O2 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. Cutting stimulates enzymes involved in phenolic metabolism which in turn leads to the formation of undesirable brown pigments. To ensure packaged salad products with no brown edges, very low O2 (<0.5%) and high CO2 (>7%) atmospheres are used commercially (**Fig. 8**). 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 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. 9**). Although product 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.

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 develops the disorder brown stain when to CO2 >2%). Green bell peppers provide another example in which modified atmosphere 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 5.**

Packaging technology is indispensable for most fresh-cut products. The selection of the plastic film packaging material strives to achieve an equilibrium between the oxygen demand of the product (oxygen consumption by respiration) and the permeability of the film to oxygen and carbon dioxide transmission. In practice, films are often selected on the basis of the oxygen transmission rate (OTR expressed in units of ml/m2-day-atm). Several product factors need to be considered in selecting film packaging: the rate of respiration of the product and 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: 1) the permeability of a given thickness of the plastic film to O_2, CO_2 and water at a given temperature; 2) total surface area of the sealed package; and 3) the free volume inside the package.

Many types of films are commercially available and used for fresh-cut packaging, including polyethylene (PE), polypropylene (PP), blends of PE and ethylene vinyl acetate (EVA), and co-extruded polymers or laminates of several plastics. Besides the permeability characteristics described above, films must also satisfy other requirements (Zagory, 1995). They must have strength and be resistant to tears and splits (oriented PP or polystryene), punctures (low density PE), stretching (oriented PP or polyethylene terephthalate), slip to work on bagging machines (acrylic coatings or stearate additives), have flex resistance, clarity and printability, and in some cases resealability (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 pressurized chamber) or “leakers”. There can be considerable variability in O2 concentrations in well sealed salad bags, perhaps due to slight variations in film permeability during the manufacturing process. An example of how a poor seal or pinholes in a package can greatly affect O2 concentrations but have less effect on CO2 concentrations is shown in **Table 6.**

Other packaging options include rigid impermeable trays covered with a permeable film or membrane patch. Microperforated films (i.e., FreshHold™) provide very 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 (oxygen demand) at warmer temperatures. With lack of oxygen, anaerobic metabolism occurs resulting in off-odors and other quality problems**.** There are current attempts to develop “intelligent films”, “customized films” or “sense and respond” technologies to meet the demands of fluctuating temperatures. One company employs “temperature-activated pores” that open and allow a rapid increase in OTR under temperature abuse situations. Anti-fog films capable of dispersing water droplets to avoid condensation, incorporation of antimicrobials in films, 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 (i.e. *Hepatitis*) and parasites (i.e. *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*.

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, 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 IFPA has prepared specific voluntary guidelines for fresh fruit and vegetable processing operations to maintain high levels of microbiological safety (Gorny, 2001). Implementation of GMP (Good Manufacturing Practices) and HACCP (Hazard Analysis Critical Control Points) principles are an integral part 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 (i.e. ozone) are active areas of research.

Clean product can become re-contaminated, especially after passing through operations where debris can accumulate, such as cutters and package filling equipment. This problem is illustrated by data in **Table 7** where swabs from the package filler showed a much higher bacterial count than that of 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 relative humidity and very low oxygen conditions), 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* can potentially develop on minimally processed fruits and vegetables under such conditions. Low temperature during and after processing generally retards microbial growth but may select for psychrotropic organisms such as Pseudomonads and *Listeria*.

Microorganisms differ in their sensitivity to modified atmospheres. Low oxygen (1%) atmospheres generally have little effect on the growth of fungi and bacteria. Concentrations of CO_2 at 5-10% are usually needed to have an effect on microbial growth. High CO2 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 O2 and CO2 conditions (**Table 8**). Gram-negative bacteria are very sensitive to CO_2. Anaerobic bacteria and lactic acid bacteria are quite resistant to CO2. Fungi are generally very sensitive to CO2 whereas yeasts are relatively resistant to CO_2.

Packaging materials modify the humidity and atmosphere composition surrounding minimally processed products and may modify the microbial profile. Modified atmospheres 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 modified atmospheres can extend the visual shelf-life of fresh-cut products by suppressing common spoilage organisms. Again an organism such as *Listeria*, which presents no spoilage symptoms, could develop to high levels by the end of visual shelf-life in the MAP 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. Specific 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 U.S., but rather food safety is based on prevention strategies through GMP and HACCP programs. Although there is no kill step, several "hurdles" are used to maintain 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 (**Table 9**).

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 ground spot areas can seriously reduce the quality of the fresh-cut product. Pieces from sunburned and ground spot areas consistently have lower sugar content, less orange color, less aroma, and less firmness than pieces from sound areas. Areas of produce items with tip-burn, 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 nutritional qualities of fresh-cut products. This will be an even greater challenge for fresh-cut fruits which inherently have more rapid losses in quality 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 fresh-cut specific requirements that need to be met: varieties of lettuce, potato, apples, peaches, etc. with lower browning potential are needed; fruits with high sugar contents and firm texture are needed; and varieties that facilitate cleaning, trimming and cutting operations are needed. 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. 10**). In the case of romaine lettuce, only 1 week storage was required to reduce the quality of the salad product. Variable quality of fresh-cut products such as peppers, tomatoes, jicama, squash, beans may be related to pre-processing storage at chilling temperatures. Much California-grown product goes to regional processors, and a better understanding of the impact of pre-processing conditions on fresh-cut product quality and shelf-life is needed.

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 (U.S.D.A, 1994). In addition industry guidelines for safe production and handling of fresh-cut products, and expectations by regulatory agencies, places them in the food processing realm (FDA, 1998; Zagory and Hurst, 1996). 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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Table 1. Respiration rates of leaves of kale stored at different temperatures for 5 days. (Cantwell, unpublished).

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

Table 2. Average respiration rates of intact, peeled and chopped cloves of garlic stored 5 days. (Cantwell, unpublished).

	Respiration rate (mL $CO_2 \bullet kg^{-1} h^{-1}$)			
Temperature, °C	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

Table 3. Responses of fresh-cut pieces compared to the physiology of the intact fruits (from Cantwell, 1998).

Fruit	Stage of Ripeness	Temp. °C	Temp. °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	---	4 x increase
	Ripening	20	68	0.4 cm	increase	increase
	Ripe	20	68	4 cm	same	same
Cantaloupe	Ripe	20	68	0.2 mm	---	10 x increase
	Ripening	2	36	2x1 cm cylinder	same	same
	Ripe	2	36	"	same	same
	Ripening	10	50	"	same	same
	Ripening	20	68	"	2 x increase	same
Kiwi	Ripe	20	68	1 cm	increase	8 x increase
Pear	Ripening	2	36	1 cm wedge	same	same
		20	68	"	increase	reduced
Strawberry	Ripe	2	36	quarters	same	same, none
		20	68	"	increase	4 x increase
Tomato	Mature-green	20	68	1cm	same	same
	MG+C_2H_4	20	68	0.7cm slice	same	same
	Ripening	20	68	1 cm	increase	5 x increase
	Ripe	20	68	1 cm	same	same

Table 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 post-processing 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 post-processing 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 post-processing 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

Table 5. Physiology and storage characteristics of fresh-cut products. All products should be stored at 0-5°C.

Commodity	Fresh-cut Product	Respiration[1] rate, In air at 5°C ($mL\ CO_2 \cdot kg^{-1} \cdot h^{-1}$)	Common quality defects (other than microbial growth)	Beneficial Atmosphere[2] % O_2	Beneficial Atmosphere[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)	Leakage; texture loss	2-4	5-10
Leek	Sliced, 2mm	25	Discoloration	5	5
Lettuce, iceberg	Chopped, shred	6; 10	Browning of cut edges	<0.5-3	10-15
Lettuces, not iceberg	Chopped	10-13	Browning of cut edges	1-3	5-10
Melon, Cantaloupe	Cubed	5-8	Leakage; softening; glassiness (translucency)	3-5	5-15
Melon, Honeydew	Cubed	2-4	Leakage; softening; glassiness (translucency)	2-3	5-15
Mushrooms	Sliced, 5mm	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	Sliced; sectioned	3	Leakage;	14-21	7-10
Peach	Sliced	6	Browning	1-2	5-12
Pear	Sliced	6-8 (2.5°C)	Browning	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 5mm	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
Watermelon	Cubed	2-4	Leakage; softening	3-5	5-15

[1] compiled from data from M. Cantwell, T. Suslow; Mirjami et al., 1995; Watada et al., 1996; Avena-Bustillos et al., 1997
[2] modified from Gorny, 1997; * indicates unpublished results.

Table 6. Effect of small holes on atmospheres in bags of commercial products stored at 0° or 10°C (32 or 50ºF). Holes were made in the bags with a hot 25 gauge needle (Peiser and Cantwell, unpublished).

		Day 3		Day 5	
Product		O_2 %	CO_2 %	O_2 %	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, food service 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

Table 7. Total microbial population at different steps of a fresh-cut lettuce line (modified from Hurst, 1990).

Operation	**Number per square inch**
Bin Dump	92,000
Coring belt	210
Cutter	2,290
Transfer belt	40
Cooling water	5
Centrifuge	10
Package filler	3,350

Table 8. Microbial counts of fresh-cut cantaloupe melon stored in air or controlled atmospheres at 5°C (41°C) (from Portela et al., 1997).

Atmosphere	Day 0	Day 12 at 5 °C	
	APC/g	APC/g	*Lactobacilli*/g
Air	1.0×10^2	1.8×10^{11}	4.0×10^7
1.5% O_2		1.9×10^9	9.9×10^6
3% O_2		1.1×10^{10}	1.4×10^7
7.5% CO_2		7.6×10^6	1.8×10^5
15% CO_2		1.1×10^6	6.5×10^5
3% O_2 + 7.5% CO_2		3.8×10^5	1.5×10^5
3% O_2 + 15% CO_2		2.7×10^5	4.2×10^4

APC = Aerobic Plate Count at 29 °C

Table 9. Basic requirements for preparation of minimally processed fruits and vegetables (modified from Ahvenainen, 1996).

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

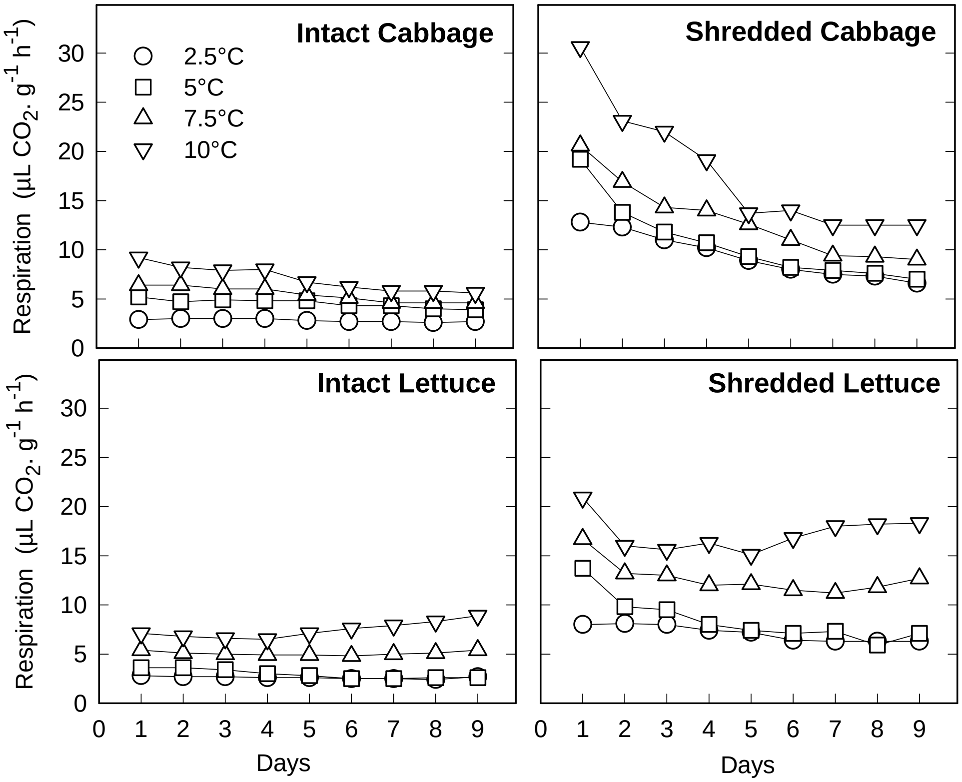


Fig. 1. Respiration rates of intact and shredded cabbage and lettuce stored at 4 temperatures (Cantwell, unpublished).

Fig. 2. Respiration rates of florets, stem and intact heads of broccoli (Cantwell, unpublished).

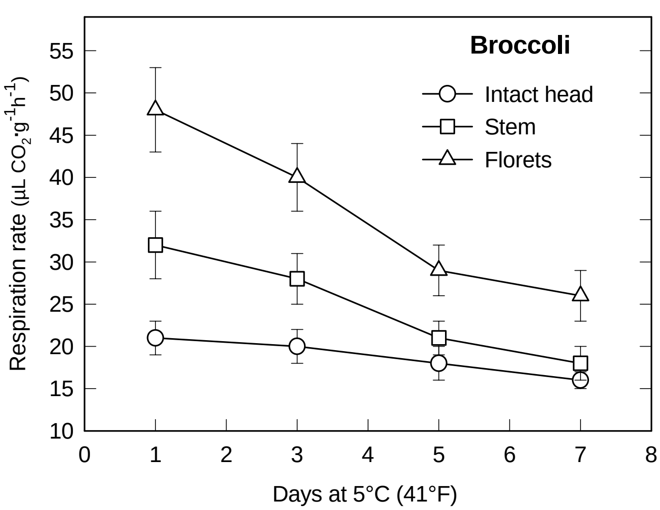


Fig. 3. Respiration rates, color and firmness changes of intact and sliced white mushrooms (Tuncel and Cantwell, unpublished).

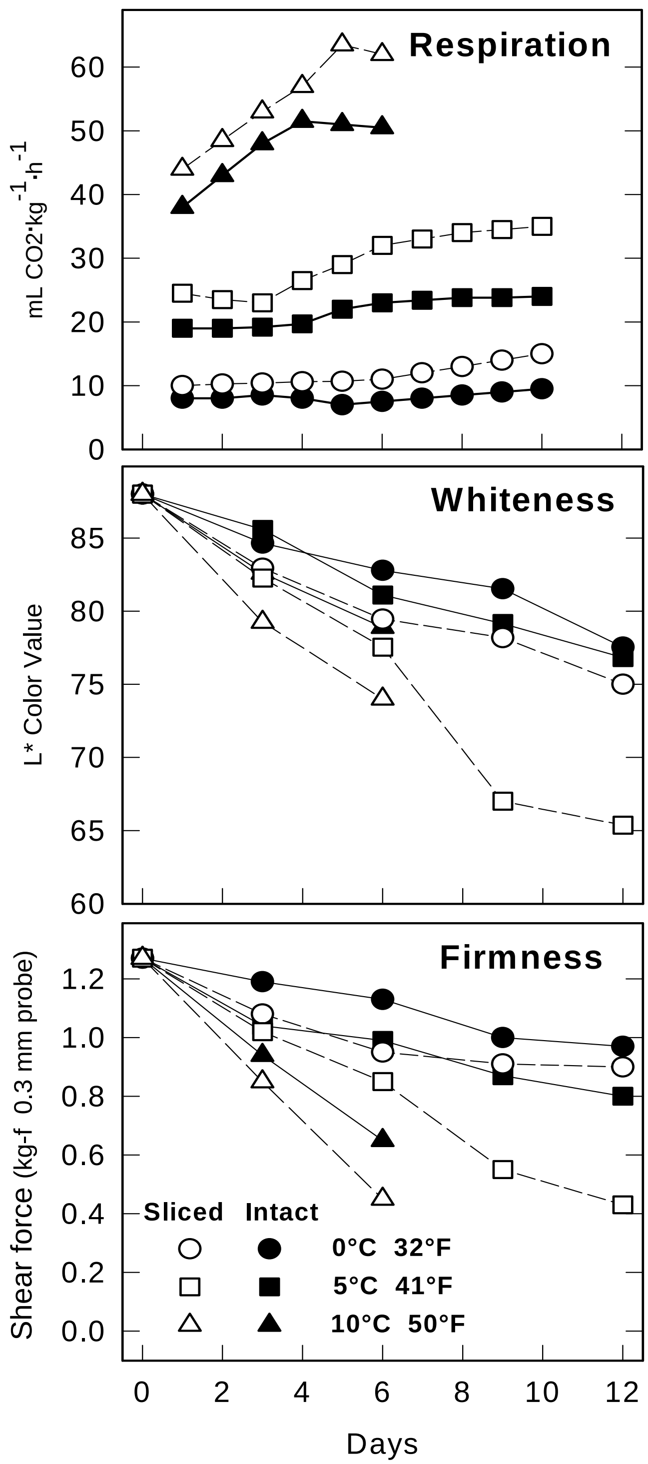


Fig. 4. Flow diagram for preparation of minimally processed lettuce products at source of production.

1. Harvest (lettuce from first harvest results in better quality)

↓

2. Field-pack & local transport

(plastic bins or totes/cartons)

↓

3. Vacuum or forced-air cooling

(not always done; depends on product temperature and delay to process)

↓

4. Trim and core (inside cold room)

(on conveyor with manual coring devices)

↓

5. Chop/shred/tear

(continuous-feed cutter; manual for some lettuce types)

↓

6. Wash

(water containing desinfectant, usually chlorine

↓

7. Centrifugation or other drying technique

(remove moisture so surface of product dry)

↓

8. Combine different products for salad mixes

(after washing may be combined, then centrifuged)

↓

9. Package in plastic film bags

(manual or automated machines; vacuum or gas-flushing)

↓

10. Box, palletize and store temporarily

(<5 °C = <41°F; 0°C = 32°F is optimum)

↓

11. Transport to food service outlets and/or retail markets

(<5 °C = <41°F; 0°C = 32°F is optimum)

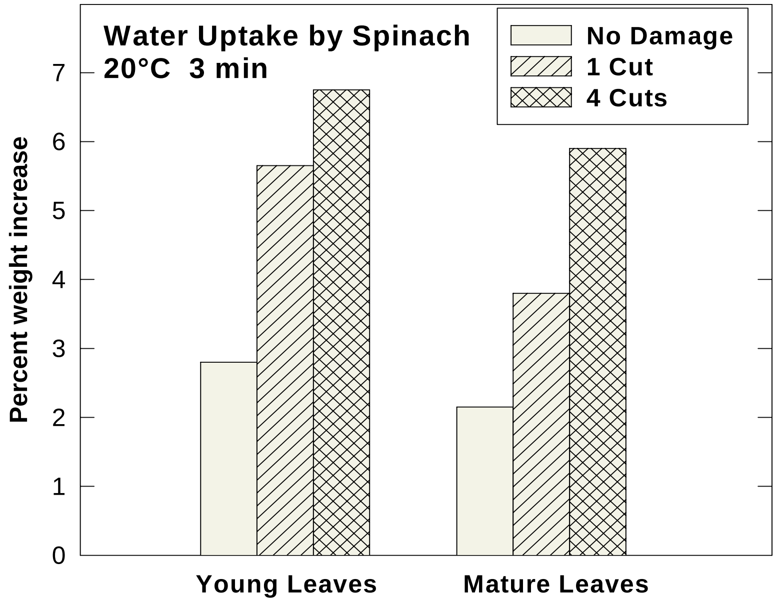
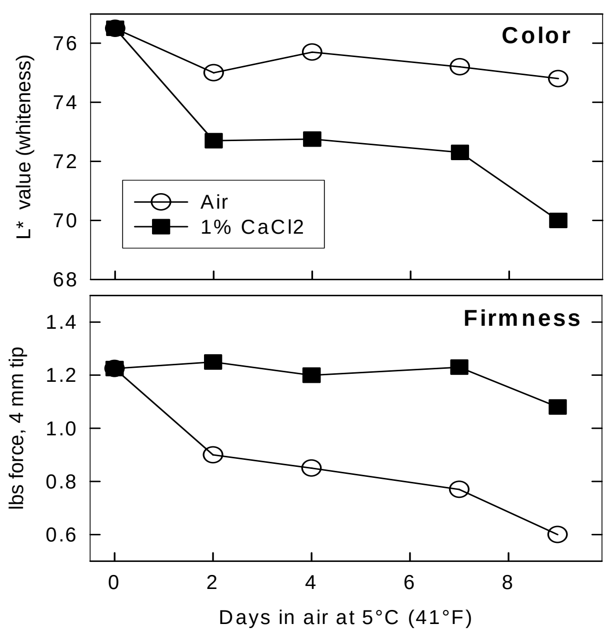


Fig. 5. Water uptake by young (6 cm) and mature (12 cm) spinach leaves in relation to the number of cut surfaces (Cantwell, unpublished).

Fig. 6. Effects of a 1% calcium chloride dip on color and firmness of pear slices (Gorny and Kader in Cantwell, 1998).



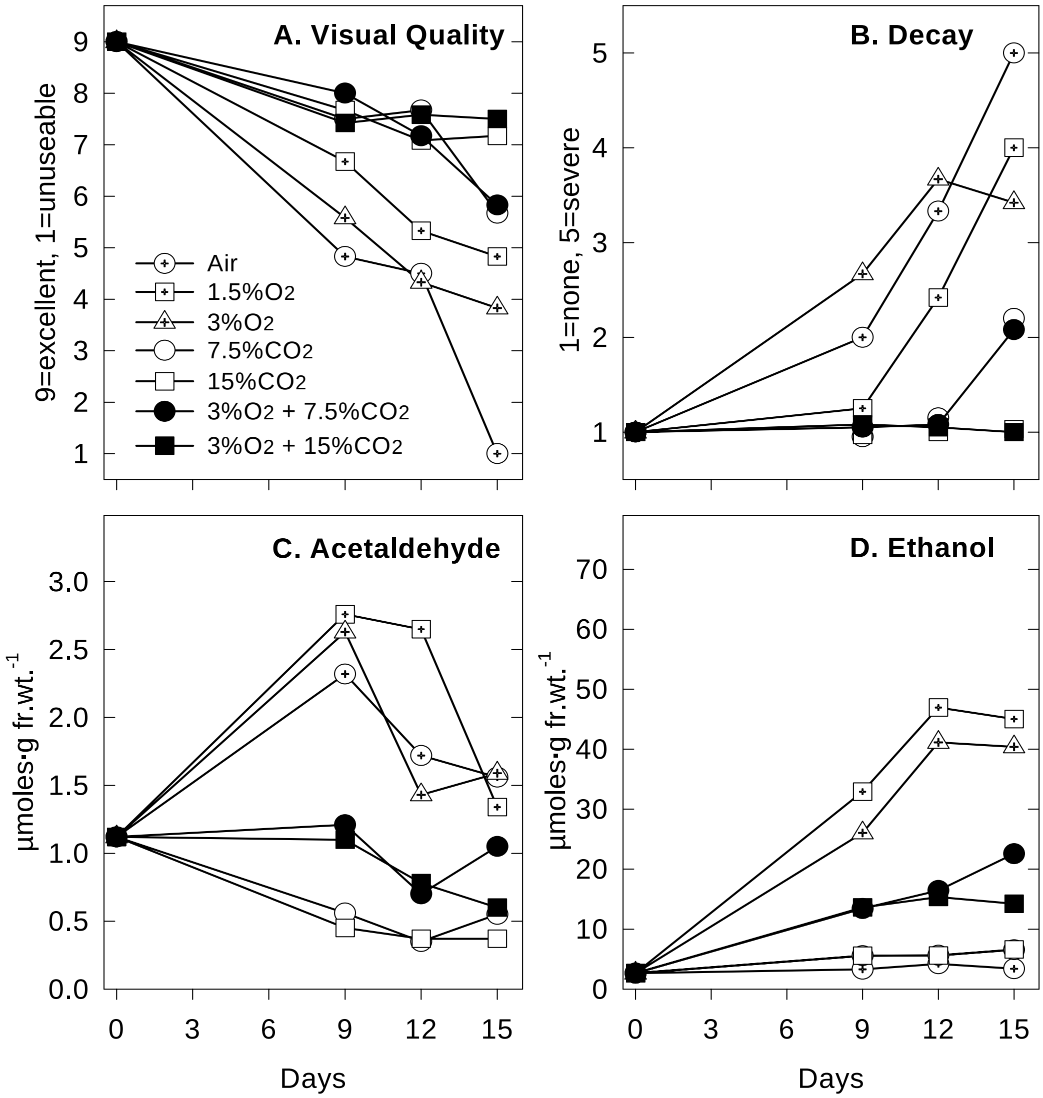


Fig. 7. Changes in quality of cantaloupe melon pieces stored at 5°C (41°F) under different controlled atmospheres (Portela et al., 1997).

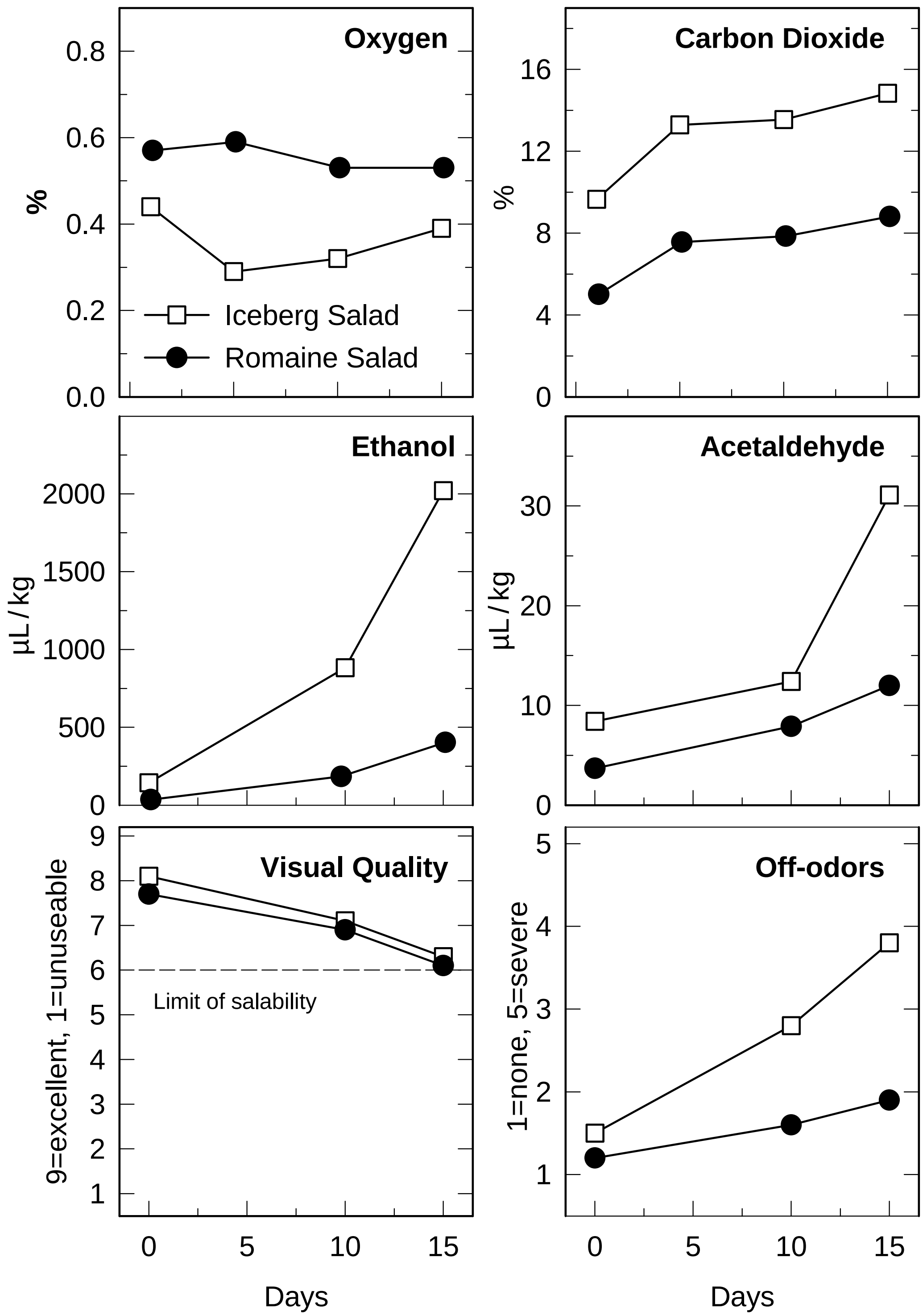


Fig. 8. Average changes in gas composition, fermentative volatiles, visual quality and off-odors of commercial iceberg (Garden salad) and romaine (Caesar salad) (from López-Gálvez et al., 1997).

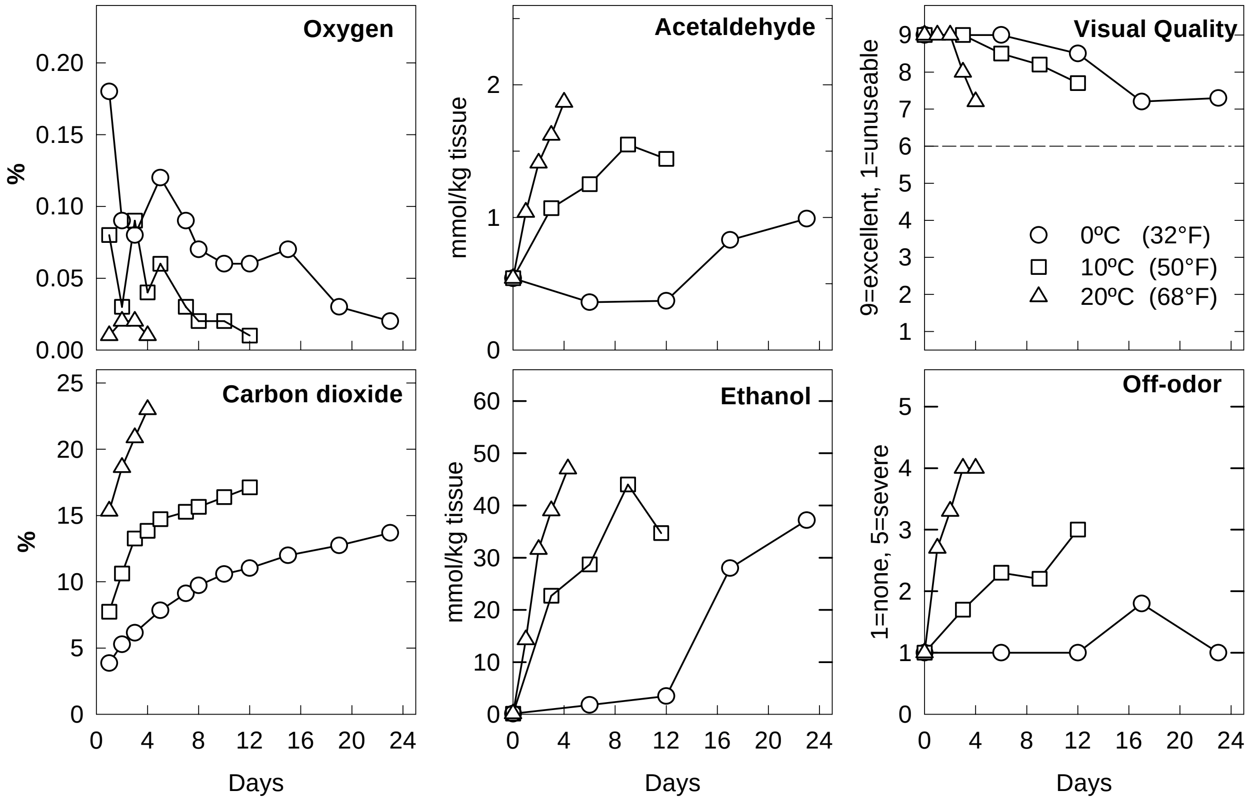


Fig. 9. Effect of storage temperature on the gas composition and quality parameters of iceberg lettuce packaged for retail market

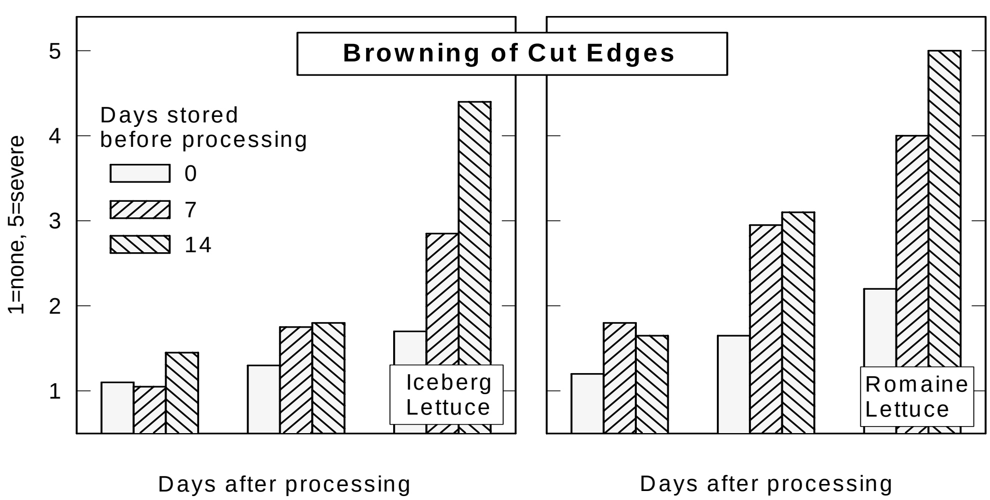


Fig. 10. Browning of cut edges of lettuce in relation to storage of the intact heads. Intact heads and the fresh-cut products were stored at 5°C (41°F) (López-Gálvez and Cantwell, unpublished).