Physiology of Lightly Processed Fruits and Vegetables

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The physiology of lightly processed (LP) fruits and vegetables is essentially the physiology of wounded tissue. This type of processing, involving abrasion, peeling, slicing, chopping, or shredding, differs from traditional processing in that the tissue remains viable (or "fresh") during subsequent handling. Thus, the behavior of the tissue is generally typical of that observed in plant tissues that have been wounded or exposed to stress conditions. This behavior includes increased respiration and ethylene production, and, in some cases, induction of wound-healing processes. Other consequences of wounding are chemical or physical in nature, such as oxidative browning reactions and lipid oxidation, or enhanced water loss. Appearance of new RNA and protein species in wounded tissue provides evidence for genomic control of the response.

Many factors may affect the intensity of the wound response in LP tissues. Among these are species and variety, stage of physiological maturity, extent of wounding, temperature, O_2 and CO_2 concentrations, water vapor pressure, and various inhibitors. Wounded tissues undergo accelerated deterioration and senescence. Minimizing the negative consequences of wounding in LP fruits and vegetables will result in increased shelf life and greater maintenance of nutritional, appearance, and flavor quality in these products.

Reviews of physiological aspects of lightly processed products (LPP) that have appeared in recent years include Huxsoll et al. (1989), King and Bolin (1989), Rolle and Chism (1987), and Watada et al. (1990). Miller's (1992) review of the postharvest physiology of mechanical stress in fruits and vegetables is germane to this discussion, as are Shewfelt's (1987) review of quality aspects and Klein's (1987) review of nutritional consequences of lightly processing fruits and vegetables.

CONSEQUENCES OF WOUNDING

Ethylene synthesis induction

Wounding plant tissues induces elevated ethylene production rates, sometimes within a few minutes, but usually within 1 h, with peak rates achieved usually within 6 to 12 h (Abeles et al., 1992) (Fig. 1). Wound ethylene may accelerate deterioration and senescence in vegetative tissues and promote ripening of climacteric fruit. Ethylene produced by the physical action of light processing was sufficient to accelerate softening of banana (*Musa* spp. AAA) and kiwifruit (*Actinidia deliciosa* L.), and chlorophyll loss in spinach (*Spinacia oleracea* L.), but not broccoli (*Brassica oleracea* L. Italica Group) (Abe and Watada, 1991). Ethylene level increases in proportion to the amount of wounding in several fruits and vegetables. Levels of ACC and ACC synthase activity increase along with ethylene in wounded tomato (*Lycopersicon esculentum* Mill.), winter squash (*Cucurbita maxima* Duch.), and cantaloupe muskmelon (*Cucumis melo* L. var. *reticulatus*) (Abeles et al., 1992). Olson et al. (1991) have reported the existence of three ACC synthase isoforms in tomato fruit, two of which (ACC synthase 1 and 2) are expressed in ripening fruit. However, only ACC synthase 1 expression is enhanced by mechanical stress.

Wounding climacteric fruits may cause increased ethylene production, which can speed up the onset of the climacteric, resulting in a difference in physiological age between intact and sliced tissue (Watada et al., 1990). Slicing breaker-stage tomato fruit increased ethylene production 3- to 4-fold and increased ripening compared to whole fruit (Mencarelli et al., 1989). Within individual mature-green tomato fruit, tissue excised from the distal (blossom) end entered the climacteric before tissue from the equator or proximal (stem end) regions (Fig. 2). Excised tissue from all regions also produced much higher ethylene levels than intact fruit during the climacteric. Wounding effects also differ between climacteric and nonclimacteric fruit (Rosen and Kader, 1989). Wound ethylene production is usually greater in preclimacteric and climacteric than postclimacteric tissues (Abeles et al., 1992), and whereas wound ethylene has no effect on ripening of nonclimacteric fruit, it may advance ripening of climacteric fruit.

Membrane lipid degradation

Wounding plant tissues in the course of preparation of LPP may cause membrane lipid degradation (Rolle and Chism, 1987). Extensive enzymatic degradation occurs in damaged membrane systems, causing loss of lipid components and loss of compartmentation of enzymes and substrates. The ethylene produced upon wounding may play a role in this process by increasing the permeability of membranes and reducing phospholipid biosynthesis (Watada et al., 1990).

The enzymatic reactions catalyzed by lipid acyl hydrolases and phospholipase D produce free fatty acids from the membrane lipids. These free fatty acids are toxic to many cellular processes and are capable of causing organelle lysis, and binding to and inactivating proteins. Lipoxygenase catalyzes the peroxidation of certain fatty acids to form conjugated hydroperoxides, generating free radicals that can attack intact membranes and thus cause further membrane disruption. Lipoxygenase activity is also involved in the production of desirable and undesirable aroma volatiles (Mazliak, 1983).

Elevated respiration

The increase in respiration in wounded plant tissues is thought to be a consequence of elevated ethylene, which stimulates respiration. Starch breakdown is enhanced, and both the tricarboxylic acid cycle and electron transport chain are activated (Laties, 1978). The respiratory climacteric may also be affected by wounding. When tomato fruit were bruised by dropping them 1 to 8 times from a height of 40 cm, respiration and ethylene production were elevated compared to control fruit throughout ripening, and the ripening rate was accelerated (MacLeod et al., 1976). The respiration of sliced and peeled ripe kiwifruit doubled compared to whole fruit, but ripe bananas were unaffected by peeling and slicing (Watada et al., 1990). Sliced strawberry (*Fragaria*×*ananassa* Duch.) and pear (*Pyrus communis* L.) fruit respired at higher rates than whole fruit throughout 7 days of storage at 2.5C, and after transfer to 20C for 1 day (Rosen and Kader, 1989).

Wound respiration in some plant tissues may be related to alpha-

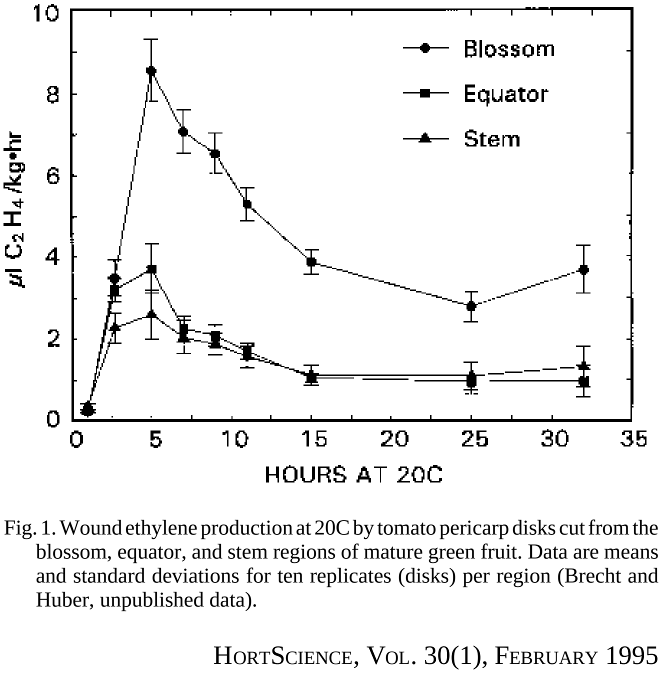

Fig. 1. Wound ethylene production at 20C by tomato pericarp disks cut from the blossom, equator, and stem regions of mature green fruit. Data are means and standard deviations for ten replicates (disks) per region (Brecht and Huber, unpublished data).

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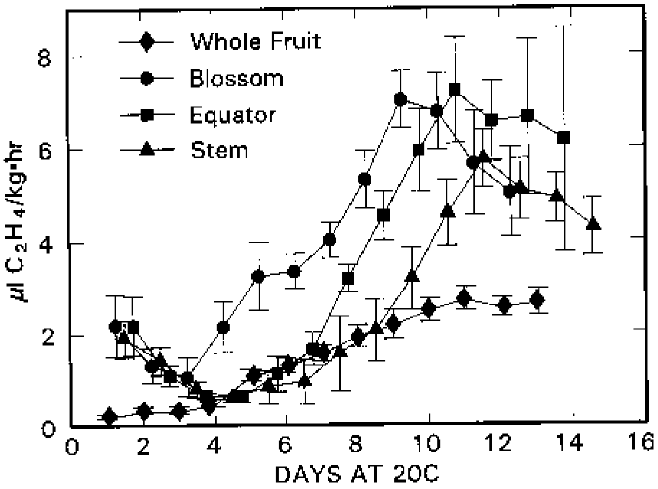

Fig. 2. Ethylene production at 20C by tomato pericarp disks and whole fruit. Fruit were at mature-green stage at the time of excision. Data are means plus standard deviations for six replicates (disks or fruit) (Brecht and Huber, unpublished data).

oxidation of fatty acids (Shine and Stumpf, 1974), which oxidizes fatty acids to CO_2, and is responsible for the CO_2 released after slicing potato (*Solanum tuberorum* L.) tubers (Rolle and Chism, 1987).

Oxidative browning

Discoloration occurs at the cut surface of fruits and vegetables as a result of the disruption of compartmentation that occurs when cells are broken, allowing substrates and oxidases to come in contact. Wounding also induces synthesis of some enzymes involved in browning reactions or substrate biosynthesis (Rolle and Chism, 1987). Thus, browning intensity in diverse tissues and crops can be affected by relative oxidase activities and substrate concentrations (Hansche and Boynton, 1986). Oxidative browning at the cut surface is the limiting factor in storage of many LP fruits and vegetables.

Phenylalanine ammonia-lyase (PAL) catalyzes the rate-limiting step in phenylpropanoid metabolism (Ke and Saltveit, 1989). Both ethylene and wounding induce PAL activity in many plant tissues (Abeles et al., 1992), but apparently by separate mechanisms. Investigations using inhibitors of either ethylene synthesis aminoethoxyvinylglycine (AVG) or action (STS or 2,5-norbornadiene) have shown that ethylene alone does not control PAL induction in winter squash (Hyodo and Fujinami, 1989) or crisphead lettuce (*Lactuca sativa* L.) (Ke and Saltveit, 1989). Browning occurs when the products of phenylpropanoid metabolism, such as various phenolic and possibly other substrates (e.g., anthocyanins), are oxidized in reactions catalyzed by phenolases, such as polyphenoloxidase (PPO) or peroxidases (Hanson and Havir, 1979).

Wound healing

While the physiological processes discussed thus far all probably have as their biological role the ultimate sealing of the site of injury, the phrase "wound healing" generally is used to refer to suberin and lignin production and deposition in cell walls at the wound site, possibly followed by cell division beneath the suberized layer to form a wound periderm (Burton, 1982). The first observable change at the cut surface of plant tissue is desiccation of the first layer of broken cells and one to a few additional subtending layers of cells. Suberization of the next cell layers occurs in many tissues, including potato and yam (*Dioscorea* spp.) tubers, sweetpotato (*Ipomoea batatas* L.) and carrot (*Daucus carota* L.) roots, bean (*Phaseolus vulgaris* L.) pods, and tomato and cucumber (*Cucumis sativus* L.) pericarp (Kolattukudy, 1984; Walter et al., 1990). Lignification occurs at wound sites in orange (*Citrus sinensis* Osbeck) peel (Brown, 1973).

Suberization and wound periderm formation are influenced by the environment surrounding the tissue. Wigginton (1974) reported that suberization of potato tubers can take 3–6 weeks at 5C, 1–2 weeks at 10C, and 3–6 days at 20C, while wound periderm initiation requires 4 weeks, 1–2 weeks, and 3–5 days, respectively. Wound healing of potato at 10C was optimal at 98% relative humidity (RH) and decreased at <90% RH, but at 20C, wound healing was similar at all RH levels >70%. Concentrations of O_2 <10% and CO_2 concentrations >5% inhibit suberization and periderm formation in potato tubers (Lipton, 1975; Wigginton, 1974).

Secondary metabolites

In response to wounding, plants synthesize an array of secondary compounds, many of which appear to be related to wound healing or defense against attack by microorganisms and insects. The specific complement of secondary compounds formed depends on the plant species and tissue involved. In certain cases, these compounds may affect the aroma, flavor, appearance, nutritive value, or safety of LPP. Some aroma and flavor compounds may be evanescent, resulting in poor flavor after a short storage period compared to freshly prepared items, while some off-odors and -flavors may be persistent. The classes of compounds produced in wounded fruits and vegetables include phenylpropanoid phenolics, polyketide phenolics, flavonoids, terpenoids, alkaloids, tannins, glucosinolates, and long-chain fatty acids and alcohols (Miller, 1992).

Water loss

Plant tissues are in equilibrium with an atmosphere at the same temperature and a RH of 99% to 99.5% (Burton, 1982). Any reduction of water vapor pressure in the atmosphere below that in the tissue results in water loss. In whole organs, water in intercellular spaces is not directly exposed to the outside atmosphere. However, cutting or peeling a fruit or vegetable exposes interior tissues and drastically increases the water evaporation rate. The difference in rate of water loss between intact and wounded plant surfaces varies from ≈5- to 10-fold for organs with lightly suberized surfaces [e.g., carrot and parsnip (*Pastinaca sativa* L.)], 10- to 100-fold for organs with cuticularized surfaces (e.g., spinach leaf, bean pod, and cucumber fruit), to as much as 500-fold for heavily suberized potato tubers (Burton, 1982).

Avoiding desiccation at the cut surface of some LPP is critical for maintaining acceptable visual appearance. For example, the development of "white blush" on abraded "baby" carrot surfaces, caused by desiccation of cellular remnants on the carrot surface, is the limiting factor in marketing the product despite the use of polymeric film packages. However, for most LPP, centrifugation or other procedures are recommended for complete water removal or even slight desiccation of the surface (Cantwell, 1992). This is done primarily to reduce microbial growth. Desiccation can also induce stress ethylene production in detached fruits and vegetables (Yang, 1985).

VARIABLES AFFECTING TISSUE RESPONSE TO WOUNDING

Species and variety

Fruits and vegetables are diverse in their physiology; they represent numerous morphological structures and tissues. Horticultural commodities have been classified according to their respiration rates and respiratory patterns, ethylene production, sensitivity to chilling injury, and relative perishability (Kader, 1992). Species differ inherently in perishability, and high perishability is generally reflected in higher respiration rates. Ethylene production rates may vary 1000-fold among species, affecting the perishability not only of the producing species, but also other items exposed to the ethylene, such as in salad mixes.

LP fruits and vegetables are always more perishable than their intact counterparts; therefore, selecting varieties with enhanced shelf-life characteristics may be important. Such selection might include mutants or genetically modified crops with slower ripening, better texture retention, or enhanced flavor characteristics (Romig, 1995).

Since chilling injury limits the use of temperature reduction to control deterioration, chilling-sensitive, but otherwise similar, crops usually have shorter potential storage lives than nonchilling-sensitive crops. Selecting varieties with reduced chilling sensitivity for use as LPPs should allow more flexibility in temperature management and result in better storage life and quality.

Physiological maturity

Negative consequences of wounding are magnified early and late in fruit and vegetable development. Crops, such as broccoli, okra (*Abelmoschus esculentus* L. Moench), and sweet corn (*Zea mays* L.), harvested early in development are usually in a rapid phase of growth, which is characterized by intense metabolic activity and low levels of reserve storage compounds. The wounding caused by preparing LPP increases respiration and ethylene production rates, as discussed previously, as well as other metabolic reactions. Thus, immature crops consume their already meager storage reserves quickly and deterioration occurs rapidly. Crops, such as potatoes, tree fruits, and winter squash, harvested later in development, when growth is largely complete, tend to have relatively low metabolic activity and high storage reserves. Their response to wounding is more manageable and potential storage life longer.

Climacteric fruit sometimes are harvested when mature but unripe, which allows commercial handlers to prolong storage life by controlling the onset of ethylene production to delay ripening. In contrast, nonclimacteric fruits are harvested when fully or nearly ripe; thus, some are more perishable than climacteric fruits. Since LPPs are intended for convenient, immediate consumption, it is necessary for LP climacteric fruits to be ripe or nearly ripe as well. Selecting the optimum fruit maturity for light processing is an important consideration for achieving the best possible combination of quality and storage life.

Severity of wounding

Ethylene production increases with increasing severity of wounding in many plant tissues, including apple (*Malus domestica* Borkh.) and tomato fruit, sweetpotato roots, bean petioles, and etiolated pea (*Pisum sativum* L.) stems (Abeles et al., 1992). The way in which LP lettuce is prepared can have a dramatic effect on storage life, apparently due to differences in the amount of damage incurred. Slicing and using sharp knife blades increase storage life of shredded and salad cut lettuce compared to chopping and using dull knife blades (Bolin and Huxsoll, 1991; Bolin et al., 1977). Reducing the shred size also reduces lettuce storage life. Interestingly, tearing, which results in less exudation of cell sap, increases lettuce storage life compared to slicing. Not only the amount of cutting, but also the direction of the cut affects deterioration of LP green bell pepper (*Capsicum anuum* L.) fruit. When peppers were cut lengthwise in quarters, lengthwise in 10-mm-wide strips, lengthwise in 10-mm-wide strips 10 mm long, and crosswise in 10-mm-wide rings, the slowest deterioration occurred with the crosswise rings (Zhou et al., 1992), and this was associated with greater solubilization of pectin at the cut surface of the lengthwise slices (Abe et al., 1992).

Temperature

Temperature management is the most useful and important technique available for minimizing the effects of wounding in LP fruits and vegetables. Metabolic reactions in fruits and vegetables are reduced about two to three times for each 10C reduction in temperature. The increases in respiration and ethylene production rates, as well as other reactions associated with wounding, are therefore minimized when the fresh product is processed at low temperature. Rinsing in cold water following processing (essentially hydrocooling) may also be beneficial for lowering or helping maintain temperatures. The temperature of the processing area and the rinse water should be as near to 0C as possible for maximum benefit. Because of the short exposure time, chilling injury is not likely to be a concern as long as the storage temperature is at or above the chilling threshold. Maintaining the temperature at the lowest safe level throughout handling is critical for LP fruits and vegetables. Low temperatures during transport, storage, and retail display slow ripening and other metabolic processes, reduce deterioration, and can minimize the effects of ethylene.

Water vapor pressure deficit

The unprotected cut surface of LP fruits and vegetables loses moisture at an extremely rapid rate when exposed to an atmosphere less than water-saturated (Burton, 1982). When fruits and vegetables are prepared as LPPs, the cell contents on the cut surface can damage intact cells and serve as an ideal substrate for microorganism growth. Consequently, LPPs are normally rinsed to remove the material present on the cut surface, and the water is removed by centrifugation. The latter step slightly desiccates the product.

To subsequently maintain the lowest possible water vapor pressure deficit, LPPs are routinely handled in semipermeable film packages with low water vapor transmission rates. Since fluctuating storage temperatures can cause condensation of water within the package, water loss from the tissue may still occur. Condensation within the package is most severe when the product is at a higher temperature than the storage atmosphere, which is often the case when the product is first placed into the storage room or transport vehicle. Thus, adequate precooling and subsequent temperature management help reduce water loss from LP fruits and vegetables. The use of coatings, another approach for reducing water loss, is described by Baldwin and Nisperos-Carriedo (1995).

Atmospheric composition

Modified and controlled atmospheres help maintain quality and extend storage life by inhibiting metabolic activity, decay, and, especially, ethylene biosynthesis and action (Kader, 1986). The most common atmospheres consist of reduced O_2 and elevated CO_2 concentrations. Carbon monoxide also is sometimes included for inhibition of browning and microorganism growth. Modified-atmosphere packaging (MAP) is widely used for LP fruits and vegetables. Semipermeable plastic films are chosen for MAP so that the film permeability and product respiration can combine to produce a desirable, steady-state atmosphere within the package (Kader et al., 1989). Because of the LPP's perishability, the MAP atmosphere is often actively established, either by flushing with the desired atmosphere or by pulling a slight vacuum and then injecting a desired gas mixture.

The tolerances of fruits and vegetables to low O_2 and elevated CO_2 concentrations have, for the most part, been determined in long-term storage tests with intact fruits and vegetables. LP fruits and vegetables

Table 1. Effects of water, water temperature, and chlorine on abrasion-related browning of 'Strike' snap beans after storage for 7 days at 10C (Brecht and Sargent, unpublished data).

Treatment	Appearance rating (1–9)[z]
Water	
+	5.2
–	5.5
P > F	NS
Water temperature (°C)	
25	6.5
5	6.2
P > F	NS
Chlorine (ppm)	
0	5.1
175	7.6
P > F	***
Temperature (°C) × chlorine (ppm)	
25 × 0	5.2
25 × 175	7.8
5 × 0	5.0
5 × 175	7.3
P > F	NS
Dry control	5.5

[z] Ratings were based on browning severity, with 1 = worst, 9 = best appearance.

NS, ***Nonsignificant or significant at $P \leq 0.001$, respectively.

Table 2. Enzymatic browning, expressed as lightness (L), at cut surface of potato tubers and apple fruits (from Brecht et al., 1993).[z]

			Change in L (%)	
Compound	Concn	pH	Potato	Apple
Ca hypochlorite	0	4	–7.9	–16.2
	140	4	–9.6	–8.5
	0	7	–3.2	–16.6
	140	7	–2.2	–10.7
	0	11	–5.5	–9.1
	140	11	–1.3	–10.8
Ascorbic acid (%)	0		–7.7	–9.8
	3.2		–0.3	–7.8
Sodium m-bisulfite (ppm)	0		–6.1	–13.3
	200		+0.7	–2.6
4-hexylresorcinol (ppm)	0		–7.4	–12.3
	200		–1.0	+0.7

[z] Slices were dipped for 1 min at ambient temperature (23–25C), blotted dry with paper towels, and L values were measured after 6 h with a tristimulus colorimeter.

differ from intact items by having higher levels of metabolic activity, including higher respiration rates and higher ethylene production. The gas diffusion properties of LP fruits and vegetables are also completely different from those of intact organs, likely resulting in much reduced gas concentration gradients within the tissue. The typical storage time of LPPs is probably significantly shorter for many items compared to the intact commodity. Thus, there is a reasonable expectation that tolerances of LP fruits and vegetables to modified atmospheres differ significantly from those of the same intact fruits and vegetables.

Because of the importance of ethylene in the physiology of LP fruits and vegetables, researchers have attempted to exclude or absorb ethylene in such packages (Abe and Watada, 1991). Including palladium chloride on activated charcoal in packages of banana or kiwifruit slices reduced ethylene concentrations in the packages from ≈10 or 2 ppm, respectively, to 0 ppm, and significantly reduced softening. Palladium chloride reduced ethylene from ≈0.4 to 0 ppm in spinach and broccoli packages, but chlorophyll degradation was reduced only in spinach. Carbon dioxide concentrations also were reduced when ethylene was absorbed.

Chemical treatments

Chemical treatments are used on LP fruits and vegetables mainly for controlling decay, reducing browning, and retaining firmness. Use of chlorine as a sanitizing agent is standard practice in light-processing facilities. The pH of chlorine solutions must be maintained near 7 to keep the chlorine in the active hypochlorous acid form. Low-pH organic acid solutions and sorbic acid also are used to control bacteria and fungi.

Bolin et al. (1977) reported that chlorine dips produced results similar to sulfur dioxide in reducing browning of shredded lettuce. Including 175 ppm NaOCl in the rinse water significantly reduced browning of snap beans, while water alone, whether at ambient (25C) or low (5C) temperature, had no effect (Table 1). We have found $Ca(OCl)_2$ to be more effective than NaOCl in reducing browning of sliced potatoes and apples (unpublished data), possibly due to a direct inhibitory effect of Ca on PPO. Chlorine at pH 11 was more effective than at pH 7 in reducing browning, expressed as change in lightness (L), of potato slices, while pH 4 was more effective with apple slices (Table 2). Chlorine at 140 ppm was about as effective as 3.2% ascorbic acid, 200 ppm meta-bisulfite, or 200 ppm 4-hexylresorcinol on potato, but meta-bisulfite and 4-hexylresorcinol were more effective than chlorine or ascorbic acid in reducing browning on apple.

While sulfiting agents have been the standard for inhibiting browning reactions in fruits and vegetables, concerns over possible allergic reactions of some consumers have led to the use of alternative antibrowning agents (Monsalve-Gonsalez et al., 1993). Other agents to control enzymatic browning include ascorbic acid derivatives and isomers (Sapers et al., 1990, 1991), sodium dehydroacetic acid (Hicks and Hall, 1972), citric acid, zinc chloride plus calcium chloride (Bolin and Huxsoll, 1989), resorcinol derivatives (Monsalve-Gonzalez et al., 1993), cysteine, CO_2, and carbon monoxide (Kader, 1986).

Calcium stabilizes membrane systems and maintains cell wall structure in fruits and vegetables (Poovaiah, 1986). Calcium reduces ethane production, a marker of lipid peroxidation, in potato tuber disks (Evensen, 1984). Calcium and a combination treatment of Ca and ascorbic acid were effective in preventing discoloration of apples (Drake and Spayd, 1983; Ponting et al., 1972) and pears (Rosen and Kader, 1989). Calcium also maintains firmness of sliced strawberries and pears (Morris et al., 1985; Rosen and Kader, 1989).

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Sanitation of Lightly Processed Fruits and Vegetables

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SANITATION LINKED TO SHELF LIFE AND SAFETY

What is the importance of sanitation to the lightly processed fruit and vegetable industry? To a processor its value is difficult to measure because sanitation is not directly reflected on the (profit and loss) statement. Unlike affixing a price to a piece of equipment designed to deliver x units of product per hour, sanitation's economic value cannot be readily pinpointed in accounting terms. Thus, some processors do not invest the resources necessary to ensure good sanitation in their processing plant. Yet, research has demonstrated that an increase in microbial populations on lightly processed produce (LPP) (i.e., shredded lettuce) will have a direct impact on shelf life. The higher the initial microbial load, the shorter the storage life (Bolin et al., 1977). While psychrotrophic gram-negative rods are the predominant microorganisms on LPP (Neelima et al., 1990), the primary spoilage organism on prepackaged salads appears to be a fluorescent pectinolytic pseudomonad, *Pseudomonas marginalis* (Nguyen and Prunier, 1989). [Note: More information concerning the bacteria cited in this paper can be found in Bergey's Manual (Krieg and Holt, 1984)].

So what should be the goal of processors wanting microbial reduction and shelf life extension of LPP? They should institute and maintain consistent sanitary practices via chlorinated washes (Adams et al., 1989) and uniform refrigeration management (Bolin et al., 1977; Gertmenian, 1992). Shelf life, however, is not the critical sanitation issue in the lightly processed fruit and vegetable industry. It is product safety. To ensure product acceptance, safety is the single greatest challenge for this industry. But, the same technology developed to extend the shelf life of LPP, namely modified-atmosphere (MA) packaging, may inadvertently lead to a product that is potentially more hazardous to consume. How can this be true?

WHAT ARE THE SAFETY RISKS?

I perceive five major bacteriological risks of LPP. 1) Although refrigeration is used to maintain quality, it provides inadequate protection against pathogenic microorganisms because no kill step, i.e., blanching, is used before storage. Several bacterial pathogens can survive and even reproduce under refrigerated conditions. 2) While MA storage inhibits the growth rate of many spoilage organisms, certain pathogens, i.e., *Listeria monocytogenes*, may actually thrive under these conditions (Berrang et al., 1989). 3) When the product is at 7C or above during storage, distribution, or both, the growth of other bacterial pathogens, i.e., *Clostridium botulinum*, *Bacillus*, *Salmonella* spp., and *Staphylococcus aureus*, will occur (Corlett, 1989). 4) Partial processing operations, i.e., trimming and washing, may not only eliminate the presence of normal indigenous spoilage organisms, but also give any introduced pathogens a competitive advantage for growth. 5) Finally, unlike canned or frozen fruits and vegetables, LPP is consumed raw.

PATHOGENS OF CONCERN AND THEIR SOURCE

Which bacterial pathogens most recently implicated in human foodborne disease are of most concern in LPP and where do they originate (Table 1)? In addition, other pathogens not considered a serious problem today, but which may pose a potential threat for LPP, have been reviewed (Brackett et al., 1993). Bacterial pathogens may often contaminate produce when poor field sanitation, packinghouse, and shipping practices are employed (Brackett, 1992; Hurst, 1992). Since animal feces is a good source of these pathogens, cropland should not be used for grazing livestock. Likewise, inorganic fertiliz-