

Keeping Freshness in Fresh-cut Horticultural Produce

S. V. Irtwange

Department of Agricultural Engineering, University of Agriculture,

P. M. B. 2373, Makurdi, Nigeria

svirtwange@yahoo.com

ABSTRACT

Growth in demand has led to increased marketing of fresh fruits and vegetables in fresh-cut products form. Therefore many firms dedicated to this type of food processing have been established. Fresh-cut produce can help increase the consumption of fresh produce due to its convenience and attractive appearance and flavor. However, cutting results in tissue damage that can stimulate oxidation of cellular components causing tissue browning, microbial development on the wound surface and tissue breakdown. The physical damage or wounding caused by preparation increases respiration and ethylene production, which leads to increase in other biochemical reactions responsible for changes in color, flavor, texture and nutritional quality such as vitamin loss. Development of novel approaches for assuring the quality and safety of fresh-cut produce depends on a better understanding of fresh-cut vegetable and fruit physiology, including nutrients and other functional components as affected by storage and handling. This thus requires integration of quality management techniques like sanitation, color and texture preservation and temperature management. This paper reviews the different methods and techniques used to keep fresh-cut fresh.

Keywords: Fresh-cut, horticultural produce, quality

1. INTRODUCTION

Fresh-cut products are horticultural products, which are prepared and handled to maintain their fresh nature while providing convenience to the user. Rodov (2004) defines fresh-cut as ready-to-eat fresh fruits and vegetables: washed, peeled, cut, packaged... but without thermal treatment (boiling, frying, etc) - see Figure 1. Fresh cut business is increasing because people are becoming busier in view of challenges of modern day economic realities. During lunch break in a business district of Tokyo, the business men may not have time to peel a mango or an orange. For consumers therefore, fresh-cut is convenient and saves time. For foodservice operators, fresh-cut saves time, manpower, space and equipment. The market size of fresh-cut business is estimated at US: \$10-12 billion out of \$76 billion total fresh produce marketing (about 15%) with annual growth of 10-15% in retail market and 3-5% in foodservice (Rodov, 2004a). One of the trends is to locate the industry near the growing areas.

Fresh-cut products or minimally processed horticultural products are prepared and handled to maintain their fresh nature while providing convenience to the user. The minimally processed



Figure 1: Ready-to-eat fresh fruit salads
Source (Rodov, 2004a)

ready-to-eat vegetable industry was initially developed to supply restaurants, hotels and other institutions and more recently was expanded to include food retailers for home consumption. Whereas most salads and other vegetables are still prepared at home, the inclusion of minimally processed ready-to-eat vegetables has moved the preparation of these products from the consumer. The increased time and distance between processing and consumption may contribute to higher risks of food-borne illness. Although chemical and physical hazards are of concern; such as the presence of agricultural chemicals and food additives above the maximum residue limits or the presence of metals and other injurious particles; the hazards specific to minimally processed ready-to-eat vegetables reside mainly with microbial contaminants (Besana et al., 2004).

The term minimal processing covers a wide range of technologies and methods for preserving foods during their transport from the site of agricultural production to consumer (Rodov, 2004b). Consumers are increasingly demanding convenient, ready to use and ready to eat fruit and vegetables with a fresh like quality, and containing natural ingredients. Increased product safety is also in much demand by producers and distributors. The fresh like products are highly perishable and actions that increase safety are important. Technologies that allow for a two or three fold extension of the shelf life are also very important to decrease the food losses. In order to produce fruit and vegetables with greater convenience, centralized cleaning, peeling and cutting is carried out (Wills et al., 1998). The resultant products are often less stable due to the enzymatic activity of the cut cell walls and also to bacteriological contamination from handling during treatment. Various post-harvest treatment methods are employed to increase the

biological stability and to extend the shelf life of products. In all these treatments, low temperatures and good processing hygiene are essential to maintain food safety and to achieve desired shelf life.

The objective of this paper is to review different techniques and novel methods used to maintain quality and prolong the shelf life of fresh-cut products in terms of raw material quality, color preservation and prevention of texture loss to provide a pedestal for development of fresh cut business in Nigeria.

2. RAW MATERIAL QUALITY

2.1 Microbiological aspects

Rodov (2004a) states that the pathogenic organisms of concern in minimally processed produce include *Listeria monocytogenes*, *Clostridium botulinum*, *Shigella* sp., *Salmonella* sp., Parasites and Viruses while the pathogenic organisms of potential concern include *E. coli* 0157:H7, *Aeromonas hydrophila*, *Bacillus cereus*; *Plesiomonas shigelloides* and *Yersinia enterocolitica*.

2.2 Prevention of Contamination is Key

(Rodov, 2004a) states that vegetable contamination in the field has been recognized as a source of human infection and illness. In the fields, irrigation water must not be contaminated, raw manure should not be used as fertilizer, and sanitation facilities should be provided for field workers. When ready to ship produce, the trucks should be cleaned especially if animals are also shipped in them. The use of clean ice or refrigerated trucks is recommended. Once produce is harvested, the dirt should be cleaned off with water maintained at proper temperature to prevent contamination. Use of hyper chlorinated water in the packing line is recommended. For fresh cut vegetables and fruits that are eaten raw, there is no treatment that can be relied upon to totally eliminate contaminating microorganism.

2.3 Washing

Washing with anti-microbial compounds, while important, often brings about a relatively small reduction. Washing fruits and vegetables in potable water removes a portion of microbial cells. In some instances vigorous washing can be as effective as treating with water containing 200mg/l of chlorine, which generally reduces population by 10-100 folds (1-2 logs). In washing, the temperature of the wash-water should be higher than that of the produce to minimize the uptake of micro-organism by tissues. Eliminating the risks is difficult. Managing them is based on identifying and controlling those factors that are important in preventing contamination or limiting the growth of pathogenic microorganism.

2.4 Chemical Disinfection

Prevention of contamination of fruits and vegetables at all points from the field to the plate through application of Good Agricultural Practice (GAPs), Good Manufacturing Practices (GMPs) and Hazard Analysis Critical Control Point (HACCP) programmes is preferred to the application of chemical disinfectants after contamination has occurred. Figure 2 is an example of a modern technological process for fresh-cut. Although disinfectants have variable effectiveness on pathogen control of fresh-cut fruits and vegetables, they are certainly useful for sanitizing

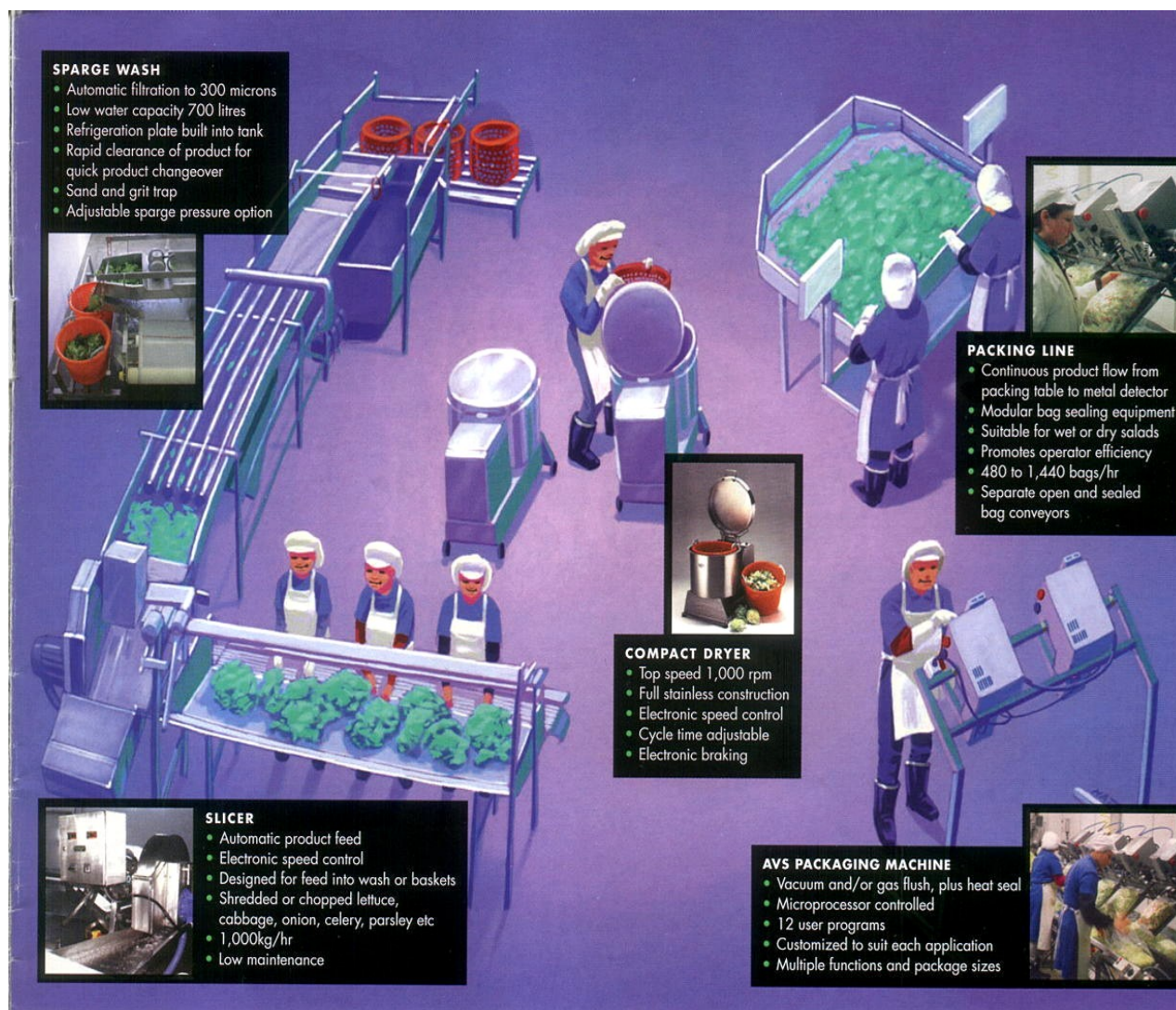


Figure 2: Modern technology process for fresh-cut
Source (Rodov, 2004a)

water to prevent contamination of produce from water reuse or water whose quality cannot be guaranteed.

2.5 Chlorination

Chlorination is still the most widely used sanitizer, though it is on its way out as environmental regulations has recommended its prohibition. Disinfection by chlorination has had many applications in harvest, post-harvest handling and marketing display of fresh fruits and vegetables for many decades. The primary uses of chlorine have been to inactivate or destroy pathogenic bacteria, fungi, viruses, cysts, and other microorganism associated with seed, irrigation water, horticultural implements, and contact surfaces - including humans, with fresh produce (Wills et al., 1998). Chlorination has been routinely used to treat post harvest cooling water, in post harvest treatments (i.e. calcium for firmness enhancement) and during dehydration

at shipping destinations. Chlorine, primarily as sodium or calcium hypochlorite, has been an important part of a properly managed horticultural sanitation program for several decades (Luna-Guzmán and Barrett, 2000). In conjunction with other disease and worker hygiene management programs, chlorination is generally very effective, comparatively inexpensive, immediately available, and may be implemented in operations of any size or scale of use. Legally, agricultural chlorine is commercially available in four forms that have been approved for use (registered) by the U.S. Environmental Protection Agency (EPA): Chlorine gas (Cl_2) - used in very large operations); Calcium hypochlorite (CaCl_2O_2) - used for disinfection of produce and produce process water; sodium hypochlorite (NaOCl) - used in small-scale operations and chlorine dioxide (ClO_2) – effective against most microbes at concentrations of 3 to 5 ppm in clean water. Some pathogens in surface water of concern to human safety are not easily killed by chlorination (i.e. *Cryptosporidium*, *Giardia*), even under optimal conditions therefore beginning with clean potable water is the best preventive step available. The effectiveness of other disinfectant options, such as ozonation of process water, is currently being evaluated against these chlorine-resistant microorganisms (Rodov, 2004a).

2.6 Disinfection by Ozone

Ozone finds applications in natural disinfection, water air purification systems and fresh fruits vegetables storage. According to Rodov (2004b), recent findings show that ozonized water keeps the quality and flavour of fruits. The hot, off-smell of chlorinated water is absent. Ozone is unsurpassed in natural control and killing of common bacteria like *E. coli*, Fecal Coliform, mold, and virus and deactivation of cysts (see Table 1). It attaches and destroys by oxidation of any offending molecule that gets in its path. It rapidly decomposes leaving no traces from oxidation and does not produce any toxic halogenated compounds. Chlorine can take hours to penetrate the cell wall of bacteria or virus, while activated oxygen oxidation occurs within seconds. Unlike chlorine, it does not produce trihalomethanes and is non-carcinogenic. Chlorine can be blamed for hundreds of thousands of deaths worldwide yet there is no evidence of any deaths to humans of over exposure to O_3 . The natural disinfection efficiency is 3,125 times faster than chlorine and it is a 50 percent stronger oxidizer than chlorine. Ozone is 25 times more effective in disinfection for processors than hypochlorous acid, 2,500 times more effective than hypochlorite and 5,000

Table 1: Efficacy of Ozone as an Anti-microbial agent*

Bacteria	Medium	Ozone Concentration (ppm)	Time (min)	Percent Reduction
<i>E. coli</i>	Water	0.51	0.16	99.9998
	Wastewater	2.2	19	99.9
<i>S. typhimurium</i>	Water	0.26	1.67	99.995
<i>Fecal streptococci</i>	Wastewater	2.2	19	99.6
<i>Giardia lamblia</i>	Water	0.5	1.1	99
<i>Cryptosporidium parvum</i>	Water	1.0	5	>90

*From Wickramanayake (1991)

Source (Rodov, 2004b)

times more effective than chloramine. Ozone will oxidize organic chemicals into safer elements. During the ozonation process, some compounds like ammonia and cyanide is broken down into nitrogen and water or other safe compounds. In all reactions, the main by-product after oxidation is oxygen. When growers or processors wash fresh fruits vegetables, the used water supplies go into waste holding ponds. The ponds are polluted with organic material and the chemicals used in the process. All of which can leach into the ground supplies or overflow into creeks and rivers. Many have had to pay high fines as a consequence. Ozone, if injected into the ponds will break down contaminates while oxygenating it at the same time. The waste material is more biodegradable after oxidation and safer for the environment. Ozone does not change the pH, nor does it react with the remaining organics to produce carcinogenic trihomethanes. Ozonated water is free of algae, bacteria, cyst, mold, viruses, yeast and parasites. The taste is improved making it softer with less scale buildup in appliances and plumbing lines with no stained fixtures and less tub rings. It oxidizes organics, iron, heavy metals and other contaminates. Water without chemicals and offensive chlorine and sulfur odors is possible.

2.7 Irradiation

The efficacy of irradiation stems from the fact that its biocidal effect is not limited to the surface, since it penetrates the product and eliminates micro-organism that present in crevices and creases (this is significant for vegetables like lettuce and cabbage), pockets and natural opening in the skin as well as the interior. Recent works on shredded carrots, pre-cut bell peppers, cut romaine lettuce, diced celery and other ready to eat vegetables showed that microbial and pathogen counts can be significantly reduced by low-dose irradiation without affecting sensory characteristics (Rodov, 2004b). The irradiation of fruits and vegetables is approved by US-FDA to a maximum of 1kGy for disinfection. It is difficult, if not impossible, to either wash pathogen off produce completely or inactivate by chemical treatments. Irradiation is a promising technology that can be used to improve the safety of ready to eat fruit and vegetables.

3. COLOR PRESERVATION

3.1 Enzymatic Browning

Enzymatic browning is the most limiting factor on the shelf life of fresh-cut products. During the preparation stages, produce is submitted to operations where cells are broken causing enzymes to be liberated from tissues and put in contact with their substrates (see Figure 3). Enzymatic browning is the discoloration, which results from the action of a group of enzymes called polyphenoloxidases (PPO), which have been reported to occur in all plants. Consequences of enzymatic browning are not restricted to discoloration, undesirable tastes can also be produced and loss of nutrient quality may result. PPO has been considered one of the most damaging enzymes to quality maintenance of fresh produce. Different factors such as preharvest, postharvest and processing factors, browning and enzymes other than polyphenoloxidase affect the browning. In preharvest factors, the agricultural practices, soil, fertilizers, climate and harvesting may contribute in the development of browning (Shewfelt, 1994). Susceptibility to browning may differ from cultivar to cultivar. The browning can be controlled through chemical and physical methods. In chemical method, sulfites had a widespread application in controlling both enzymatic and non-enzymatic browning. However, this chemical was banned for use in fruits and vegetables hence, physical methods have been sought for prevention of browning.

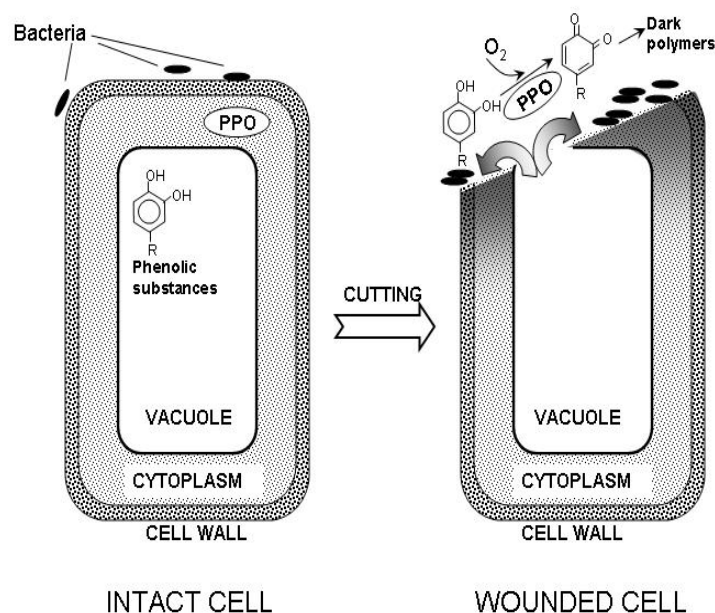


Figure 3: Wounding effects stimulating oxidation of cellular components causing tissue browning, microbial development on the wound surface and tissue breakdown (Source: Rodov, 2004a)

Heat inactivation is an effective method of browning prevention, and PPO is considered an enzyme of low thermostability, although differences in heat stability are reported for different cultivar and PPO isoforms (Gorny et al., 2000). *Low temperature* is one of the most commonly used approaches to controlling enzymatic activity in fresh-cut products during handling. At low temperatures, not only is enzymatic activity reduced, but also general metabolic rates are lower, which assists in extending product shelf life. *Reducing oxygen availability* includes modified atmosphere packaging (MAP) and edible coatings. It is important to avoid damaging low levels of oxygen or high levels of carbon dioxide, which lead to anaerobic respiration, resulting in the development of off-flavors and odors and increasing susceptibility to decay (Barth et al., 1993). Using a moderate vacuum packaging with polyethylene (80 μ m) for the storage of shredded Iceberg lettuce at 5°C (Bolin et al., 1991), browning was inhibited over a 10 day period. Browning of commercially prepared cut lettuce was retarded in packaged product, where the atmosphere was altered by the respiring product. Visual quality of the cut lettuce packaged in sealed bags received an original score of 9 (excellent), after storage for 2 weeks at 2.8°C the score dropped to 7 (good), while samples stored in unsealed package received a score of 3 (poor). MAP was also efficient in controlling microbial buildup during storage. On the other hand, edible coatings are used as a semi-permeable barrier that helps reduce respiration, retard water loss and color changes, improve texture and mechanical integrity, improve handling characteristics, help retain volatile flavor compounds and reduce microbial growth. In the application of some coatings it is possible to induce the formation of cross-links between pectin molecules of the fresh-cut product surface and the coating. Interestingly, different food additives can be incorporated into coating formulation, such as coatings with antioxidants (e.g ascorbic acid).

3.2 Other Color Changes

Although browning discoloration is the major colour change occurring on various fresh cut vegetables and fruits, other colour changes also occurs on some vegetables that also affects their quality. *White blush in carrots*: This is also known as white bloom and is a discoloration defect that results in the formation of a white layer of material on the surface of peeled carrots, giving a poor appearance to the product. This occurs upon peeling when the protective superficial layer (epidermis) of the carrots is removed, generally abrasion, leaving cell debris and an irregular surface (Cisneros-Zevallos et al., 1995). Once the carrots are exposed to the air, they dehydrate and the dried cell debris acquires a whitish color forming a white layer on the carrot surface thus affecting the quality. It has been suggested that with time, phenolic metabolism may be activated and thus induce the increases in lignin, phenolic compound and phenylalanine ammonia lyase activity and irreversible color change takes place (Howard and Griffin, 1993). The severity of the lignification depends on the harshness of the peeling process. Since enzymes mediate lignification process, inactivation of the enzymes may control it. A study carried out showed that carrots peeled with coarse sand paper and dipped for 20-30 seconds in a 2% citric acid solution at 70° C did not develop the defect for at least 5 weeks in cold storage and the products taste was not affected by the treatment. Coating carrots with edible films have also been shown to control this quality defect. Carrots coated with edible cellulose based coating had a fresh appearance (Sargent et al., 1994). Losses of carotenes have been described in fresh cuts carrots, and with application of an edible coating 50% retention of beta-carotene were obtained after 28 days of storage compared with 33% in the control. *Yellowing or degreening*: Yellowing or loss of the green pigmentation is a normal process that occurs in many fresh cut green vegetables and fruits during ripening or senescence. This is mainly accelerated by increased respiration or increased ethylene production that occurs during ripening or upon wounding of the fresh cut produce. During the preparation process of fresh cut products, there is a release of acids and enzymes and these may be involved in the loss of the green pigmentation. Use of modified atmosphere packaging and storage at 10°C has been used to retain the green color of broccoli. In the study by Barth et al. (1993), the concentrations of carbon dioxide and oxygen inside the broccoli package reached equilibrium within 48 hours and were 8% and 10% respectively. This caused reduction in respiration rate and the modified atmosphere packaging contributed to retention of the green color of the broccoli.

4. PREVENTION OF TEXTURE LOSS IN FRESH-CUTS

Appearance of a food product plays an important role on consumer's evaluation; it has been estimated that 95% of consumers take appearance into account in their purchases of fruits and vegetables (Rodov, 2004b). While genetic background is the major contributor to the texture of a plant food, other factors, such as morphology, cells wall-middle lamella structure, cell turgor, water content, and biochemical components, all affect texture (Harker et al., 1997). In addition, texture is also affected by growing conditions, including environmental factors and production practices (Sams, 1999). After harvesting it is important to store fruits and vegetables at the appropriate temperature and relative humidity to preserve their quality. Storage temperature has a major effect on water, weight loss and metabolic activity. Plant tissues are in equilibrium with

an atmosphere at the same temperature with an RH of 99-99.5%. Any reduction of water vapor pressure in the atmosphere below that in the tissue results in water loss. In whole organs, the water in the intercellular spaces is not directly exposed to the outside atmosphere. However, cutting or peeling the fruit or vegetable exposes the interior tissues and drastically increases the rate of evaporation of water. The difference in rate of water loss between intact and wounded plant surfaces varies from about 5 to 10 fold for organs with lightly suberized surfaces (e.g. carrot and parsnip), 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 (Wills et al., 1998). Tissue softening is a very serious problem with fresh-cut fruit products that can limit shelf-life. Fresh-cut fruit firmness is an important quality attribute that can be affected by cell softening enzymes present in the fruit tissue and by decreased turgor due to water loss. For example, unwrapped watermelon slices lost 47% of their firmness after 4 days at 5°C (Shewfelt, 1994). Flesh firmness of fresh-cut fruit products can be maintained by application or treatment with calcium compounds (Izumi and Watada, 1994). Calcium is thought to stabilize membrane systems and maintain cell wall structure in vegetables and fruits. Calcium also has been reported to maintain firmness of sliced strawberries and pears (Main et al., 1986; Rosen et al., 1989; Lidster et al., 1994 and Kim et al., 1994). Dipping fresh-cut products in solutions of 0.5 to 1.0% calcium chloride is very effective in maintaining product firmness. However, calcium chloride may leave bitter off flavors on some products. Firmness of slices from 12 untreated apple cultivars stored at 2°C decreased steadily for 7 days and more rapidly thereafter. However, mild heat treatment of whole apples before processing retained firmness during storage in some fresh-cut apple cultivars. It is well known that calcium is involved in maintaining the textural quality of produce. Calcium ions form cross-links, or bridges between free carboxyl groups of the pectin chains, resulting in strengthening of the cell wall. A common treatment used to improve tissue firmness is to dip fruit or vegetable pieces in calcium solutions, as described for strawberries (Main et al., 1986), pears and strawberries (Rosen and Kader, 1989), and shredded carrots (Izumi and Watada., 1994), among others. In contrast, calcium treatment was not effective in carrot slices and sticks, a fact attributed to insufficient calcium absorption by the tissue, since the levels of calcium were two and three times higher in shredded carrots than in sticks and slices, respectively. In addition, increasing the concentration of CaCl_2 in the dip solution (0.5% or 1%) brought an increase in the tissue calcium content of treated samples, without a subsequent correlation with product texture (Luna-Guzman and Barret, 2000). A combined treatment associating low temperature blanching to activate the enzyme pectinesterase (PE) prior to the calcium dip is helpful in preserving fruit texture. PE brings about the de-esterification of pectin, thus increasing the number of calcium binding sites. To such mechanism has been attributed the firming effect observed in apple slices kept at 38°C for 6 days immediately after harvest, and sliced and dipped in calcium solution after 6 months of cold storage. In fresh-cut melon cylinders dipped in calcium chloride solutions at different temperatures, texture was firmer in samples treated at 60°C (77% improvement in firmness), than at 40°C (58% improvement) and 20°C (45% improvement). Frequently, calcium chloride has been used as a firming agent, however, it may confer undesirable bitterness to the product. Fresh-cut cantaloupe cylinders dipped in calcium lactate solutions resulted in a textural improvement similar to calcium chloride treated fruit cylinders (Luna-Guzman and Barret, 2000). Sensory evaluation indicated that results were better. Heat treatment alone has been shown to have the potential to benefit product texture (Lidster et al., 1979 and Kim et al., 1994). In a comparison of 11 apple cultivars, heat treatment of whole fruit resulted in firmer products when compared with non-heated fruit; the best firmness

improvement was obtained with Golden Delicious and Delicious apples. Heat treatment of whole apples improved apple slice firmness, but the storage temperature of whole fruit after heating had a significant effect on product firmness; except for fruit of the cultivar McIntosh. Heat-treated apples stored at 2°C were firmer than products from fruit kept at 10, 18 and 25°C for 7 days. Slices prepared from heat-treated apples showed increased firmness during storage of up to 7 days for Golden Delicious (firmness 34% higher than on day zero of storage) and up to 14 days for Delicious apple (48% higher firmness than at the beginning of storage). With longer storage times there was a decrease in firmness for both cultivars. Firmness can sometimes be maintained by CA storage (Harker et al., 1997). Firmness loss averaged 10N in honeydew cylinders after 12 days of storage in air at 5°C while CA storage (air + 15% O₂) reduced the loss significantly in one of four cultivars tested. CA treatments (2% O₂ + 10% CO₂ at 5°C and 4 % O₂ + 10% CO₂ at 10°C) were more beneficial than air storage in maintaining honeydew cube quality for up to 6 days at 5°C. Controlled atmospheres retard senescence, lower respiration rates and slow the rate of tissue softening. Texture loss has been reported to decrease in controlled atmosphere packaging of fruit. Strawberry slices kept under controlled atmosphere for a week had comparable firmness to whole and to freshly-sliced fruit (Main et al., 1986). However, the effect of controlled atmosphere on firmness appeared to be cultivar-dependent.

5. ECONOMIC ASPECTS

Fresh-cut vegetables and fruits are a relatively new and rapidly developing part of the worldwide fresh produce industry. World demand, supply and trade of fresh fruits and vegetables are on the rise. Global trade in these commodities surpasses \$40 billion and world production totals approximately 1 billion tons. Industry estimates in the U.S. indicate that fresh-cut items currently account for over 10% of the U.S. fresh vegetable and fruit market (>\$8 billion) and sales are projected to increase (Besana et al., 2004). No estimates for post harvest losses of fresh-cut produce are available, but an estimate of from 9 to over 16% losses of all fresh produce is likely to be conservative given the added perishability of fresh-cut compared to intact produce. Using these percentages, the retail value of fresh-cut produce losses may total over \$750 million annually. In addition, fresh cut products save on time, personnel, storage spaces, ensures food and environmental safety and in return more income for the users.

6. CONCLUSIONS

Fresh-cut vegetable and fruit products differ from traditional, intact vegetables and fruits in terms of their physiology and their handling requirements. Fresh-cut vegetables deteriorate faster than intact produce usually because of the wounding associated with processing, which leads to a number of physical and physiological changes affecting the viability and quality of the produce. Integration of good sanitation, proper handling, proper packing and proper temperature management techniques along the marketing channel from the harvest point until the consumption point is essential to attain high quality level of fresh-cut produce.

- Avoiding desiccation at the cut surface of some fresh-cut products is critical for maintaining acceptable visual appearance.

- Flesh firmness of fresh-cut fruit products can be maintained by application or treatment with calcium compounds. Calcium is thought to stabilize membrane systems and maintain cell wall structure in vegetables and fruits.
- Yellowing or loss of the green pigmentation can be controlled by use of modified atmosphere and packaging
- Browning in fresh-cut produce can be controlled through physical methods which include heat inactivation, modified atmosphere storage and storage under controlled temperature.

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