Challenges Facing the Industry and Scientific Community in Maintaining Quality and Safety of Fresh-cut Produce

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Abstract
Fresh-cut produce industry, one of the fastest growing food industries in the United States, has been rapidly expanding in the last two decades. The flourishing of the fresh-cut produce industry is attributable to the high value placed by modern consumers on foods that are fresh, nutritious, and convenient. However, the recent food borne illness outbreaks associated with the consumption of packaged fresh-cut produce have also made bold headline news worldwide.

Unlike the intact fruits and vegetables, fresh-cut produce sustains substantial tissue injury during processing, and is thus more susceptible to microbial growth and quality deterioration; unlike traditionally processed food, fresh-cut products consist of living tissues and are processed and marketed as “ready-to-eat” yet without a microbial killing step. In addition, fresh produces grow in the open field, and contamination with human pathogens can potentially occur anywhere from farm to table. These factors reduce the shelf-life of fresh-cut produce and increase the risk of food borne illness.

This paper discusses the challenges facing the industry and scientific community. Issues involved in maintaining both quality and safety of fresh-cut produce, their current status and future research directions will be emphasized.

INTRODUCTION
The fresh-cut produce industry has experienced growth in the vicinity of 10-15% for the past two decades and is projected to continue to grow rapidly along with consumer demand for nutritious, convenient, fresh and flavorful foods (Garrett, 2002; Gorney, 2001; PMA, 2006). The benefit of consuming fresh fruits and vegetables is well documented. Fresh fruits and vegetables are nutritionally important sources of antioxidants including vitamins A, C and E, carotenoids and flavonoids, as well as minerals (McCarthy and Matthews, 1994). Furthermore, there is growing evidence that regular consumption of fresh produce may prevent or reduce the risk of several chronic diseases (Cooper, 2004).

However, epidemiological reports have shown that the occurrence of foodborne illness associated with the consumption of fruit and vegetables has increased (Beuchat, 2002; NACMC, 1999; Tauxe et al., 1997). Recently, a number of cases of foodborne illnesses associated with the consumption of fresh and fresh-cut produce have made headline news and negatively impacted the confidence of consumers in fresh produce.

Processing of fresh-cut products involves peeling, cutting, washing and sanitizing, drying and packaging. The finished products remain in a minimally processed and fresh state, and ready-to-eat. The International Fresh-cut Produce Association defines fresh-cut products as fruits or vegetables that have been peeled and/or cut into 100% usable product that is bagged or prepackaged. High standards of food quality and safety are essential for sustained industrial growth and fresh-cut product consumption.

Many new challenges exist due to the nature of minimal processing: (1) Unlike intact fruits and vegetables, the physical and chemical barriers (skins) provided by the epidermis of produce are removed during preparation of produce for the fresh-cut market. This practice creates the opportunity for the spoilage and/or human pathogenic microorganisms to directly contact the edible portion of produce, thus leading to more rapid product decay and increased health hazards; (2) Fresh-cut fruits and vegetables...
sustain substantial tissue injury during processing; the disruption of tissue and cell integrity often increases respiration rate, ethylene synthesis, enzymatic browning and development of physiological disorders (Watada et al., 1996). The damaged plant tissues provide nourished medium for microbial survival and growth (Izumi et al., 2005); (3) unlike traditionally processed food, fresh-cut products consist of living tissues and are processed and marketed as “ready-to-eat” yet without an effective microbial killing step; adding to this challenge is pressure to market “preservative free” fresh-cut products, as fresh-cut processors strive to balance consumer demand for “clean” labels with the need to inactivate or inhibit pathogen growth during distribution (Mermelstein, 2001); and (4) new unforeseen food safety issues have emerged as major concerns in the fresh-cut industry. Consequently, fresh-cut products require special handling during processing, transportation and storage.

This review article focuses on the major challenges facing the fresh-cut produce industry and the scientific community, current technologies used to combat the problems, and emerging technologies that hold promise for the future.

MODIFIED ATMOSPHERE PACKAGING FOR QUALITY MAINTENANCE

Modified atmosphere packaging technology (MAP) is the enabling technology for the blossoming of the packaged fresh-cut produce industry. However, challenges related to the development and applications of MAP remain to be overcome for improved quality and shelf life of fresh-cut produce.

MAP decreases oxygen (O₂) and increases carbon dioxide (CO₂) concentrations in the package to create an atmosphere which prolongs the shelf-life of fresh-cut produce. The passive changes in package atmosphere are due to the interaction between respiratory O₂ uptake and CO₂ evolution of packaged produce, and gas transfer through package films (Jacxsens et al., 1999, 2002; Makino, 2001; Schlimme and Rooney, 1994). Film permeability for O₂ and CO₂ should be matched to the respiration rate of the packaged fresh-cut commodity, in order to create a beneficial modified atmosphere inside the package that will reduce metabolic activity, ethylene sensitivity and production, and/or physiological and pathological deterioration during storage (Kim et al., 2003; Luo et al., 2004). The package design must be considered to assure that the materials used will provide adequate oxygen and carbon dioxide transmission for the product. A rapid establishment of a low O₂ and/or elevated CO₂ environment, in other words, active MAP, is critical for the prevention of cut surface browning of many fresh-cut vegetables, especially lettuce. This initial atmosphere can be achieved quickly by flushing the package with a gas mixture of pre-determined levels of O₂ and CO₂, or N₂. Flushing produce packages with a gas mixture, does not usually alter the equilibrium O₂ and CO₂ concentrations in the headspace, but merely accelerates equilibration. However, some fresh-cut produce appears to present exceptions to this pattern. Kim et al. (2003) found that by adjusting initial oxygen O₂ levels, CO₂ injury could be alleviated, thus minimizing quality loss of lettuce under sub-optimal film OTR conditions.

Certain fresh-cut products have either very high respiration rate or require a high oxygen level inside the package to maintain the product quality. These products are often packaged with perforated films because the OTR requirement exceeds the availability of non-perforated films. However, there have been food safety concerns over the use of perforated films because of the potential transfer of human pathogenic bacteria through the perforations. Since perforated films provide a potential means for contamination of fresh-cut produce, their replacement with high OTR films would be advantageous to alleviate food safety concerns.

Packaging design for fresh-cut fruits is different from that for cut vegetables. Due to the need for protection against mechanical injury during handling and transportation, fresh-cut fruits are often packaged in rigid containers, such as clamshells, two piece containers and trays. A major technical issue concerning rigid containers is an insufficient oxygen transmission rate because the containers are made of gas barrier materials and the gas transmission is made through the container lids with limited respiring area.
Research and technology advancement are needed in the area of developing high OTR film, rigid containers with gas transmission rates, and anti-microbial packages.

TEMPERATURE CONTROL FOR QUALITY AND SAFETY

The single most important factor in maintaining quality and safety of fresh-cut produce is temperature control. Although optimal storage temperatures are commodity dependent, microbial growth (Zagory, 1999), respiration rate (Hong and Kim, 2001), and quality deterioration of most fresh-cut produce (Jacxsens et al., 2002; Lamikanra and Watson, 2003) can be drastically reduced using cold storage temperatures. The quality of fresh-cut green onions was significantly improved by reducing storage temperature from 20 to 10°C (Hong and Kim, 2001). The green pigment of cut lettuce degraded significantly faster at 13°C than at 5°C (Castaner et al., 1999). The quality of fresh-cut cactus pear remained stable for 8 days when stored at 4°C, yet at 20°C it had a dramatic increase in ethanol accumulation, off-flavor development and loss of freshness. Lamikanra and Watson (2003) found that cut cantaloupes stored at 4°C maintained quality attributes far superior to those stored at 20°C. Zagory (1999) reported that storage temperature has significant effect on microbial growth and proliferation in his review of the effects of post-processing handling and packaging on microbial populations.

Cold storage is critical for control of Salmonella and Escherichia coli O157:H7 on cut produce. According to Zhuang et al. (1995), researchers have shown that Salmonella Montevideo grows on tomatoes stored at 20 and 30°C but not at 10°C (Zhuang et al., 1995), and Escherichia coli O157:H7 grows on fresh-cut melon at 12-25°C, but not at 5°C (Del Rosario and Beuchat, 1995).

In order to ensure food safety, the revised FDA model food code requires that potentially hazardous food, such as fresh-cut melons be stored at a temperature of 5°C (41°F) or below (Anonymous, 2001). Regulatory enforcement actions may be taken in the event that food supply chains fail to maintain this level of refrigeration. Numerous challenges face the scientific community and industry in developing and implementing cold chain management technology to maintain quality and safety. Although decreasing storage temperature vastly reduced the growth rate of E. coli O157:H7 and Salmonella app. (Ukuku and Sapers, 2007), Listeria monocytogenes remained constant or grew on a variety of whole and cut produce stored at refrigerated temperatures (Farber et al., 1998). In addition, maintaining proper storage temperatures is often most difficult at the retail level. Temperature abuse incidents occur during the entire supply chain, especially in the retail markets. Although most packaged fresh-cut salads are recommended to be stored at 1-4°C, temperatures in the produce display case/shelf are often found to be above the recommended temperature range.

MAINTAINING FOOD SAFETY OF FRESH-CUT PRODUCE

According to the Centers for Diseases Control and Prevention (CDC, 2002, 2006), the number of reported produce-related outbreaks per year in the USA doubled between the periods of 1983-1987 and 1988-1992, and there was a substantial increase in produce-related human illness in 1995 (FDA, 2001; Sivapalasingam et al., 2004). From 1996 to 2006, seventy-two food borne illness outbreaks were associated with the consumption of fresh produce, of which 25 percent (18 outbreaks) implicated fresh-cut produce (FDA, 2007).

Since fresh produce grows in farm fields, and may be handled numerous times during harvest, transport, packing, merchandising, perusal, purchase and at home, contamination with human pathogens may occur at any stage, as it travels from field to table. Processing fresh produce into fresh-cut products increases the risk of bacterial growth and contamination by breaking the natural exterior barrier of the produce. The release of plant cellular fluids during processing provides a nutritive medium for pathogens, if present, to survive and/or grow (FDA, 2001).

Washing/sanitizing is a critical step, and often the only step during the entire fresh-cut processing that can inactivate pathogens and other microorganisms. However,
potential for cross-contamination of pathogens during washing exists if the wash water is not sufficiently sanitized. Chlorine has been widely used as a sanitizer in wash, spray and flume waters in the fresh produce industry, at concentrations of 50-200 ppm (as sodium hypochlorite, NaOCl). However, various studies have shown that chlorine has only limited antimicrobial efficacies (Behrsing et al., 2000; Delaquis et al., 1999, 2004; Nguyen-the and Carlin, 2000; Simons and Sanguansri, 1997) and also loses its activity rapidly upon contact with organic matter (Gonzalez et al., 2004).

An alternative disinfection agent for produce, which has been shown to be more effective than sodium hypochlorite, especially under conditions of high organic load is acidified sodium chlorite (ASC) (Gonzalez et al., 2004). Researchers have shown that ASC significantly reduced E. coli O157:H7 counts on carrot shreds, cilantro (Allende et al., 2007) and on Chinese cabbages (Inatsu et al., 2005). However, studies have also found that ASC at the current FDA (2004a) approved application concentration range causes tissue injury to produce. Studies conducted by Ruiz-Cruz et al. (2006) suggest that a decreasing ASC concentration and increasing contact time can minimize the tissue injury while maintaining its strong efficacy against pathogens.

Many new chemical and physical alternatives, such as ozone, chlorine dioxide, ultrasound, and irradiation have been tested on fresh-cut produce with varying results. However, the high treatment intensities required for pathogen inactivation usually result in adverse effect on product quality.

Since there is no effective microbial killing step during the preparation of fresh-cut produce, preventing pathogen from contaminating produce is the key to maintaining food safety of fresh-cut produce.

Good Agricultural Practices (GAP), Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP) are important programs to ensure produce safety (FAO-UN, 1998; FDA, 2007; USDA, 2002). Both GAPs and GMPs are types of prerequisite programs for HACCP. By implementing GAPs through sound agricultural practices including the control of irrigation water, manure, worker’s hygiene, harvesting and other on the farm practices, it helps to reduce the risks of potential pathogen contamination occurring in the field. GMP addresses the practices and methods required for producing safe, wholesome food and is applicable to all food establishments regulated by the FDA. Manufacturing facilities, personnel, buildings and grounds, processing equipment and utensils, and production process control are major components of GMPs (FDA, 2003). HACCP program takes a proactive approach to prevent contamination by identifying the critical control point and developing corrective actions in advance. Both GAPs and GMPs are the foundations of HACCP program. For the fresh cut industry, although HACCP is not a mandatory program, most companies in the US have voluntarily adopted the HACCP program as one of the preventative measures for food safety.

BALANCING BROWNING INHIBITION AND PATHOGEN INACTIVATION

Browning is the major physiological disorder that afflicts the sensory properties of fresh-cut apples, discouraging consumer purchase. Enzymatic browning reactions in fruits are catalyzed by polyphenol oxidases (PPO) at the presence of molecular oxygen (Luo and Barbosa-Cánovas, 1994; Martinez and Whitaker, 1995). Control of browning on fresh-cut apples has been the focus of extensive research and many approaches have been explored for this purpose (Soliva-Fortuny and Martin-Belloso, 2003). However, due to the concerns over off-flavors and off-odors, food safety, economic feasibility, and effectiveness of inhibition, few browning inhibitors have shown potential for use in the food industry (Luo and Barbosa-Cánovas, 1996, 1997; McEvily et al., 1992).

Calcium ascorbate has been widely used by the fresh-cut apple industry to inhibit enzymatic browning and to maintain the quality and shelf life of fresh-cut apples. However, due to the incompatibility of calcium ascorbate, a reducing agent, with the widely used sanitizers, all oxidizing agents e.g., chlorine, ozone and chlorine dioxide, proper sanitizing treatment to control pathogens on fresh-cut apples is a technical
dilemma. Since the browning-control solutions are often reused from batch to batch of apples, lack of proper sanitizing treatment and thus the potential for contamination by food-borne human pathogens is cause for concern. The largest fresh-cut apple processor in the US has recently experienced a costly recall of their products after the detection by the FDA of human pathogen contamination. A sanitizer that is compatible with the current widely used anti-browning solution, or better yet, a solution that can provide dual control of browning reaction and microbial growth is urgently needed to maintain the safety and quality of fresh-cut apples. Recent studies have shown that sodium chlorite, a known anti-microbial agent, has strong inhibition on fresh-cut apples (Lu et al., 2007) by inhibiting polyphenol oxidase activity (Lu et al., 2006). Sodium chlorite has the strong potential to become the dual control agent that is needed by the food industry.

Using transgenic apples with inhibited PPO expression may be another approach to balance browning control and food safety concerns for fresh-cut apples as those apples would not need anti-browning treatments (Martinez and Whitaker, 1995; Murata et al., 2000; Murata et al., 2001). Okanagan Biotechnology, Inc. is in the process of releasing first non-browning commercial apples with a special orientation to the needs of fresh-cut industry (Anonymous, 2007).

NEW TECHNOLOGIES

Relatively new food processing technologies have been developed as alternatives to thermal treatments, such as ultraviolet irradiation, high hydrostatic pressure, gamma irradiation, and pulsed microwave irradiation (Allende et al., 2006; Lacroix and Lafontune, 2004; Morales et al., 2006; Yaghmaee and Durance, 2005). A combined treatment of ozone and active species of oxygen has also been used to reduce decay and prolong shelf-life in fruits. However, this research is still in its infancy and optimization of this technology is required to strike a balance between effective concentrations for achieving microbial inhibition, while minimizing tissue injury to produce and health risks for human workers.

Mild heat treatment has been found to be beneficial to maintain the quality of packaged fresh-cut grapes (Luo and Kou, 2007) and other fruits (Abreu et al., 2003) by inducing heat shock proteins. Researchers found that a heat shock at 50°C for 90 seconds applied either after or before cutting was effective in inhibiting lettuce browning by diverting protein synthesis to heat shock protein, phenylalanine ammonia-lyase (PAL) (Louiza-Velarde and Saltveit, 2001; Saltveit, 1997). Mild heat treatment has also shown promise for reducing chilling injury in fresh-cut tomatoes, which provide the solutions to balancing the needs for keeping sliced tomatoes at the lower temperature for food safety concerns while minimizing chilling injury and maintain quality and flavor of tomatoes.

Applications of 1-methylcyclopropene (1-MCP) to block ethylene effect and thus delay ripening and extend storage-life of apples have been successful for the apple industry (Blankenship and Dole, 2003). Recent studies have shown that 1-MCP can be used to reduce the development of water soaking appearance of fresh-cut watermelons by counteracting the deleterious effect of ethylene exposure of whole watermelons (Saftner et al., 2007; Zhou et al., 2006). Tay and Perera (2004) also reported that 1-MCP reduced the development of russet spotting and leaf yellowing and delayed senescence in shredded lettuce.

The future of fresh-cut produce industry will be dependent on new facilitating technologies currently under development. RFID (radio frequency identification) tags, which will monitor and record temperature, will eventually replace most barcodes (Hewett, 2006). Important new developments for packaging films include expanded ranges of gas permeability, and specially engineered membranes that can enhance gas transmission performance or adjust to external temperature changes. Other “active” and “smart” packaging concepts offer promise for enhancing aromas, attacking microbes, being more useful in microwave ovens, etc. (IFPA, 2004). Equipment manufactures are making new machines which minimize tissue damage during processing.

Stimulated by the recent food borne illness outbreaks associated with consumption
of packaged baby spinach and lettuce in the USA, there is a surge of industry wide support for research in finding “cures” for food safety issues. Several world-wide Industry leaders have each donated $2.0 million for research on food safety of fresh-cut produce. The leading fresh-cut company has begun to use RFID technology to improve the traceability of their products from field to retail stores (The Packer). Although many technical and practical challenges still remain to be overcome, the fresh-cut industry will continue to grow rapidly as more enabling technologies are developed and implemented.

**Literature Cited**


