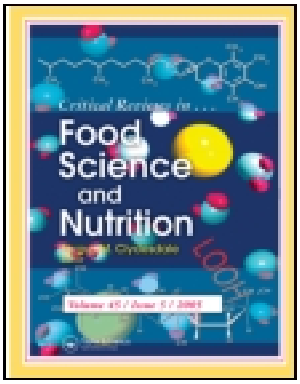

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Recent Developments in Minimal Processing: A Tool to Retain Nutritional Quality of Food

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Recent Developments in Minimal Processing: A Tool to Retain Nutritional Quality of Food

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The modernization during the last century resulted in urbanization coupled with modifications in lifestyles and dietary habits. In the same era, industrial developments made it easier to meet the requirements for processed foods. However, consumers are now interested in minimally processed foods owing to increase in their awareness to have fruits and vegetables with superior quality, and natural integrity with fewer additives. The food products deteriorate as a consequence of physiological aging, biochemical changes, high respiration rat,e and high ethylene production. These factors contribute substantially to discoloration, loss of firmness, development of off-flavors, acidification, and microbial spoilage. Simultaneously, food processors are using emerging approaches to process perishable commodities, along with enhanced nutritional and sensorial quality. The present review article is an effort to utilize the modern approaches to minimize the processing and deterioration. The techniques discussed in this paper include chlorination, ozonation, irradiation, photosensitization, edible coating, natural preservative use, high-pressure processing, microwave heating, ohmic heating, and hurdle technology. The consequences of these techniques on shelf-life stability, microbial safety, preservation of organoleptic and nutritional quality, and residue avoidance are the limelight of the paper. Moreover, the discussion has been made on the feasibility and operability of these techniques in modern-day processing.

Keywords Minimal processing, fruits and vegetables, hurdle technology, emerging technologies, MAP

INTRODUCTION

The term 'food processing' covers an enormous field from simple boiling to the use of irradiation to predict the consequences on the nutritional value of fruits and vegetables. The macro- and micronutrients within foods show varying degrees of stability during processing and storage (Ragaert et al., 2004). The degree of stability depends largely on the nature and structure of the food items and processing time to which products are subjected. Generally, food processing methods can be further categorized into intentional processing methods (milled, peeling, washing, and trimming), inevitable processing methods (blanching, sterilizing, cooking, shredding, and drying), and accidental (inept processing or systems). The nutritional losses associated with fruits and vegetables processing vary with different processing techniques and conditions employed (Henry and Massey, 2001). The heavily processed products are although safe for human consumption but allied with reduced nutritive value. In this regard, access to safe and nutritious food is considered as a basic right of humans, as it is one of the ways to prevent various ailments by building better health and reinforcing immunity. Escalating health awareness has guided the processors to opt for minimal processing of foods in recent years (Wells and Butterfield, 1997; Picouet et al., 2009).

The quality of fruits and vegetables varies with processing techniques. During processing of fruits and vegetables, various techniques are employed to improve the quantity and quality of the produce, including blanching, dehydration, salting, smoking, and concentration. Most of these technologies hold adverse consequences on the quality of food, e.g., blanching is carried out with the major objective to destroy or inactivate harmful enzymes before freezing or drying; however, it affects the color, texture, flavor, and nutritive value of fruits and vegetables

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(Henry and Massey, 2001). It is now believed that processing encourages faster deteriorative changes in fruits and vegetables, and ultimately, physiological and biochemical changes arise in these commodities even on trivial processing operations (Sandhya, 2010). The concepts need to be readdressed before selecting the appropriate techniques for the processing of fruits and vegetables. There are many modern innovative modules of processing that can be employed to replace thermal processing, thus reducing bridging the nutrient losses, resulting in better nutritive quality with greater consumer acceptability.

Food commodities subjected to minimal processing are capturing the market owing to the widespread concept that they might help in meeting the current requirement of vital nutrients (Tournas, 2005). Deployment of minimally processed commodities, especially fruits and vegetables, has augmented at both retail and consumer level during the last years (Huxley et al., 2004). Various organizations [WHO (World Health Organization), FAO (Food and Agriculture Organization), USDA (US Department of Agriculture)] boost up the utilization of minimally processed perishable commodities, including vegetables and fruits, to lessen the risk of cardiovascular diseases and cancer. Changes occurring in the eating habits have been quoted due to high anxiety for on-time availability of minimally processed fruits and vegetables. Sales of fresh-cut fruits and vegetables continue to burgeon (IAEA, 2006), and food industries are persistently expanding primarily because of consumers' trend of health realization (Gilbert, 2000; Ragaert et al., 2004). Fresh-cut fruit and vegetable industry is functioning now a day for supplying swift and expedient fruit and vegetable cuts having high nutritional value, flavor, and texture. Demand for fresh fruits, vegetables, and their cuts is always there, but a span of several days occurs between processing and consumption (Gomez-Lopez et al., 2005; Alegre et al., 2010). Increase in the consumption of more fresh appearing, more convenient, and healthier fruit and vegetable products is guided to increase the research on minimal preservation techniques such as improved prerequisite operations (cleaning and chlorination), ozonation, photosensitization, edible coatings, high-pressure processing (HPP) (Bull et al., 2004; Houska et al., 2006), modified atmosphere packaging (Soliva-Fortuny and Martín-Belloso, 2003; Soliva-Fortuny et al., 2004a), and natural antimicrobials agents (Janisiewicz et al., 1999; Leverentz et al., 2006; Trias et al., 2008).

The present review article covers approaches to minimize the processing and deterioration of fruits and vegetables. The article is split up into different headings, including washing, chlorination, ozonation, irradiation, hurdle technology, photosensitization, edible coating, natural preservative use, HPP, microwave heating, and ohmic heating. Effects of these approaches on microbial safety, shelf-life constancy, perpetuation of organoleptic, nutritional quality, and residue prevention are the attention of the paper. Moreover, a debate has been proposed on the feasibility and operability of these approaches in modern-day life. The prerequisite operations and different techniques that can be utilized in minimal processing of fruits and vegetables are described herein.

PREREQUISITE OPERATIONS OF MINIMAL PROCESSING

Preparatory operations are an essential part of processing for improving fruits and vegetables quality. Before adopting any minimal processing technique, the following prerequisites operations must be carried out: washing, peeling, cutting, trimming, and shredding. However, the selection of aforementioned processes is dependent upon the structure of raw material and its intended use.

The fruit's natural shield is usually removed during the preliminary minimal processing steps, so consequently fruit's susceptibility to microbial spoilage increases. It is therefore required that stainless steel knives or blades, as sharp as possible, should be used for cutting, trimming, and shredding (Ohlsson and Bengtsson, 2002; Martin-Belloso et al., 2006). Cross-contamination must be avoided during making fruits and vegetables cuttings, which may arise due to offensive sanitation procedures (Heard, 2002). Likewise, the release of oxidizing enzymes should be controlled. The mechanisms behind enzyme release include improper peeling and cutting, which may damage many cells, thus releasing intracellular products that speed up the decaying of the product. The cut surfaces further support microbial growth, thus deteriorating the quality of produce (Laurila and Ahvenainen, 2002).

Washing under clean and running water is an excellent way to control turgor pressure of fresh-cut commodities after cutting and shredding. This runny milieu helps in flushing out potentially damaging enzymes far from plant tissues. Since the cutting should take place under water, one of the approaches tested in France is 'water jet cutting.' Additionally, ultraviolet C (UV-C) light can also be used during fruit cutting to produce hypersensitive defensive mode within fruit cuts, which ultimately reduces fruit and vegetable browning (Lamikanra and Bett-Garber, 2005). Immersion therapy is a novel technique to avoid the spoilage of fruits and vegetables after cutting (AR-USDA, 2005). Moreover, packaging guidelines for minimally processed fruits and vegetables must be followed to prevent the proliferation of pathogenic bacteria and viruses. In addition, a washing or sanitizing step is required to remove filth, pesticide residues, and certain microbes from the food products (Ahvenainen, 2000; Yamaguchi, 2006). Washing should be performed by single method or combination of methods involving mechanical action (scrubbing, brushing, and water jet spraying) or chemical cleaning (acidic or alkali detergent, sulfite dipping, nonsulfite dipping, and chlorinated water treatment). Sulfiting agents are primarily used to avoid spoilage and discoloration during the preparation, storage, and distribution of fruit and vegetable cuts. However, because of safety concerns with their usage, the use of non-sulfite agents is being demanded. In this regard, fresh-cut fruits and vegetables can be dipped in solutions of ascorbic acid, citric acid, and calcium chloride at their various concentrations (0.1–1.5%) for a period of 10–15 minutes (Zhu et al., 2007). A detergent or a disinfecting detergent can also be applied to prevent the formation of bacterial biofilms (Ohlsson and Bengtsson, 2002; US Department of Agriculture, Food and Nutrition Service, & National Food Service Management Institute, 2005). Various washing as well as disinfectant treatments inadequately influence the nutritional and sensory attributes of food products (Laurila and Ahvenainen, 2002). Efficient rinsing with potable water can eliminate the detached particles and detergent residues (Ohlsson and Bengtsson, 2002). It is therefore required that the materials used in disinfection treatments must be approved as 'Generally Recognized as Safe' (GRAS) (Gorny and Zagory, 2002). Various disinfectants can diminish the microbial load on fruits and vegetables to control plant pathogens, food pathogens, and spoilage microorganisms. These prerequisite operations if employed are effective in retaining the nutritional quality of minimally processed food products. Some techniques that can be employed to process fruits with minimal processing requirements are described herein.

Chlorination

Traditionally, processors use water with or without chemical sanitizers to wash products, subjected to minimal processing, and the one of extensively used sanitizers is chlorine. It is routinely used for washing, spraying, or fluming treatments, along with water, for disinfecting fresh fruits and vegetables (Beuchat, 2000). Application of chlorination has gained prestigious value to disinfect fruits and vegetables (Rabin, 1986). The crucial role of chlorine is to inactivate or kill the pathogenic microbes, i.e. bacteria, fungi, and viruses. In combination with farmers' field and management programs for workers' hygiene, chlorination is highly effective, comparatively inexpensive, and immediately available, and can be implemented in certain operations of any dimension. Legally, chlorine is available in commercial markets in different forms. The US Environmental Protection Agency (EPA) has approved the use of chlorine gas, calcium hypochlorite, and sodium hypochlorite (Ruiz-Cruz et al., 2010).

The effectiveness of chlorination depends upon various factors, including water pH (pH 6.5–7.5), concentration of chlorine (100–150 ppm), contact time (<1 min), amount of organic matter (lowest as possible), water temperature, and the type and growth stage of pathogen. The use of chlorine, associated with hygienic processing, permits a significant improvement in the microbiological quality of the products with minimal processing (Ohlsson and Bengtsson, 2002). Long ago, very elevated chlorine dosage rates were frequently used because of the misconception that no residues will remain on the produce at the time of consumption. But in reality, chlorine oxidizes the organic matter incompletely to produce objectionable byproducts, e.g., chloroform ($CHCl_3$) and some other trihalomethanes, which have been reported as potential carcinogens at elevated doses (EPRI, 1997). However, the role of chlorine in reducing microbial load on surfaces of fruits and vegetables is not very significant when low chlorine doses are utilized (Beuchat, 2000; Sapers, 2001). Traditional technologies also indicate that chlorine has restricted effect on bacterial destruction on surfaces of fruits and vegetables. Environmental and health organizations have articulated apprehensions about conventional sanitizers, along with the byproducts they form, e.g., trihalomethanes and other chemical residues produced in the wastewater re-entering the environment (Graham, 1997). Moreover, there are some serious health concerns regarding chlorination, as selection of sources and side-effects associated with their application demands thorough investigations for final recommendations.

Ozonation

In current years, escalating attention has been paid to fruit and vegetable safety issues, particularly with regard to the intervention processes of reducing and eradicating pathogens and pesticide residues (Selma et al., 2008; Gabler et al., 2010). Processors are anxious about the likelihood of future regulatory restrictions on chlorine use as a sanitizer. So, research and business institutions have verified that traditional sanitizers can be replaced with ozone as an alternative treatment (Travagli et al., 2010). Various documents and studies have confirmed that ozone application is beneficial for the food industry (Rice et al., 1982; Ikeura et al., 2011).

Ozone is triatomic, a form of natural oxygen that was first recognized in 1840:

$$3O_2 \rightleftarrows 2O_3 + \text{heat} + \text{light}.$$

It is moderately soluble in water, and like most gases, its solubility increases with the decrease in temperature. It can effectually destroy microorganisms in the course of their cell membrane oxidation, organic matter deodorization, bleaching and putrefaction, and mycotoxin degradation (Karaca and Velioglu, 2009; Karaca et al., 2010). Auto-decomposition is a unique property of ozone, without accumulation of toxic residues. Its oxidation potential is 1.5 times higher than that of chlorine. So, it has been reported that ozone can be effective over a much wider continuum of microorganisms than chlorine and such other sanitizers. Fruit and vegetable washing in ozonated water or ozone-microbubbled solution is an important key for maintaining or even improving fresh produce safety issues (Kim et al., 1999; Ikeura et al., 2011a). Potatoes' shelf-life can be extended to 6 month at 6–14°C and 93–97% relative humidity by means of 3 ppm of ozone without lowering the potato quality. In cold, ozone slows down the fruit and vegetable ripening process. Ozone is predominantly effective against *E. coli,* the food pathogen of most unease to the industry (Ikeura et al., 2011a, 2011b). They reported that residual fenitrothion in contaminated vegetables (lettuce, cherry tomatoes, strawberries) was removed more proficiently by the ozone microbubbles (OMB) process. Ozone can be used in the minimally processed fresh food industry to enhance the antioxidant level of food products (Alothman et al., 2010).

A new approach for disinfection of fruits and vegetables is the application of ozone and chlorine in combined form, which shows comparable or superior results in microbial diminution and shelf-life expansion than chlorine alone. Using an ozone–chlorine combination for commercial lettuce salads, there were no visible turbidity changes in the processing water. The quality of the water remained constant for longer periods of time, making it available for longer reuse. Therefore, ozone–chlorine combinations may have beneficial effects on the shelf-life and quality of lettuce salads as well as on the water used for rinsing or cleaning the lettuce (Garcia et al., 2003).

Natural Chemical Sanitizers

Awareness in the utilization of natural preservatives to avoid microbial growth has remarkably increased in the recent past in order to replace chemically synthesized additives in fruits and vegetables (Oms-Oliua et al., 2010). Natural sanitizers can be defined as substances produced by living organisms, including plants, microorganisms, and animals (Ohlsson and Bengtsson, 2002). They are mainly of three types: antimicrobials, antioxidants, and antibrowning agents. The antimicrobial activity of a broad range of volatile compounds, e.g., hexanal, hexanol, 2-(E)-hexenal, and 3-(Z)-hexenol—vital constituents of the aroma of tomatoes, tea, strawberry, olive oil, grape, apples, pear, and plant essential oils (EOs), primarily containing terpenoids—has been studied against microbial growth and augmentation in wounded areas, together with numerous pathogens (Lanciotti et al., 2004).

Food antimicrobials are chemical compounds that interrupt microbial growth and ultimately bring their demise on incorporation into a food medium. The foremost targets for antimicrobials are the microbes that cause food poisoning and spoilage (Davidson, 2001). The accurate mechanism of action of these antimicrobial compounds is not clear till now, but it is assumed that passive diffusion across the plasma membrane is implicated (Lanciotti et al., 2004). It was also reported that the addition of 0.02% (v/v) citrus, mandarin, cider, lemon, and lime plant EOs to a minimally processed fruit mix can repress the microbes. They can also lower the growth rate of inoculated *Saccharomyces cerevisiae* cells, thus extending the shelf-life of the produce without damaging its sensory properties.

Photosensitization

Conventional thermal technologies are useful against microorganisms, but frequently, they encourage numerous uncontrolled chemical reactions in the food matrix and ultimately reduce its nutritive quality (Manas and Pagan, 2005). Natural compounds, e.g., EOs, chitosan, niacin, lysozime, etc., are also utilized to enhance the quality of the food produce. However, some of these bioactive molecules are not accepted owing to their poor organoleptic perceptions (Senorans et al., 2003; Devlieghere et al., 2004; Manas and Pagan, 2005). Certainly, food scientists were keen to develop novel approaches to inactivate pathogenic and harmful microorganisms in a cost-effective, nonthermal, and environmentally friendly means (Luksiene and Zukauskas, 2009; Buchovec et al., 2010).

In photosensitization, interaction of two nontoxic factors, i.e., the photoactive compound and visible light, occurs that results in selective microbial cell destruction in the presence of oxygen.

At present, photosensitization is used for blood disinfection (Demidova and Hamblin, 2004). The chief advantages of antimicrobial action of photosensitization comprise the following:

(1) Treatment efficiency is independent of the antibiotic resistance pattern of the strain.
(2) Inactivation of pathogen population by up to six orders.
(3) No harmful effect on the environment.
(4) No mutagenicity or bacterial resistance to photosensitization.
(5) Cost-effective, easy to maintain, and environmentally friendly source (Jori et al., 2006).

Various microorganisms such as multidrug-resistant bacteria, yeasts, microfungi, and viruses are vulnerable to this preservation method. Therefore, photosensitization might open a novel prospect for developing a nonthermal, effective, economical, and environmentally friendly antimicrobial technology applicable in safe food processing (Sibata et al., 2001).

Edible Coatings

An edible coating can be defined as a thin layer of an edible substance as a film on the exterior of fruits and vegetables (Ghasemzadeh et al., 2008). These coatings are applied straight on the food surface by dipping, spraying, or brushing for generating a modified atmosphere (Mchugh and Senesi, 2000). In the past, edible coatings have been used to lessen water losses, but modern developments of formulated edible coatings with assorted functionalities have enhanced their potential applications for fresh produce (Avena-Bustillos et al., 1994). Some advantages of edible coating include enhanced retention of colors, acids, sugars, and flavor compounds. Furthermore, reduced weight loss results in the preservation of quality throughout shipping and transportation (Duan et al., 2011). All these changes lead to improved consumer appeal, along with an extension in the shelf-life. Last but not least, edible coatings add to the value of the food produce and trim down the requirement of synthetic packaging (Lima et al., 2010; Ali et al., 2010).

Edible coatings of various types have been in use for shelf-life extension of the fresh produce by reducing the respiration rate and moisture loss (Sanchez-Gonzalez et al., 2011). Edible coatings may comprise polysaccharides, proteins, lipids, or a blend of all these compounds. Some of the polysaccharides that have been used in coating formulations are starch, pectin (Oms-Oliu et al., 2008), cellulose (Tien et al., 2001), chitosan (Ansorena et al., 2011; Jiang and Li, 2001; Chien et al., 2007), and alginate (Tien et al., 2001; Montero-Calderon et al., 2008).

These coatings act as potent oxygen, aroma, and oil barriers, so they have the ability to provide strength to products and maintain their structural integrity. However, they are hydrophilic in nature, so cannot be considered as successful moisture barriers. Similarly, chitosan, a film-forming polysaccharide, has been extensively used due to its ability to restrain the growth of many pathogenic microorganisms, i.e., bacteria and fungi (Romanazzi et al., 2002). Chitosan is effective in quality maintenanace and shelf-life extension of sliced mango (Chien et al., 2007).

Edible coatings offer a brilliant approach to control additives since they are shown to maintain high concentrations of preservatives on the food surfaces, reducing the impact of chemicals on overall consumer acceptability of fresh-cut fruit (Oms-Oliu et al., 2010). Surface treatments include dipping of fruit pieces into aqueous solutions having antimicrobial agents, antioxidants, calcium salts, or functional ingredients, e.g., minerals and vitamins are widely used for improving the quality of fresh-cut fruits. The utilization of edible coatings for distributing active substances is one of the foremost advancements made for amplifying the fresh-cut produce's shelf-life (Correa-Betanzo et al., 2010; Alandes et al., 2006; Quiles et al., 2007). The combination of antioxidant agents (e.g., N-acetylcysteine and glutathione) with edible coatings (e.g., alginate and gellan) is considered helpful in avoiding browning of fresh-cut apples, pears, and papayas (Tapia et al., 2005; Rojas-Grau et al., 2007, 2008; Oms-Oliu et al., 2008). Methylcellulose and methylcellulose–stearic acid coatings containing some additives (ascorbic acid, calcium chloride, and sorbic acid) show positive effects in controlling browning of fresh-cut pears (Olivas et al., 2003). The future prospects include the concept of fortification, coupled with edible coatings. The fortificants that can be incorporated include vitamin A, vitamin D, iron, zinc, etc.

Modified Atmosphere Packaging

Consumer demand for convenience and healthy diet are major factors in the growth of the minimally processed food sector. Food products processed commercially or conventionally are often considered of poor quality due to nutritional losses and unsuitable packaging (Timon and Relay, 2005; Lucera et al., 2010). The packaging protects the product from the external environment and helps to ensure a sterile environment around the product. The major problems that limit the shelf-life of minimally processed fruits and vegetables are the high respiration rate, off-flavors production, acidification, loss in firmness and discoloration, high ethylene production, and microbial spoilage (Amanatidou et al., 2000; Barry-Ryan and Beirne, 2000; Barry-Ryan et al., 2000; Sandhya, 2010). Modern food packaging technologies include modified atmosphere packaging (MAP), active packaging, and smart packaging, thus enhancing food safety and quality in as natural a way as possible (Hotchkiss, 1995). MAP of minimally processed fruits and vegetables is related to sealing actively respiring commodities in polymeric film packages to modify the O_2 and CO_2 levels within the package atmosphere. This technique desirably generates an atmosphere low in O_2 and high in CO_2, which influences the metabolism of packed product or the activity of food spoilage-causing organisms, which ultimately results in increased storability and shelf-life. Some fruit and vegetable cuts require modification in both O_2 and CO_2; indeed, change in the level of O_2 automatically changes the level of CO_2. MAP hinders spoilage mechanisms, as well as reduces respiration, delays ripening, decreases ethylene production and sensitivity, retards textural softening, reduces chlorophyll degradation, and alleviates physiological disorders by using different oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2) concentrations (Ohlsson and Bengtsson, 2002; Farber et al., 2003; Xing et al., 2010). In addition to gas mixtures, various packaging materials are used within the package of fresh-cut produce at appropriate levels, such as oxygen (O_2) scavengers or absorbers, carbon dioxide (CO_2) absorbers or generators, ethanol emitters, ethylene absorbers, and moisture absorbers (IFPA, 2003; Barry-Ryan and Beirne, 2000). The aim of these active or interactive methods is to maintain a product's desired shelf-life throughout (Ohlsson and Bengtsson, 2002). The use of MAP has greatly expanded over the past few decades and is now used around the world to extend the shelf-life of a wide range of food products, as given in Tables 1 and 2.

Irradiation

The development of new techniques to guarantee the safety of fresh fruit and vegetable cuts is vital, and one of the most important techniques is irradiation (Niemira and Fan, 2006). The reasons pertaining include greater interest of consumers focusing on produce-related food-borne ailments (Thayer and Rajkowski, 1999). Due to the well-built desire to diminish the chemical exposure on fruits and vegetables, the nonresidual characteristics of ionizing radiations have imperative benefits (Manzocco et al., 2010). Internationally, food irradiation has been considered as a safe and effectual technology by the WHO, FAO, and IAEA, in Vienna (El-Samahy et al., 2000).

Food irradiation (radio frequency, visible light, infrared light, microwave, and ultraviolet light) has damaging effects on DNA and cells become inactivated. Consequently, reproduction of microbes and insect gametes is prohibited, thus resulting in improving the shelf-life of the fresh produce (Thayer, 1990; Liu et al., 2010; Wang et al., 2010). UV-B irradiation also appears to be a useful nonchemical way of maintaining postharvest quality and enhancing antioxidant capacity in fruits and vegetables. The irradiation treatment of 1 kGy (100 krad) is permitted for fruits and vegetables by the Food and Drug Administration (FDA, 2007). Microbiological assessment is carried out by various methods such as direct epi-fluorescent filter technique (DEFT) and aerobic plate count (APC) for irradiated food stuffs and they provide considerable and satisfactory results in irradiation processing (Araujo et al., 2009; Liu et al., 2010) Low irradiation dose levels of 1 kGy or less produce minor changes in most fresh-cut vegetables' appearance, flavor, color, and texture, even

Table 1 Modified atmosphere technology used in different fruits and vegetables

S. No.	Fruit	Conditions	Effects	Researcher
1	Mango	(1) 4-kg film-lined cartons using microperforated polyethylene (PE) or Xtend® film (XF) (2) 3 weeks of storage at 12°C plus 1 week at 20°C.	(1) Modified atmosphere treatment was effective in reducing chilling injury. (2) Delays ripening of certain mangoes. (3) Reduced level of sap in the packaging.	Pesis et al. (2005) Aharoni et al. (2008) Jacobi and Giles (1997)
2	Apple	(1) Initial atmosphere of 90.5% N_2 + 7% CO_2 + 2.5% O_2 and plastic pouches of 30 cm^3/cm^2 for 24 hours. (2) Preserved in plastic bags of15 cm^3 O_2 for 24 hours and flushed with 100% N_2.	(1) A maximum 62% color and polyphenols oxidase activity depletion was observed. (2) The faster the initial PPO activity decays, the lesser the color change. (3) Longest stability with microbial counts below 5 logCFU during the first 2 month of refrigerated storage.	Soliva-Fortuny et al. (2001) Soliva-Fortuny et al. (2004a) Smith et al. (2007) Rocha et al. (2003)
3	Carrot	(1) Packed with passive (in air) and active modified atmospheres at low (5% O_2, 10% CO_2, 85% N_2) and high oxygen. (2) Concentrations (80% O_2, 10% CO_2, 10% N_2) (3) Microbial, chemical, physical, and sensory analyses were conducted in carrots for 21 days at 4°C	(1) There was no yeast or mold growth during the 21 days of storage. (2) The growth of mesophilic aerobic bacteria was observed at all treatments. (3) The carrots packed with high oxygen and passive MAP retained quality properties better compared with low oxygen. (4) The whiteness index did not significantly change during the 21 days of storage in all applications, indicating the good retention of orange color. (5) The texture values declined for both passive and active MAP applications after 14 days of storage indicating a significant softening.	Ayhan et al. (2008) Lafortune et al. (2005)
4	Citrus	(1) All fruits were subjected to quarantine 'Q' treatment at 2°C and 90% RH) for 2 months, followed by a marketing period at 20°C and 65% RH for 7 days.	(1) Fruits could be safely quarantined under modified atmosphere packaging to the longest possible storage period (60 days) with the most proper food quality.	Serry (2010) Techavises and Hikida (2005)
5	Tomato	(1) Fruits are packed on the same day of harvest in low-density polyethylene firm (LDPE) (44.4 mm thick) (2) Six different weights of fruits ranging from 140 to 640 gm were packed in 800 cm^2 area and stored at 20°C (3) Each treatment is composed of 18 sealed packs and l2 perforated bags as controls. (4) The concentration of carbon dioxide and oxygen within the packed units were measured by withdrawing daily 2 × 1 mL of the gas in the headspace of the packages by inserting a hypodermic needle with 1 mL volume plastic syringe through a silicone rubber fixed onto 1 cm^2 electric black tape on the plastic bag.	(1) These conditions retained flesh firmness, low acidity and soluble solids concentration and delayed fruit lycopene development. (2) Modification of O_2 and CO_2 in the atmosphere surrounding the commodity by selecting a suitable film and fruit physiological stage could improve fruit quality, reduce weight loss and other wastage, and consequently increase the life harvested tomato.	Vanndy et al. (2008)
6	Peach	(1) Firm-breaker fruit: 12% CO_2 and 4% O_2 in standard type polypropylene, 23% CO_2 and 2% O_2 in oriented-type polypropylene (2) Firm-mature fruit: (22% CO^2 and 3% O^2 in standard polypropylene and 21% CO_2 and 2% O_2 in oriented polypropylene (3) 14 days storage plus a 3-day shelf-life test	(1) Woolliness and slight internal browning developed in fruits stored in macroperforated polypropylene. (2) Ethanol and acetaldehyde accumulated to higher levels in oriented polypropylene bags for both firm-breaker and firm-mature fruit. (3) Modified atmospheres in both unperforated bags were associated with lower weight loss, less senescence and chilling injury, absence of decay, and delayed ripening changes of the fruit after a shelf-life period.	Fernández-Trujilio et al. (1999)
7	Pomegranate	(1) Stored at 2 or 5°C for 12 week in unperforated polypropylene (UPP) film of 25 μm thickness in modified atmosphere packaging (MAP). (2) Perforated Polypropylene (PPP) film of 20 μm thickness and conventional cold storage were applied as control treatments. (3) Quality was evaluated after storage and after shelf-life of 6 days at 15°C and 75% RH	(1) PPP at 5°C was the best treatment for maintaining the red skin color of the arils at the end of storage. (2) All treatments suffered a decrease in total anthocyanins content at the end of shelf-life. (3) MAP strongly reduced water loss and chilling injuries without incidence of decay.	Caleb et al. (2011)

(Continued on next page)

Table 1 Modified atmosphere technology used in different fruits and vegetables *(Continued)*

S. No.	Fruit	Conditions	Effects	Researcher
8	Strawberry	(1) Stored for 4 days at 2°C, followed by 2 days at 10°C and by 2 days at 18°C. (2) Polymeric films of polyvinyl chloride (PVC) and low-density polyethylene (LDPE) for MAP technique and perforated polypropylene (PP) as control were used. (3) 80% O_2:20% N_2; (B) 5% O_2:5% CO_2:90% N_2; (C) 20% O_2:80% N_2; and (D) in the absence of packaging.	(1) Highest fungal attacks (*Botrytis* spp) were found in PP treatment (41.8%), whereas strawberries stored in PVC and LDPE showed less than 7% damage. (2) In comparison with values at harvest, at the end of shelf life strawberries wrapped with LDPE were the only one that did not show differences in taste. (3) At the end of shelf-life, no significant differences in visual appearance and firmness between MAP treatments were detected. (4) As conclusion, LDPE was the best treatment for keeping strawberry quality and could be a good alternative to PVC, the only commercial treatment nowadays used in Spain for wrapping strawberries.	Artés-Hernández et al. (2010)

though some products can lose firmness (Aiamla-or et al., 2009; Aiamla-or et al., 2010). In this regard, acceptability by the products is very important as some vegetables can tolerate even an irradiation dose of 3.85 kGy (Foley et al., 2004). Apart from improvements in food safety through pathogen destruction, irradiation also provides other advantages. Some of these benefits comprise raising the shelf-life of fruits and vegetables, providing an appropriate substitute to chemical treatments, mainly for fruits and vegetables (Murano et al., 1998). Furthermore, it provides economic savings due to less food-borne illness frequency. Despite these added benefits, this technology is still in less use within the food industry (Thayer and Rajkowski, 1999).

High-Pressure Processing

A variety of methods can be utilized for food preservation in order to ensure food safety from microbial activities. Among them, high-pressure processing (HPP) is an incredibly promising method for food industries as a replacement for thermal processing. HHP can provide abundant opportunities for new product development having long shelf-life, high nutritional value, and exceptional organoleptic characteristics (Fonberg-Broczek et al., 2005; Perera et al., 2010). In HPP, products are subjected to high pressure in the range of 3000–8000 bars to inactivate microorganisms and enzymes without degrading flavors and nutrients. The microbial resistance to pressure varies significantly, and it depends upon the range of the applied pressure and temperature, treatment period, and type of microbe. The technology was first commercialized in Japan in the early 1990s for pasteurization of chilled low-acid foods (Hoogland et al., 2001).

The protocol for killing microorganisms is a combination of various reactions, disintegration of noncovalent bonds, and disruption of the permeability of the cell membranes. For instance, vegetative cells are deactivated at about 3000 bars at 25°C temperature, while spore inactivation needs more pressure (6000 bars). Some enzymes are also denatured at 3000 bars, while others are very difficult to decompose within the pressure range that is practically obtainable today (Butz et al., 2003). Moisture level is very important in this milieu, which should be below 40%. Various food products are subjected to HHP, such as jams, jellies, fruit dressings and sauces, toppings, yoghurt, and grapefruit, avocado and orange juice. In most cases, HHP minimizes losses of beneficial components in fruit and vegetable commodities (Hoogland et al., 2001). Little research has been done on the impact of HPP in relation to the nutritional and health-promoting attributes of food commodities, and most of it has paid attention on juices and purees of fruits such as oranges and tomatoes.

Table 2 O_2 limits below which and CO_2 partial pressures above which injury can occur for selected fruits and vegetables

S. No.	Produce	O_2%	CO_2 kPa
1	Most apples and pears	1.5	5
2	Asparagus, Brussels sprouts, cabbage, celery, nectarine, and peach (freestone)	1.0	10
3	Cubed or sliced cantaloupe	3.0	20
4	Blackberry, blueberry, fig, raspberry, and strawberry	2.5	25
5	Lemon, lime, and orange	5.0	10

Microwave and Ohmic Heating

For production of minimally processed fruit and vegetable products, one of the imperative technologies is the utilization of microwaves for attaining gently pasteurized fruit and vegetable products. In modern kitchens, this technology is well recognized and has become an essential tool, but on industrial scale, particularly in food industries, this technology is not utilized to a greater extent. There is a need to overcome numerous problems prior to having a successful industrial-scale system of microwaves in operation (Picouet et al., 2009).

Ohmic heating is a kind of electroheating technique that is accepted by the food industry as an innovation for processing of a wide variety of food products (Chaminda et al., 2005). Ohmic heating can also be termed as electrical resistance heating, and is a kind of heat treatment in which an electric current is passed through the food for attaining food sterilization and required cooking level. On the other hand, it can also be termed as resistant heating or direct resistance heating (Anderson, 2008). The current produces heat (Joule effect) in the food itself and transfers thermal energy for microbial inactivation. In certain areas of food processing (blanching, evaporation, dehydration, fermentation, and extraction), ohmic heating applications have a marvelous potential of avoiding microbial load and maintaining the quality characteristics of minimally processed fresh fruits and vegetables (Leizerson and Shimoni, 2005).

Ohmic heating is considered as a cost-effective treatment because its operational costs is found to be comparable to those for freezing and retorting treatments of low-acid products (Zoltai and Swearingen, 1996). Flow rate, temperature, heating rate, and holding time are certain factors that can affect the application of ohmic heating to industrial scale, and the size, shape, orientation, specific heat capacity, density, thermal and electrical conductivity, and specific heat capacity of the carrier medium are those factors that can influence heat transfer in the food (Ruan et al., 2001).

Emerging Technologies

Pulsed electric field (PEF) processing technology is a non-thermal method of food preservation that uses short bursts of electricity for microbial inactivation. It can be used for processing liquid and semi-liquid food products (Soliva-Fortuny et al., 2009). Electric treatment involves the application of high-voltage electric pulses (up to 70 kV/cm with 50–200 kJ/kg energy) to the food product, which is sited between two electrodes for a few microseconds (Toepfl et al., 2007). PEF, a promising preservation technology, conserves volatile flavor compounds and thermolabile nutrients as compared with conventional heat pasteurization (Jia et al., 1999). Likewise, the use of hybrid drying technologies appears to be a good future alternative (Chou and Chua, 2001). It employs radiofrequency waves to cater an environment for heat-sensitive food components (Zhao et al., 2000; Vega-Mercado et al., 2001). The principle motive behind the development of hybrid drying technologies is to minimize, as far as possible, product degradation and to produce a product with the desired moisture content. Hybrid drying technologies generally result in shorter drying time to achieve the desired product moisture content consequential in a favorable improvement in the energy required per unit of water removed. Freezing is among one of the known preservation techniques that lowers temperature to the point where the expansion of microorganisms is severely restricted and hinders microbial activity (Luh and Lorenzo, 1988). The three chief types of freezing processes used in fruit and vegetable processing are: (1) individual quick freezing, (2) freezing in the container, and (3) immersion in a freezing solution (Luh and York, 1988). Products are subject to freeze prior to packaging using fluidized-bed or air-blast freezers, both of which rely on the flow of chilled air. Products frozen in containers can be frozen using plate freezers, in which containers are sandwiched between two refrigerated plates, or air-blast freezers. In immersion freezers, packaged products are passed through a bath of refrigerant (typically propylene glycol, brine, glycerol, or calcium chloride) on a submerged mesh conveyor. Antifreeze proteins (AFPs) have the typical ability to manipulate ice growth by interacting directly with ice surfaces. For times, these proteins are consumed in the food industry and are known to contribute toward food quality and nutritional value. Likewise, UV treatment has been in practice to combat microbial growth and maintain quality during storage of fresh-cut products (Allende and Artes, 2003a; Allende et al., 2006). The use of UV light with a wavelength of 240 nm (UV-C) for surface disinfection of minimally processed fruits and vegetables has been proposed (Erkan et al, 2001; Allende and Artes, 2003b). Irradiation of food serves as one of the methods to preserve foods and to retain their keeping quality (Bintsis et al., 2000).

Hurdle Technology

The concept of minimal processing is mainly aimed at reducing the processing of foods without compromising on quality. A number of novel and emerging techniques are often in use to congregate some of these objectives. Among them, hurdle technology is an innovative concept for producing safe, stable, nutritious, tasty, and economical foods. It employs the intellectual blend of diverse preservation techniques for decontamination of fruits and vegetables. Hurdle technology can also be termed as combined processes, combined methods, combination preservation, combination techniques, or barrier technology (Montville, 1987; Lee, 2004). Hurdle technology is used in industrialized as well as in developing countries as a moderate but valuable preservation technique for food commodities. These outcomes are due to consumer anxiety for healthy and better food products retaining natural nutritional characteristics. Ready-to-eat and convenience foods necessitate little additional processing by consumers and consumer preference for more 'natural' food that requires less processing and fewer chemical preservatives (Lee, 2004). The most significant hurdles used in food preservation are temperature (high or low), water activity, acidity, redox potential, preservatives, and competitive microorganisms (Ohlsson and Bengtsson, 2002; Leistner, 2000).

In industrialized countries, at present, for minimally processed foods that have undergone mild heat or fermentation processes, the hurdle technology approach is of most interest (Leistner, 2000). In hurdle technology, microbes are subjected to a hostile environment for inhibiting their proliferation and growth or shortening their existence or causing their death. The practicable responses of microorganisms to this hostile environment are homeostasis, metabolic exhaustion, and stress reactions (Ohlsson and Bengtsson, 2002). The root for the implementation of advanced hurdle technology is the physiological behavior of microorganisms during preservation of various food commodities (i.e., their homeostasis, metabolic exhaustion, and stress reactions). The microorganisms' homeostasis interruption is the key phenomenon of food preservation (Gould, 1995). Microbial stress reactions may obscure food preservation, whereas the metabolic exhaustion of microorganisms during stable hurdle technology of foods could promote food preservation. Homeostasis is the continuous propensity of microorganisms to retain a stable and balanced (uniform) domestic environment. Food preservation is attained by upsetting the homeostasis of microorganisms, and this can be achieved by disturbing numerous homeostatic mechanisms intentionally (Leistner, 2000). Multitarget food preservation is an innovative and determined aspiration for the best-possible food preservation in which wisely applied gentle hurdles have synergistic and valuable effects. This multitargeted approach is the core of hurdle technology. It is more highly effective than single targeting techniques and allows hurdles of lower strengths to improve product quality (Barbosa-Cánovas et al., 1998).

CONCLUSION

The meticulousness of fresh-cut vegetables and fruits is persistently escalating owing to customer demand. A distinguishing attribute of the minimal processing trend is an integrated approach, where raw materials, washing, handling, processing, packaging, and delivery to consumers must all be properly considered to make shelf-life extension possible. New techniques for maintaining quality and inhibiting undesired microbial growth are demanded in all the steps of the production and distribution chain. However, the main steps throughout the processing chain of minimal processing fruits and vegetables are washing and disinfection. Much research is still needed to develop minimally processed fruit and vegetable products that have a high sensory quality, microbiological safety, and nutritional value.

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