Journal of Scientific & Industrial Research
Vol. 70, October 2011, pp. 823-834

Advances in minimal processing of fruits and vegetables: a review

Md Wasim Siddiqui[1*], Ivi Chakraborty[1], J F Ayala-Zavala[2] and R S Dhua[1]
[1]Department of Post Harvest Technology of Horticultural Crops, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur 741 252, India
[2]Centro de Investigación en Alimentación y Desarrollo, A.C. (CIAD, AC). Carretera a la Victoria Km 0.6, La Victoria. Hermosillo, Sonora 83000, Mexico

Received 04 January 2011; revised 08 August 2011; accepted 11 August 2011

This paper covers an exhaustive review on advances in minimal processing of fruits and vegetables. The review includes an exclusive discussion on production chain of minimally processed products from raw material selection to its consumption with different aspects including food safety issues. The intent is to provide a level of understanding that can be used to underpin future research directions in order to resolve existing issues that limit fresh-cut quality and shelf life.

Keywords: Fresh-cut fruits and vegetables, Minimal processing, Physiological activity, Preservation techniques

Introduction

Minimally processed (MP) fruits and vegetables are fresh fruits and vegetables processed to increase their functionality without greatly changing their fresh like properties. Fresh-cut produce industry has been on a double-digit growth rate in response to an increased demand by consumers, particularly in developed countries. Demand of MP fruits and vegetables has increased rapidly in Europe and USA, where demand is expected to represent 25% of the total food market in the near future[1]. In Spain[2] this market is showing an annual increase of sales of 20%, with 53,465 t sold in 2006. A major challenge facing the industry, however, is the rapid quality deterioration and reduced shelf-life of fresh-cut products compared with whole vegetables due to physiological disorders and decays[3]. Minimal processing (MPg) of fruits and vegetables is important to keep the product fresh but convenient without losing its nutritional quality and the product should have a shelf life sufficient to distribution feasible within the region of consumption[4]. Microbiological, sensory, and nutritional shelf life of MP fruits and vegetables should be at least 4-7 days but preferably even longer[5,6]. Production chain of MP or fresh-cut fruit and vegetables change fresh-like character of fresh-cut produce in a rather limited way[7]. The processes used for preparing fresh-cut fruits and vegetables induce mechanical injury in the tissue changing its physiology, accelerating deterioration during gestation period (transportation & retailing) and consequently shortening their shelf life. Cells of MP fruits and vegetables are often physiologically active, resulting in ongoing protective and/or deteriorative changes in cell structure and cell chemistry, as well as alteration in chemical composition of environment. MPg increases perishability rather than stability of fruits and vegetables[8]. Other types of deterioration include chemical and enzymatic changes, microbial deterioration and improper handling, processing and packaging[9]. Color and appearance are quality aspects for a product. Shelf life of MP fruits and vegetables is generally limited by changes in sensory properties than by microbial growth[3]. MP fruits and vegetables are preserved by different techniques[4].

This paper reviews advances in MPg of fruits and vegetables.

Minimal Processing (MPg)

MP products may be prepared at source of production or at regional and local processors. Preparation procedure generally includes processes such as washing, peeling, cutting, trimming, slicing, shredding, dicing and coring etc. Physiological age and cultivar type of raw material used for producing MP products can affect the quality and storage life. The first essential step in reducing overall contamination of raw material is by removing the outer leaf layer or surface dirt. Washing also helps to remove sugars and other nutrients at cut

*Author for correspondence
E-mail: wasim_serene@yahoo.com

surface of the produce, which favor microbial growth and discoloration. To prepare a ready to eat product, most of the fruits and vegetables are subjected to preliminary operations as MPg procedure (peeling and coring) to avoid inedible parts[8]. Peeling process depends on raw material types and influences quality of finished products. Peeling methods involved hand peelers or knives, which produce high quality products, but this method is not suitable for bulk production. Abrasion, steam, and lye peeling are common commercial methods. Abrasion peeling method using a carborundum disc and running water is generally used for peeling of potatoes and root vegetables. Other methods of peeling include freeze, lame, and vacuum peeling where acid, calcium chloride and ammonium salts amongst others, are used to peel various fruits and vegetables[8].

Some of the fruits and vegetables require further operations such as slicing, shredding or dicing, before packaging. Such fruits and vegetables become more susceptible to spoilage by releasing nutrient rich vascular and cellular fluids on disruption of protective epidermal layers[10]. A number of factors (final piece size, sharpness of cutting surface & mechanical aspects of cutting action and mechanical properties of product being cut) are responsible for the extent of injury to the product, influenced by slicing. Increasing wound area increases rate of deterioration; vertical as opposed to a horizontal cut also increased the rate. Slicing caused physical damage, physiological stress and enhanced microbial growth in peeled carrot. Sharpness of blade also has effect on injury to commodity such as blunt blade > Sharp machine blade > razor blade[11].

Physiological Responses and Bio-Chemical Changes of Minimally Processed (MP) Fruits and Vegetables

Fruits and vegetables are living, respiring, edible tissues that continue to be metabolically active even after harvest but in modified form. Physiology of MP fruits and vegetables is generally typical of that observed in plant tissues wounded or exposed to stress conditions[12]. Physiological process leads to deterioration, affected by intrinsic (climacteric and non-climacteric commodities) and extrinsic [temperature, ethylene, oxygen (O_2) and carbon dioxide (CO_2) concentrations] factors. Increased respiration rate causes major tissue disruption as enzymes and substrate become mixed with other cytoplasmic and nucleic substrates and enzyme. Despite respiration, fruits and vegetables demonstrate wound-induced ethylene production and increase surface area per unit volume, thus exacerbating water loss[13]. Temperature induced injury during low temperature storage and physical abrasions resulting from processing and packaging induce abusive atmosphere or desiccation, resulting in undesirable changes in product flavor, texture, and nutritional quality[13]. Shelf life of un-cut or fresh-cut produce is almost invariably dependent upon stress tolerance and stress induced senescence dynamics of raw commodity[14]. Other types of deterioration include chemical and enzymatic changes and microbial deterioration. Physical damage (improper harvesting, handling, processing and packaging) can also affect shelf life of MP fruits and vegetables[15,16].

Ethylene

MP fruits and vegetables produce large amount of ethylene, which results in shorter shelf life of the products. Ethylene accelerates ripening, softening, and senescence, which lead to membrane changes. Ethylene production is promoted by stresses (chilling injury and wounding) and this stress-induced ethylene can enhance fruit ripening, but may cause chlorophyll loss and yellowing of green stem and leafy vegetables[17] such as yellowing of harvested broccoli florets[18] at 5°C. It stimulates phenolic compounds in lettuce and increases activities of phenyl-alanine-ammonialyase (PAL), peroxidase (POD) and polyphenoloxidase (PPO). Crisp texture of cucumbers and peppers is lost upon exposure to ethylene[17]. Ethylene induced POD activity is correlated with increased lignin formation and cell wall thickening in lettuce.

Respiration

MP products have higher rate of respiration, which generally leads ageing of the products by using reserve energy during oxidative-reduction process. Higher the rate of respiration, shorter will be the shelf life. Peeling and slicing increase respiration rate up to 2-3 folds in baby carrot[19], and 2-fold in kiwi fruit. However, rate of respiration remained unaffected after peeling and slicing in ripe banana. Thus, effect of peeling and slicing on the rate of respiration and ethylene production differs between climacteric and non-climacteric fruit and with physiological age of climacteric fruit. Wound respiration in some plant tissues may be related to α-oxidation of fatty acids, CO_2 and responsible for increased respiration after slicing of potato[20].

Water Loss

Plant tissues must be in equilibrium with atmosphere, at the same temperature [relative humidity (RH), 99-

99.5%]. Fresh-cut products are highly susceptible to weight loss because internal tissues are exposed and lack skin or cuticle[21]. Water present in intercellular spaces of intact fruits and vegetables is not directly exposed to the outside atmosphere but in case of MP products due to severe operations (cutting & peeling), interior tissues are exposed and drastically increase water evaporation rate[11]. However, RH generally is very high in film bags or containers overwrapped with film, so dehydration typically is not a problem.

Oxidative Browning

Browning or discoloration of MP fruits and vegetables is one of the most important factors, which hinders acceptance and storage life of commodity. This occurs at the surface of fruits and vegetables because of disruption of compartmentation that occurs when cells are broken, allowing substrates, and oxidase enzymes to come in contact with each other[11]. Wounding also induces synthesis of some enzymes involved in browning reaction or synthesis of their substrates. PAL is a key enzyme for synthesizing phenolic compounds, which can then be oxidized by PPO, producing brown polymers that can contribute to tissue browning of commodities (lettuce)[22]. PPO oxidizes flavonoids and chlorogenic acid to brown compound[23].

Microbiology of Minimally Processed (MP) Fruits and Vegetables

Increase in microbial populations on MP products is associated to damaged tissues and broken cells, as microbial growth is greater on fresh-cut products than intact product[24-26]. Cell disruption leads to release and intermixing of enzymes and substrates that may be used by native or exogenous microorganisms to grow on the product. Heat treatments, however, minimal, as well as peeling, trimming, topping, pitting, slicing and bruising destroy protective membranes and barriers of living plants, permitting entry and contamination with microbial pathogens. The chances of food borne illness due to pathogens or spoilage organisms growing in these products are very high[27]. Yeast growth might be a limiting factor of shelf life for fresh-cut celery, mushroom slices, and chicory endive[28]. Yeast growth was not inhibited by 0.8 kPa O_2, or a combination of 0.8 kPa O_2 and 10 kPa CO_2 treatment or a super atmospheric O_2 (95 kPa) treatment[29] of mixed salad. Growth of microorganisms is facilitated by plant cell injury, senescence, or stress. Stressed and senescent tissues have leaky membranes, which allow diffusion of small molecular weight compounds and water into intercellular spaces and wound surfaces. Thermal processing and endogenous enzymes from damaged cells may change proteins and carbohydrates into compounds more readily usable by microorganisms and may destroy natural micro flora on the food, which competes with pathogenic microbes for nutrients[30].

Hazard analysis and critical control points (HACCP), an effective and rational means of assuring food safety, can be applied throughout the food chain from primary production to final consumption[31]. HACCP was first introduced in European Directive 93/43/CE (1993). HACCP technique has progressively been recognized as a cost-effective procedure for ensuring food safety[32]. It can be considered as efficient tool for both food industry and health authorities to prevent food borne diseases. HACCP identifies potential avenues of contamination; establishes control measures to eliminate or minimize these hazards; and monitors and documents effectiveness of the program. HACCP provides a more specific and critical approach to the control of hazards than achievable by traditional inspection and quality control procedures[33]. With consumption of fresh-cut fruits and vegetables in USA, Food and Drug Administration (FDA)[34] set out clear guideline to minimize microbial food safety hazards for fresh fruits and vegetables. These guideline span from "farm to fork" and include good agricultural practices (GAP), good manufacturing practices (GMP) and HACCP.

Treatments for Quality Maintenance of MP Fruits and Vegetables

Different treatments, used to control undesirable changes, are physiological and physical changes that adversely affect the quality of MP products[4]. MP fruits and vegetables are preserved by refrigeration, chemical preservatives, additives, bio-preservatives, mild heat treatments, microwave processing, reduction of water activity, ionizing irradiation, disinfectants [electrolyzed water treatment, chlorination, hydrogen peroxide (H_2O_2)], high hydrolytic pressure technology, high intensity pulsed electric field, pulsed light, ozone technology, mano-thermosonification, oscillating magnetic field, ohmic heating, vacuum/hypobaric packaging and hurdle technology[24,25]. Edible coatings (multilayer coating, osmotic membrane coating) are also being used in MPg of fruits and vegetables[35]. Hot air and water treatment, electrolyzed oxidizing water (EOW) refrigeration, humidity control and dipping in different chemical solutions (ascorbic acid and calcium salts) have been used successfully to maintain quality and to extend shelf life of MP products.

Sanitizers

Different decontaminants[36-40] (chlorinated water, sulphites, sodium hypochlorite, neutral EOW and peroxiacetic acid) are used in MP products to enhance their shelf life and for giving good appearance. In general, fresh-cut fruits should be rinsed just after cutting with cold (0-1°C), chlorinated water at pH 7.0. Chlorination (not more than 200 ppm total chlorine) may not be desirable for all fresh-cut fruits[41]. Treatment with neutral EOW containing free chlorine (5 & 30 mg/l) reduces respiration of cabbage and leek respectively. Neutral EOW with different free chlorine concentrations (12, 60 and 120 mg/l) reduces respiration rate of fresh-cut iceberg lettuce[42]. Peroxiacetic acid has influence on respiration rate of vegetables[43] (carrot, fresh-cut white cabbage, green bell pepper). MP grapes treated with ethanol show reduced cell load of spoilage organisms. Other natural compounds of plant origin like aroma compounds are used to control decay of MP fruits and vegetables[44], particularly when packed in modified atmosphere packaging (MAP)[45,46]. Dipping of whole vegetables in 5 or 10% H_2O_2 for 2 min, prior to slicing, is highly effective in delaying soft rot. H_2O_2 treated products have no adverse effect on aroma, flavor, and appearance. Other chemicals as sanitizers for use in fresh-cut produce include chlorine dioxide (ClO_2), bromine, and iodine compounds, and ozone[47].

To reduce microbial loads on fruit surface, hot water immersion treatments[48] are used to reduce browning development in fresh-cut tissue of fruits and vegetables (lettuce, apples, pear)[49]. Fresh-cut peach fruit treated at 40°C for 70 min and 50°C for 10 min effectively control browning and retains firmness during storage[50]. Temperatures (≥45°C) for shorter period have been effectively proposed to reduce browning in fresh-cut products (lettuce, celery and Chinese water chestnut)[45]. Heat treatment is also effective in reducing respiration and ethylene production[44], and also helps in retaining firmness of fresh-cut slices of muskmelon, apple, pear, peach and mango[48,50]. Heat treatments with UV-C radiation have been used in different MP fruits and vegetables like mango[51], cantaloupe[52], onion[53], garlic[54], leek[55], celery[56] and broccoli[57]. Heat treatment may reduce activities of enzymes that are normally increased during ripening, senescence or storage. The use of heat treatments as hot water or hot air can be successfully utilized to delay degreening of broccoli[57].

Food irradiation has the potential to preserve fruits and vegetables for longer period of time almost in their fresh like state[58,59]. Combined use of MAP and UV-C radiation reduced psychrotrophic and coliform bacteria and yeast growth in MP 'Red Oak Leaf' lettuce without adversely affecting its sensory quality[60]. UV-C inhibited microbial growth, retarding decay, and delaying senescence of mango[51], zucchini squash[61], strawberries[62] and watermelon[63]. However, UV-C can change cell permeability in leafy vegetables, increasing leakage of electrolytes, amino acids and carbohydrates, which can stimulate bacterial growth and lead to shortened shelf life of MP products[64]. Current FDA limit for irradiation on fresh produce is 1.0 kGy, but to destroy yeast and molds spores, required irradiation levels (1.5-20 kGy) are damaging plant tissues. UV-C have been utilized to extend post harvest life of fresh processed lettuce[60] and pomegranate[65]. Combination of heat treatment and UV-C has been applied in strawberries[66] and processed broccoli florets[57,67]. Irradiation reduces respiration as well as ethylene production of produce. It can also delay chlorophyll degradation and retention of reducing sugar in broccoli florets[57]. UV-C doses (0.5-20 kJ /m) inhibit microbial growth by inducing formation of pyrimidine dimmers that distort DNA helix and block microbial cell replication. Cells unable to repair their radiation-damaged DNA die. However, UV induces enzymatic photo repair and expression of excision repair genes that may restore DNA integrity in exposed microbial cells. Effectiveness of UV-C seems to be independent of temperature (5-37°C), but depends on the incident irradiation determined by the structure and surface topography of treated product[68]. Low to moderate UV-C radiation can be an effective alternative to chlorine for sanitizing MP spinach leaves and preserving their quality[64].

Antimicrobial compounds may be added to fresh-cut fruits and vegetables to inhibit deleterious microorganisms and several natural volatile compounds have been reported to possess antimicrobial activity[69]. Methyl jasmonate (MJ) either as a vapor or as an emulsion reduce microbial contamination of fresh-cut celery and peppers suppress green mould growth on grapefruit[69] and inhibit grey mould infection on strawberries alone or as a co-fumigant with ethanol[70]. Ethanol has antimicrobial properties, and postharvest ethanol dips eliminate most of the fungal and bacterial populations on surface of grapes without impairing bunch appearance or berry firmness[71]. Garlic oil has shown bacteriostatic properties against growth of several bacterias:[65]. Although antimicrobial activity of garlic oil represents a promising research area, its use as natural food preservative is not common practice yet[4]. Different natural antimicrobial agents, present in food that could be blended with foods or incorporate into MAP packaging systems are[72,73] benzoic acid (cranberries, prunes, cinnamon, cloves), organic acids (acetic, lactic, citric, malic, tartaric, propionic, fumaric), nisin/bacteriocins (produced by lactic acid bacteria), allyl-isothiocynate (mustard, radish, rape seed), allicin: diallylthiosulphinic acid (garlic, onion), lysozyme: lytic enzyme (plant tissues), ethyl alcohol and CO_2.

Antioxidants

Antioxidants [acids (citric acid, ascorbic acid, ascorbyl palmitate, sorbic acid, benzoic acid)[74] and salts (potassium sorbate, sodium benzoate)] can inhibit or interfere with free radical formation. Dipping of fresh-cut apples, Chinese cabbage, endive, lettuce, melon and pears in solution of ascorbate, erythorbic acid and citric acid reduce enzymatic browning[75,76]. Acidification can be used to preserve tomato, snap bean and pea etc. Ascorbic acid, H_2O_2, edible coatings and MAP, together with low temperature storage are used to inhibit enzymatic browning and increase shelf life of fresh-cut fruits and vegetables[77]. Li-Qin[77] concluded that treatment with ascorbic acid (0.2%) and nitric oxide (5 µM) inhibit browning of fresh-cut peach by protecting cell microstructure and inhibiting PPO and POD activity with nitric oxide the most effective treatment.

Firmness Retainers

Undesirable textural changes in MP products can be reduced by implying Ca salts (Ca chloride, Ca carbonate, Ca lactate, Ca propionate, Ca pectate etc.) because softening rate is related to calcium level in fruit tissues[78,79]. Application of Ca salts to pears, strawberries, kiwifruits, shredded carrot, honeydew disc, nectarines, peaches and melon help to retain tissue firmness[52,80,81]. Calcium rigidifies cell wall structure in middle lamella by forming Ca pectate, which retards polygalacturonase activity and preserves structural and functional integrity of membrane systems. Exogenous treatments with calcium chloride ($CaCl_2$) dip can reduce browning and flesh softening of zucchini squash slices[82]. However, $CaCl_2$ may also cause detectable off-flavor when used at higher levels (>0.5%). Hernandez-Munoz[83] observed that addition of calcium gluconate to chitosan (1%) coating formulation increase firmness of strawberries during refrigerated storage.

Use of 1-Methylecyclopropene (1-MCP), an ethylene action inhibitor[84] and Aminoethoxyvinylglycine (AVG), an ethylene synthesis inhibitor[85] may extend shelf life of MP products. 1-MCP is currently formulated as SmartFresh™, a 0.14% powder for post harvest use in fruit and vegetables. AVG is formulated as ReTain®, containing 15% (w/w) AVG. Removal of ethylene from storage environment of MP fruits and vegetables can retard tissue softening[86]. 1-MCP acts best at concentrations of 0.5 nl/l and effect is prolonged. Its effect on fruits and vegetables include inhibiting ripening of tomatoes[87], peach[88], watermelon[89], papaya[90], delaying senescence in strawberries[91], broccoli[92], inhibiting yellowing of cut lettuce[93], extending firmness and shelf life of MP apples[94,95], papaya[96], peach[97], pear[98] and degreening of oranges[99]. 1-MCP sensitivity of ripening tomato fruit was transiently negated or enhanced in response to short-term increases or decreases, respectively, in internal ethylene levels[100]. Sorption of 1-MCP to targets other than ethylene receptors might influence 1-MCP responsiveness. Sorption of 1-MCP at quantities in excess of those expected based on estimated levels of ethylene receptors has been demonstrated for avocado fruit and oil[101] and a diverse range of fruits and vegetables[102-104]. AVG inhibits ethylene synthesis by blocking conversion of methionine to 1-aminocyclopropane-1-carboxylic acid (ACC), precursor of ethylene[85]. AVG significantly suppresses ethylene production and reduces softening by retarding ripening of peaches[105-107] and nectarines[108].

Edible coatings have been formulated to prolong shelf life and maintain quality of MP fruits and vegetables by preventing changes in aroma, taste, texture, and appearance[109]. These coatings are generally made from one or more of four major types of materials [lipids, resins, polysaccharides (cellulose, pectin, starch, alginates, chitosan, gums, carrageenam etc.[93]) and proteins[110]]. Various edible films have been practiced in fruits and vegetables such as whey protein coatings for apple[111], potato starch based edible coating on guava[112], hydroxypropyl methylcellulose-lipid (HML) edible composite coatings on plum[113], whey protein and HML edible composite coatings on fresh-cut apples[114] and wheat gluten-based films and coatings on refrigerated strawberries[115]. Incorporation of ascorbic acid and potassium sorbate (as antimicrobial) is more beneficial than only coating in cut-apple and potato. Edible coating also reduces white blush on peeled carrots by increasing water vapor resistance[116]. Edible coating of MP (peeled) grapefruit segment with calcium alginate enhances firmness and control leakage of segment and it improves crispiness of lettuce[93].

Presently, fruit and vegetable purees (peach, strawberry, apricot, apple, pear, mango, carrot and broccoli) have been used as alternative components of edible coatings[117,118]. These films have good barrier quality against gas diffusion, but are poor barriers to water vapor diffusion under certain temperature and RH conditions by creating modified atmosphere. Most of the fruits (mango) contain high levels of carbohydrate, protein, and fat, which are the main components for edible films[119]. Apple and mango film might therefore be an alternative natural wrapping for maintaining shelf life and quality of MP or fresh-cut apple and mango[118].

Effect of Storage Conditions on Quality of Fresh-Cut Produce

Cold Storage

In post harvest life of fruits and vegetables, temperature affects respiration & transpiration rates, and also biological & biochemical reactions[7,120]. A decrease of 10°C usually decreases respiration rate by a factor of 2 to 3. Exposure to cold temperature following harvest in order to minimize and/or inhibit effects of wounding stress is recognized as one of the principal factors controlling quality of fresh-cut leafy vegetables[121]. Guidelines for Handling Chilled Foods[122] recommend a storage temperature (0-8°C) for salad vegetables depending on their susceptibility to chilling injury. MP products should be refrigerated (0-5°C) to prolong their quality and safety[7]. Although 0°C is usually desirable temperature for most fresh-cut products, in reality, many of them are shipped and marketed at 5-10°C. Duration of cold storage also has an impact on final product quality (overall sensory quality decline and microbial load increase)[80]. Chilling injury of fresh-cut products can manifest diverse symptoms. Sliced tomato shows mealiness[123] and fresh-cut pieces of jicama root exhibits surface browning[124]. Other symptoms include reduction in firmness, increased rate of electrolytic leakage, changes in texture, increase in soluble solid contents, internal browning, surface lesions, skin darkening, water soaked patches, bleaching, increase in ethylene and CO_2 production[125]. Most of the chilling injury symptoms result due to lipid membrane phase separations weakened hydrophobic bonding, affecting protein-protein and protein-lipid interactions, and effects on cell signaling processes[126,127]. Baby spinach leaves have a very high respiration rate and its post-harvest quality are tissue decay and off-odours development. To improve quality, cold storage of fresh-cut baby spinach leaves below 5°C under a reduced O_2 partial pressure combined with moderated CO_2 within packages should be conducted[128].

Modified Atmosphere Packaging (MAP)

MAP reduces unwanted metabolic reactions (respiration, water loss) and protects commodities against contamination by microorganisms, thus slowing down the process of physiological ageing[20]. MAP also inhibits biosynthesis and action of ripening hormone ethylene, slows down various compositional changes associated with ripening (softening, browning, decay etc.), and protects color of green vegetables. It also avoids incidence of chilling injury[7]. The most common atmosphere consists of reduced O_2 and elevated CO_2 levels; however, some other gases (carbon monoxide, ethylene, propylene, and acetylene) are sometimes included. Gas level within a package ranges: O_2, 3-5; and CO_2, 3-10%. Effect of low O_2 and elevated CO_2 are additive, but concentration of gases differ with variety, origin and season. CO_2 (>1%) causes brown strain in Crisphead lettuce and CO_2 (>15%) induce off-flavors in several fruits. On the other hand, extremely reduced O_2 concentration (2%) induces anaerobic respiration and off-odors take place[129]. Besides O_2 and CO_2, nitrogen (N_2) can also be used in MAP. N_2 exhibits little or no antimicrobial activity. N_2 is not soluble in water and prevents package collapse when combined with large concentrations of CO_2. N_2 is often utilized to displace oxygen in MAP, delaying oxidative browning and inhibiting aerobic microorganisms[130]. Quality deterioration of packaged MP products may take place due to improper film selection or flushing protocols, variation in respiration from different cultivars or varieties, seasonal variation and storage duration of products prior to fresh-cut processing[46,127]. This practice, however, raises a food safety concern that human pathogenic bacteria may transfer through the perforations and result in post-processing contamination of the produce.

Treatment of super atmospheric O_2 is an effective means for both inhibiting microbial growth and enzymatic discoloration and preventing anaerobic fermentation reactions[131]. Improved effect of super atmospheric O_2, when combined with increased CO_2 concentrations on fresh-cut vegetables, has been demonstrated[132]. Yet, negative impact of super atmospheric O_2 on postharvest physiology and product quality is also reported. Super atmospheric O_2 concentration in packaging has been found to be particularly effective at inhibiting enzymatic discoloration, preventing anaerobic respiration, off-flavor production, and moisture loss and reducing microbial growth[131-134]. On the other hand, high O_2 combined with high CO_2 in package found effective up to some certain limits[133-135]. High level of O_2 reduces adverse effects of elevated CO_2 concentrations, allowing them to be used to regulate decay in lettuce[135] and grapefruit[133]. Under controlled storage conditions, use of high O_2 gas mixture[136] (O_2, 80-85% + CO_2, 15-20%) enhanced sensory quality and antimicrobial benefits for a wide range of fresh-cut fruits and vegetables. High O_2 combined with high CO_2 has positive effects on color due to inhibition of enzymatic discoloration[133-138]. Improved quality in super atmospheric O_2 treatment suggests that inclusion of super atmospheric O_2 in bags helped to maintain quality under extremely high CO_2 conditions. Antimicrobial activity of CO_2 at high concentration has been well established[139]. Jacxsens *et al*[139] found no difference in aerobic psychrotrophic growth in chicory endives between conventional (3 kPa O_2 and 5 kPa CO_2) and super atmospheric O_2 (95 kPa O_2 and 5 kPa N_2) MAP, yet a significant growth reduction in packaged celery under the same super atmospheric O_2 MAP condition. Super atmospheric O_2 treatments are also advantageous to perforated packages in reducing aerobic mesophilic growth and eliminating the possibility of post-processing contamination[139].

MAP essentially maintains quality of fresh-cut fruits and vegetables by matching oxygen transmission rate (OTR) of packaging film to respiration rate of packaged products; O_2 and CO_2 levels within the package can also changes as a function of area of the film as well as ambient temperature[28]. To devise suitable MAP systems for particular commodities, it is necessary to tailor the permeability of the film to package design (pillow pack or rigid tray over wrap) and to the rate of tissue respiration[140]. Shelf-life of shredded lettuce can be doubled with MAP (1-3% O_2 and 5-6% CO_2) at 4°C using 35 µm low density polyethylene[141]. Some alternative non-conventional gas mixtures for active MAP of fresh-cut products, like high O_2 levels and N_2O or noble gases, might be favorable for keeping quality[142]. High O_2 extends shelf life of fresh-cut vegetables by inhibiting enzymatic discoloration, preventing anaerobic fermentation, and reducing aerobic and anaerobic microbial growth[143]. O_2 levels (> 70 kPa) have been recommended for MAP of fresh-cut vegetables to preserve sensory and microbial quality[139]. N_2O that has 77% solubility in fruit cell, although its absorption in tissues is completely reversible has a direct effect by extending shelf life of MP products[144]. In this way, apple[143] and kiwifruit[144] slices maintained their fresh quality for up to 12 days at 4°C when packed under MAP with decreased O_2 and increased CO_2 levels (both at 5.07 kPa), balanced with N_2O.

Moderate Vacuum Packaging (MVP)

One interesting MAP method is moderate vacuum packaging (MVP)[145], where respiring produce is packed in a rigid airtight container (atmospheric pressure, < 40 kPa; temp., 4-7°C). Initial gas composition is that of normal composition of air (21% O_2, 0.04% CO_2 and 78% N_2) but at a reduced partial gas pressure. Lower oxygen content stabilizes produce quality by slowing down the metabolism of produce and the growth of spoilage microorganisms. Gorris *et al*[145] found that MVP improved microbial quality of red pepper, chicory endive, sliced apple and sliced tomato, the sensory quality of apricot and cucumber and the microbial and sensory quality of mung bean sprout and a mixture of cut vegetables.

Equilibrium Modified Atmospheric Packaging (EMAP)

Equilibrium modified atmospheric packaging (EMAP) is another effective method of packaging fresh-cut fruits and vegetables and used to prolong shelf life of products. An EMAP is established inside the package, when O_2 transmission rate of packaging film is matched to O_2 consumption rate of packaged commodity[3,134]. In addition to classic parameters (temperature and O_2 level), other factors (degree of processing including decontamination) and time between processing and packaging must also be taken into consideration to establish an optimal EMAP for particular fresh-cut commodities.

Active or Smart Packaging

Active packaging is a type of packaging that changes the condition of packaging to extend shelf life or improve safety or sensory properties while maintaining quality of food[72]. Cameron *et al*[146] introduced concept of sense-and-response technology, wherein some components of package would sense a signal such as an increase in temperature and initiate a marked increase in permeability to compensate for perceived change signal[147]. Some tissues produce ethanol on fermentation when lower O_2 limit is surpassed, a truly smart package will continuously monitor ethanol and adjust O_2

permeability. This level of control may never be applicable for small consumer package due to economic considerations. However, smart packaging techniques may be appropriate for longer containers used for shipments by truck, ship, or air. To control undesirable microorganisms on foods, antimicrobial substances can be incorporated in or coated onto food packaging materials[148]. Principle action of antimicrobial films is based on the release of antimicrobial entities, some of which could pose a safety risk to consumers if release is not tightly controlled within packaging material[149].

Conclusions

The demand for fresh-like MP fruits and vegetables have increased; mainly due to consumer's concerns about health and convenience particularly during last decade[150,151]. A characteristic feature of MPg is the need for an integrated approach, where raw material, handling, processing, packaging, and distribution must each be properly managed to achieve extended shelf life of the produce. Siddiqui *et al*[152] recommended that 6-Benzylaminopurine (10 ppm) could be a useful method to improve shelf life, organoleptic quality, and health promoting compounds of fresh-cut broccoli florets during storage at 6±1°C at commercial level. Much research is still to be done to develop MP fruits and vegetables products with high acceptability, high sensory quality, microbiological safety and nutritional value. Strict temperature control of MP produce is of eminent importance. More information on growth of pathogenic bacteria or nutritional changes in MP fruits and vegetables with longer shelf life is needed. It is probable that in future, fruits and vegetables intended for MPg will be cultivated under specified controlled conditions and that plant genetics will develop selected and created cultivars or hybrids adapted to specific requirements of MPg[142]. New packaging systems, particularly active packaging and edible films, as well as more permeable plastic films, which better match with the respiration of fruits and vegetables, are active areas for development. Regulatory issues associated with novel processing technologies, and safety assessment of process-specific effects needs to be carried out.

References

1 Valverde M T, Marín-Iniesta F & Calvo L, Inactivation of *Saccharomyces cerevisiae* in conference pear with high pressure carbon dioxide and effects on pear quality, *J Food Eng*, **98** (2010) 421-428.

2 Abadias M, Usall J, Anguera M, Solsona C & Viñas I, Microbiological quality of fresh, minimally-processed fruit and vegetables, and sprouts from retail establishments, *Int J Food Microbiol*, **123** (2008) 121-129.

3 Jacxsens L, Devlieghere F & Debevere J, Temperature dependence of shelf-life as affected by microbial proliferation and sensory quality of equilibrium modified atmosphere packaged fresh produce, *Postharvest Biol Technol*, **26** (2002) 59-73.

4 González-Aguilar G A, Ayala-Zavala J F, Olivas G I, de la Rosa L A & Álvarez-Parrilla E, Preserving quality of fresh-cut products using safe technologies, *J Verb Lebensmitt*, **5** (2010) 65-72.

5 Ahvenainen R, Ready-to-use fruits and vegetables, in *Flair-Flow Europe Technical Manual*, 2000.

6 Burns J L, Lightly processed fruits and vegetables: introduction to the colloquium, *HortScience*, **30** (1995) 14-17.

7 Rivera-López J, Vázquez-Ortiz F A, Ayala-Zavala J F, Sotelo-Mundo R R & González-Aguilar G A, Cutting shape and storage temperature affect overall quality of fresh-cut papaya cv 'maradol'**,** *J Food Sci*, **70** (2005) 482-489.

8 Watada A E, Ko N P & Minott D A, Factors affecting quality of fresh-cut horticultural products, *Postharvest Biol Technol*, **9** (1996) 115-125.

9 Barry-Ryan C & O'Berine C, Effect of peeling method on the quality of ready-to-use carrots, *Int J Food Sci Technol*, **35** (2000) 1-11.

10 Adams M R, Hartley A D & Cox L J, Factors affecting the efficacy of washing procedures used in the production of prepared salads, *Food Microbiol*, **6** (1989) 69-77.

11 Barry-Ryan C & O'Beirne D, Quality and shelf-life of fresh-cut carrot slices as affected by slicing method, *J Food Sci*, **63** (1998), 851-856.

12 Brecht J, Physiology of lightly processed fruits and vegetables, *HortScience*, **30** (1995) 18-22.

13 Gonzalez-Aguilar G A, Villa-Rodriguez J A, Ayala-Zavala J F & Yahia E M, Improvement of the antioxidant status of tropical fruits as a secondary response to some postharvest treatments, *Trends Food Sci Technol*, **21** (2010) 475-482.

14 Toivonen, P.M.A. Effects of storage conditions and postharvest procedures on oxidative stress in fruits and vegetables, in *Postharvest Oxidative Stress in Horticultural Crops*, edited by Hodges, D.M (The Haworth Pres Inc., Binghamton, New York) 2003, 69-90.

15 Lester, G.E. Oxidative stress affecting fruit senescence in fruits and vegetables, in *Postharvest Oxidative Stress in Horticultural Crops*, edited by Hodges, D.M (The Haworth Pres Inc., Binghamton, New York) 2003, 113-123.

16 Thybo A K, Christinansen J, Kaack K & Petersen M A, Effect of cultivars, wound healing and storage on sensory quality and chemical components in pre-peeled potatoes, *LWT Food Sci Technol*, **39** (2006) 166-176.

17 Saltveit M, Effect of ethylene on quality of fresh fruits and vegetables, *Postharvest Biol Technol*, **15** (1999) 279-292.

18 Tian M S, Downs C G, Lill RE & King G A, A role for ethylene in the yellowing of 'broccoli after harvest, *J Am Soc Hort Sci*, **119** (1994) 276-281.

19 Simõ A D N, Allende A, Tudela J A, Puschmann R & Gil, M I, Optimum controlled atmospheres minimise respiration rate and quality losses while increase phenolics compounds of baby carrots, *LWT Food Sci Technol*, **44** (2011) 277-283.

20 Gunes G & Lee C Y, Color of minimally processed potatoes as affected by modified atmosphere packaging and anti browning agents, *J Food Sci*, **62** (1997) 572-575.

21 Ayala-Zavala J F, Del-Toro-Sánchez L, Alvarez-Parrilla E & González-Aguilar G A, High relative humidity in-package of fresh-cut fruits and vegetables: Advantage or disadvantage considering microbiological problems and antimicrobial delivering systems? *J Food Sci*, **73** (2008) 41-47.

22 Barry-Ryan C & O'Beirne D, Quality and shelf-life of fresh-cut carrot slices as affected by slicing method, *J Food Sci*, **63** (1998) 851-856.

23 Fan X & Mattheis J P, Reduction of ethylene-induced physiological disorders of carrots and iceberg lettuce by 1-methylcyclopropene, *HortScience*, **35** (2000) 1312-1314.

24 Ayala-Zavala J F, Rosas-Domínguez C, Vega-Vega V & González-Aguilar G A, Antioxidant enrichment and antimicrobial protection of fresh-cut fruits using their own byproducts: Looking for integral exploitation**,** *J Food Sci*, **75** (2010) 175-181.

25 Ayala-Zavala J F & González-Aguilar G A, Optimizing the use of garlic oil as antimicrobial agent on fresh-cut tomato through a controlled release system, *J Food Sci*, **75** (2010) 398-405.

26 Toivonen P M A & DeEll J R, Physiology of fresh-cut fruits and vegetables, in *Fresh-cut Fruits and Vegetables: Science, Technology and Market*, edited by Lamikanra (CRC Press, Boca Raton) 2002, 91-123.

27 Manvell P M & Ackland M R, Rapid detection of microbial growth in vegetable salad at chill and abuse temperatures, *Food Microbiol*, **3** (1986) 59-65.

28 Al-Ati T & Hotchkiss J H, The role of packaging film permselectivity in modified atmosphere packaging, *J Agric Food Chem*, **51** (2003) 4133-4138.

29 Kader A A & Ben-Yehoshua S, Effect of superatmospheric oxygen levels on postharvest physiology and quality of fresh fruits and vegetables, *Postharvest Biol Technol*, **20** (2000) 1-13.

30 King A D & Bolin H R, Physiological and microbiological storage stability of minimal processed fruit and vegetables, *Food Technol*, **43** (1989) 132-135.

31 Bertolini M, Rizzi A & Bevilacqua M, An alternative approach to HACCP system implementation, *J Food Eng*, **79** (2007) 1322-1328.

32 Vela A R & Fernandez J M, Barriers for the development and implementation of HACCP plans: Results from a Spanish regional survey, *Food Control*, **14** (2003) 333-337.

33 Martin-Belloso O, Soliva- Fortuny R & Osm-Oliu G, Fresh-cut fruits in *Handbook of Fruits and Fruit Processing*, edited by Y H Hui (Blackwell Publishing, USA) 2006, 129-144.

34 Odumeru J A, Noulter J, Knight K, Lu X & McKellar R, Assessing of a thermal-chemical process to extend the shelf life of ready-to-use lettuce, *J Food Qual*, **26** (2002) 197-209.

35 González-Aguilar G A, Valenzuela-Soto E, Lizardi-Mendoza J, Goycoolea F, Martínez-Téllez M A, Villegas-Ochoa M A, Monroy-García I N & Ayala-Zavala J F, Effect of chitosan coating in preventing deterioration and preserving the quality of fresh-cut papaya 'Maradol', *J Sci Food Agric*, **89** (2009) 15-23.

36 Gomez-Lopez V M, Devlieghere F, Ragaert P & Debevere J, Shelf-life extension of minimally processed carrots of chlorine dioxide gas, *Int J Food Microbiol*, **116** (2007) 221-227.

37 Nascimento M S, Silva N, Catanozi M P & Silva K C, Effects of different disinfection treatments on the natural microbial of lettuce, *J Food Prot*, **9** (2003) 1697-1700.

38 Nieuwenhuijsen M J, Toledano M B & Elliott P, Uptake of chlorination disinfection by-products: a review and a discussion of its implications for exposure assessment in epidemiological studies, *J Expo Anal Environ Epidemiol*, **10** (2000) 586-599.

39 Pesis E, The role of the anaerobic metabolites, acetaldehyde and ethanol, in fruit ripening, enhancement of fruit quality and fruit deterioration, *Postharvest Biol Technol*, **37** (2005) 1-9.

40 Martínez-Téllez M A, Rodríguez-Leyva F J, Espinoza-Medina I E, Vargas-Arispuro I, Gardea A A *et al*, Sanitation of fresh green asparagus and green onions inoculated with Salmonella, *Czech J Food Sci*, **27** (2009) 454-462.

41 Hurst W C, Sanitation of lightly processed fruits and vegetables, *HortScience*, **31** (1995) 22-24.

42 Rico D, Martin-Diana A B, Barry-Ryan C, Frias J M, Henehan G T M *et al*, Use of neutral electrolysed water (EW) for quality maintenance and shelf-life extension of minimally processed lettuce, *Innovat Food Sci Emerg Technol*, **9** (2009) 37-48.

43 Du J, Fu M, Li M & Xia W, Effects of chlorine dioxide gas on postharvest physiology and storage quality of green bell pepper (*Capsicum frutescens* L. var. Longrum), *Agric Sci China*, **6** (2007) 214-219.

44 Tripathi P & Dubey N K, Exploitation of natural products as an alternative strategy to control postharvest fungal rotting of fruit and vegetables: A review, *Postharvest Biol Technol*, **32** (2004) 235-245.

45 Valero D, Valverde J M, Martinez-Romero D, Guillen Castillo S & Serrano M, The combination of modified atmosphere packaging with eugenol or thymol to maintain quality, safely and functional properties of table grapes, *Postharvest Biol Technol*, **41** (2006) 317-327.

46 Xiao C, Zhu L, Luo W, Song X & Deng Y, Combined action of pure oxygen pretreatment and chitosan coating incorporated with rosemary extracts on the quality of fresh-cut pears, *Food Chem*, **121** (2010) 1003-1009.

47 Beuchat L R, Use of sanitizers in raw fruit and vegetable processing, in *Minimally Processed Fruits and Vegetables*, edited by S M Alzamora *et al* (Aspen, Gaithersburg) 2000, 63-78.

48 Dea S, Brecht J K M, Nunes M C N & Baldwin E A, Quality of fresh-cut 'Kent' mango slices prepared from hot water or non-hot water-treated fruit, *Postharvest Biol Technol*, **56** (2010) 171-180.

49 Campos-Vargas R, Nonogaki H, Suslow T & Saltveit M E, Heat shock treatments delay the increase in wound-induced phenylalanine ammonialyase activity by altering its expression, not its induction in Romaine lettuce (*Lactuca sativa*) tissue, *Physiol Plant*, **23** (2005) 82-91.

50 Koukounaras A, Diamantidis G & Sfakiotakis E, The effect of heat treatment on quality retentiion of fresh-cut peach, *Postharvest Biol Technol*, **48** (2008) 30-36.

51 González-Aguilar G A, Villegas-Ochoa M A, Martínez-Téllez M A, Gardea A A & Ayala-Zavala J F, Improving antioxidant capacity of fresh-cut mangoes treated with UV-C, *J Food Sci*, **72** (2007) 197-202.

52 Luna-Guzman & Barrett D M, Comparision of Ca chloride and Ca lactate effectiveness in maitaining shelf stability and quality of fresh-cut cantaloupes, *Postharvest Biol Technol*, **30** (2000) 61-72.

53 Hong G, Peiser G & Cantwell M I, Use of controlled atmospheres and heat treatment to maintain quality of intact and minimally processed green onions, *Postharvest Biol Technol*, **20** (2000) 53-61.

54 Cantwell M I, Kang J & Hong G, Heat treatments control sprouting and rooting of garlic cloves, *Postharvest Biol Technol*, **30** (2003) 57-65.

55 Tsouvaltzis P, Siomos A S & Gerasopoulos D, Effect of hot water treatment on leaf extension growth fresh weight loss and color of stored minimally processed leeks, *Postharvest Biol Technol*, **39** (2006) 56-60.

56 Vina S Z & Chaves A R, Effect of heat treatment and refrigerated storage on antioxidant properties of pre-cut celery (*Apium graveolens* L.), *Int J Food Sci Technol*, **43** (2008) 44-51.

57 Lemoine M L, Civello M, Martinez G & Chaves A R, Influence of a postharvest UV-C treatment on refrigerated storage of minimally processed broccoli (*Brassica oleracea* var *italic*), *J Sci Food Agric*, **87** (2007) 1132-1139.

58 Foley D M, Dufour A, Rodriguez L, Caporaso F & Prakash A, Reduction of *Escherichia coli* 0157:H7 in shredded iceberg lettuce by chlorination and gamma irradiation, *Radiation Phy Chem*, **63** (2002) 391-396.

59 Molins R A, Motarjemi Y & Kaferstein F K, Irradiation: A critical control point in ensuring the microbiological safety of raw foods, *Food Control*, **12** (2001) 347-356.

60 Allende A & Artes F, Combined ultraviolet-C and modified atmosphere packaging treatments for reducing microbial growth of fresh processed lettuce, *LWT – Food Sci Technol*, **36** (2003) 779-786.

61 Erkan M, Wang C Y & Krizek D T, UV-C radiation reduces microbial populations and deterioration in *Cucurbita pepo* fruit tissue, *Enviro Exp Bot*, **45** (2001) 1-9.

62 Erkan M, Wang S Y & Wang C Y, Effect of UV treatment on antioxidant capacity, antioxidant enzyme activity and decay in strawberry fruit, *Postharvest Biol Technol*, **48** (2008) 163-171.

63 Fonseca J M & Rushing J W, Effect of ultraviolet-C light on quality and microbial population of fresh-cut watermelon, *Postharvest Biol Technol*, **40** (2006) 256-261.

64 Artes-Hernandez F, Escalona V H, Robles P A, Martýnez-Hernandez G B & Artes F, Effect of UV-C radiation on quality of minimally processed spinach leaves, *J Sci Food Agric*, **89** (2009) 414-421.

65 Lopez-Rubira V, Consea A, Allende A & Artes F, Shelf life and overall quality of minimally processed pomegranate arils modified atmosphere packaged and treated with UV-C, *Postharvest Biol Technol*, **37** (2005) 174-185.

66 Pan J, Vicente A, Martinez G, Chaves A & Civello M, Combined use of UV-C irradiation and heat treatment to improve postharvest life of strawberry fruit, *J Sci Food Agric*, **84** (2004) 1831-1838.

67 Lemoine M L, Civello P M, Chaves A R & Martinez A, Effect of combined treatment with hot air and UV-C on senescence and quality parameters of minimally processed broccoli (*Brassica oleracea* L. var. *Italica*), *Postharvest Biol Technol*, **48** (2008) 15-21.

68 Bintsis T, Litopoulou-Tzanetaki E & Robinson R K, Existing and potential applications of ultraviolet light in the food industry – a critical review, *J Sci Food Agric*, **80** (2000) 637-645.

69 Ayala-Zavala J F, González-Aguilar G A & Del-Toro-Sánchez L, Enhancing safety and aroma appealing of fresh-cut fruits and vegetables using the antimicrobial and aromatic power of essential oils, *J Food Sci*, **74** (2009) 84-91.

70 Ayala-Zavala J F, Wang S Y, Wang C Y & González-Aguilar G A, Methyl jasmonate in conjunction with ethanol treatment increases antioxidant capacity, volatile compounds and postharvest life of strawberry fruit, *Euro Food Res Technol*, **221** (2005) 731-738.

71 Lichte A, Zutkhy Y & Sonego L, Ethanol Controls Postharvest Decay of Table Grapes, *Postharvest Biol Technol*, **24** (2002) 301-308.

72 Ayala-Zavala J F, Del Toro-Sánchez L, Alvarez-Parrilla E, Soto-Valdez H, Martín-Belloso, O *et al*, Natural antimicrobial agents incorporated in active packaging to preserve the quality of fresh fruits and vegetables, *Stewart Postharvest Rev*, **4** (2008), art no 9.

73 Benkeblia N, Antimicrobial activity of essential oil extracts of various onions (*Allium cepa*) and garlic (*Allium sativum*), *LWT Food Sci Technol*, **37** (2004) 263-268.

74 Rojas-Grau M A, Soliva-Fortuny R & Martýn-Belloso O, Edible coatings to incorporate active ingredients to fresh-cut fruits: a review, *Trends Food Sci Technol*, **20** (2009) 438-447.

75 Raju P S, Ashok N, Mallesha & DasGupta D K, Physiological and quality changes during minimal processing and storage of shredded cabbage, *Ind Food Pack*, **51** (2000) 51-58.

76 Soliva-Fortuny R C, Ricart-Coll M & Martin-Belloso O, Sensory quality and internal atmosphere of fresh-cut Golden Delicious apples, *Int J Food Sci Technol*, **40** (2005) 369-375.

77 Li-Qin Z, Jie Z, Shu-Hua Z & Lai-Hui G, Inhibition of browning on the surface of peach slices by short-term exposure to nitric oxide and ascorbic acid, *Food Chem*, **114** (2009) 174-179.

78 Aguayo E, Escalona V H & Artes F, Effect of hot water treatment and various calcium salts on quality of fresh-cut 'Amarillo' melon, *Postharvest Biol Technol*, **47** (2008) 397-406.

79 Aguayo E, Escalona V & Artes F, Metabolic behavior and quality changes of whole and fresh processed melon, *J Food Sci*, **69** (2004) 148-155.

80 Gorny J R, Hess-Pierce B, Cifuentes R A & Kader A A, Quality changes in fresh-cut peach and nectarine slices as affected by cultivar, storage atmosphere and chemical treatments, *J Food Sci*, **64** (1999) 429-432.

81 Picchinoi G A, Watada A E, Whitaker B D & Reyes A, Calcium delays membrane lipid changes and increases net synthesis of membrane lipid components in shredded carrots, *Postharvest Biol Technol*, **9** (1996) 235-245.

82 Izumi H & Wantada A E, Calcium treatment to maintain quality of zucchini squash slices, *J Food Sci*, **60** (1995) 789-793.

83 Hernandez-Munoz P, Almenar E, Valle V D, Velez D & Gavara R, Effect of chitosan coating combined with postharvest calcium treatment on strawberry (*Fragaria ananassa*) quality during refrigerated storage, *Food Chem*, **110** (2008) 428-435.

84 Blankenship S M & Dole J M, 1-Methylcyclopropene: a review, *Postharvest Biol Technol*, **28** (2003) 1-25.

85 Yu Y B & Yang S F, Auxin-induced ethylene production and its inhibitors by aminoethoxyvinylglycine and cobalt ion, *Plant Physiol*, **64** (1979) 1074-1077.

86 Abe K & Watada A E, Ethylene absorbent to maintain quality of lightly processed fruits and vegetables, *J Food Sci*, **56** (1991) 1589-1592.

87 Leliever J, Latche A, Jones B, Bouzayen M & Pech J, Ethylene and fruits ripening, *Physiol Plant*, **101** (1997) 727-739.

88 Hayama H, Ito A & Kashimura Y, Effect of 1-methylcyclopropee (1-MCP) treatment under sub-atmospheric pressure on the softening of 'Akatsuki' peach, *J Jpn Soc Hort Sci*, **74** (2005) 398-400.

89 Mao L C, Karakurt Y & Huber D J, Incidence of water-soaking and phospholipid catabolism in ripe watermelon (*Citrus lanatus)* fruit: Induction by ethylene and prophylactic effects of 1-methylcyclopropene, *Postharvest Biol Technol*, **33** (2004) 1-9.

90 Ergun M & Huber D J, Suppression of ethylene perception ex-tends shelf-life and quality of 'Sunrise Solo' papaya fruit at both pre ripe and ripe stages of development, *Euro J Hort Sci*, **69** (2004) 184-192.

91 Ku V V V, Wills R B H & Ben-Yehoshua S, 1-Methylcyclopropene can differently after the postharvest life of strawberries exposed to ethylene, *HortScience,* **34** (1999) 119-120.

92 Ku V V V & Wills R B H, Effect of 1-methylcyclopropene on the storage life of broccoli, *Postharvest Biol Technol*, **17** (1999) 127-132.

93 Tay S L & Perera C O, The effect of 1-MCP and edible coatings on quality of minimally processed Baby Butterhead lettuce, *J Food Sci*, **69** (2004) 131-135.

94 Perera C O, Belchin L, Baldwin E A, Stanllry R & Tian M S, Effect of 1-methylcyclopropene on the quality of fresh-cut apple slices, *J Food Sci*, **68** (2003) 1910-1914.

95 Cin V D, Rizzini F M, Botton A & Tonutti P, The ethylene biosynthetic and signal transduction pathways are differently affected by 1-MCP in apple and peach fruit, *Postharvest Biol Technol*, **42** (2006) 125-133.

96 Ergun M, Huber D J, Jeong J & Bartz A, Extended shelf life and quality of fresh-cut papaya derived from ripe fruit treated with the ethylene antagonist 1- Methylcyclopropene, *J Amer Soc Hort Sci*, **13** (2006) 97-103.

97 Hayama H, Tatsuki M & Nakamura Y, Combined treatment of aminoethoxyvinylglycine (AVG) and 1-methylcyclopropene (1-MCP) reduces melting-flesh peach frui softening, *Postharvest Biol Technol*, **50** (2008) 228-230.

98 Arias E, López-Buesa P & Oria R, Extension of fresh-cut "Blanquilla" pear (*Pyrus communis* L) shelf-life by 1-MCP treatment after harvest, *Postharvest Biol Technol*, **54** (2009) 53-58.

99 Porat R, Weiss B, Cohen L, Daus A, Goren R *et al*, Effects of ethylene and 1-methylcyclopropene on the postharvest qualities of "Shamout" oranges, *Postharvest Biol Technol*, **15** (1999) 155-163.

100 Zhang Z, Huber D J, Hurr B M & Rao J, Delay of tomato fruit ripening in response to 1-methylcyclopropene is influenced by internal ethylene levels, *Postharvest Biol Technol*, **54** (2009) 1-8.

101 Dauny P T, Joyce D C & Gamby C, 1-Methylcyclopropene influx and efflux in 'Cox' apple and 'Hass' avocado fruit, *Postharvest Biol Technol*, **29** (2003) 101-105.

102 Huber D J, Suppression of ethylene responses through application of 1-methylcyclopropene: a powerful tool for elucidating ripening and senescence mechanisms in climacteric and non climacteric fruits and vegetables, *HortScience*, **43** (2008) 106-111.

103 Choi S T & Huber D J, Differential sorption of 1-methylcyclopropene to fruit and vegetable tissues, storage and cell wall polysaccharides, oils and lignins, *Postharvest Biol Technol*, **52** (2009) 62-70.

104 Huber D J, Hurr B M, Lee J S & Lee J H, 1-Methylcyclopropene sorption by tissues and cell-free extracts from fruits and vegetables: Evidence for enzymic 1-MCP metabolism, *Postharvest Biol Technol*, **56** (2010) 123-130.

105 Bregoli A M, Scaramagli S, Costa G, Sabatini E, Ziosi V *et al*, Peach (*Prunus persica*) fruit ripening: aminoethoxyvinylglycine (AVG) and exogeneous polymanies affect ethylene emission and flesh firmness, *Physiol Plant*, **114** (2002) 472-481.

106 Cline J A, effect of aminoethoxyvinylglycine and surfactants on preharvest drop, maturity and fruit quality of two processing peach cultivars, *Hortscience*, **41** (2006) 377-383.

107 Garner D, Crisosto C H & Otieza E, Controlled atmosphere storage and aminoethoxyvinylglycine postharvest dip delay post cold storage softening of 'Snow King' peach, *Hort Technol*, **11** (2001) 598-602.

108 Bregoli A M, Ziosi V, Biondi S, Claudio B, Costa G *et al*, A comparison between intact fruit and fruit explants to study the effect of polyamines and aminoethoxyvinylglycine (AVG) on fruit ripening in peach and nectarine (*Prunus persica* L. Batsch), *Postharvest Biol Technol*, **42** (2006) 31-40.

109 Tharanathan R N, Biodegradable films and composite coatings: past, present and future, *Trends Food Sci Technol*, **14** (2003) 71-78.

110 Cisneros-Zevallos L & Krochta J M, Whey protein coatings for fresh fruits and relative humidity effects, *J Food Sci*, **68** (2003) 176-181.

111 Cisneros-Zeyallos L & Krochta J M, Dependence of coating thickness on visocity of coating solution applied to fruits and vegetables by dipping method, *J Food Sci*, **68** (2003) 503-510.

112 Quezada Gallo J A, Diaz Amaro M R, Gutierrez Cabrera D M B, Castaneda Alvarez M A, Debeaufort F *et al*, Application of edible coatings to improve shelf-life of Mexican guava, *Acta Hortic*, **599** (2003) 589-594.

113 Perez-Gago M B, Rojas C & Del Rio M A, Effect of hydroxypropyl methylcellulose-lipid edible composite coatings on plum (cv. Autumn Giant) quality during storage, *J Food Sci*, **68** (2003) 879-883.

114 Perez-Gago M B, Serra M, Alons M, Mateos M & Del Rio M A, Effect of whey protein and hydroxypropyl methyl cellulose-based edible composite coatings on color change of fresh-cut apple, *Postharvest Biol Technol*, **36** (2005) 77-85.

115 Tanada-Palmu P S & Grosso C R F, Effect of edible wheat gluten-based films and coatings on refrigerated strawberry (*Fragaria ananassa*) quality, *Postharvest Biol Technol*, **36** (2005) 199-208.

116 Sargent S A, Brecht J K, Zoellner J J, Baldwin E A & Campbell C A, Edible films reduce surface drying of peeled carrots, *Proc Fla State Hort Soc*, **107** (1994) 245-247.

117 Sothornvit R & Rodsamran P, Effect of a mango film on whole and minimally processed mangoes, *Postharvest Biol Technol*, **47** (2008) 407-415.

118 McHug T H & Olsen C W, Tensile properties of fruit and vegetable edible films, in *U S Jpn Copper Program Nat*, 2004, 104-108.

119 McHugh T H & Senesi E, Apple wraps: a novel method to improve the quality and extend the shelf-life of fresh-cut apples, *J Food Sci*, **65** (2000) 480-485.

120 González-Aguilar G A, Ayala-Zavala J F, Ruiz-Cruz S, Acedo-Félix E & Díaz-Cinco M E, Effect of temperature and modified atmosphere packaging on overall quality of fresh-cut bell peppers, *LWT - Food Sci Technol*, **37** (2004) 817-826.

121 Artes F & Allende A, Processing lines and alternative preservation techniques to prolong shelf life of minimally fresh processed leafy vegetables, *Euro J Hort Sci*, **70** (2005) 231-245.

122 *Guidelines for the handling of chilled foods. Institute of Food Science and Technology* (IFST, London, UK) 1987.

123 Jeong J, Brecht J K, Huber D J & Sargent S A, 1-Methylcyclopropene (1-MCP) for maintaining texture quality of fresh-cut tomato, *HortScience*, **39** (2004) 1359-1362.

124 Aquino-Bolanos E N, Cantwell M I, Peiser G & Mercado-Silva E, Changes in the quality of fresh-cut jicama in relation to storage temperatures and controlled atmospheres, *J Food Sci*, **65** (2000) 1238-1243.

125 Flores F B, Martinez-Madrid M C, Ben Amor M, Pech J C, Latche A *et al*, Modified atmosphère packaging confer additional chilling tolerance on ethylene-inhibited cantaloupe Charentais melon fruit, *Euro Food Res Technol*, **219** (2006**)** 614-619.

126 Hodges D M & Toivonen P M A, Quality of fresh-cut fruits and vegetables as affected by exposure to abiotic stress, *Postharvest Biol Technol*, **48** (2008) 155-162.

127 Artes F, Gomez P & Artes-Hernandez F, Physical, physiological and microbial deterioration of minimally fresh processed fruits and vegetables, *Food Sci Technol Int*, **13** (2007) 177-188.

128 Rodrýguez-Hidalgo S, Artes-Hernandez F, Gomez P A, Fernandez J A & Artes F, Quality of fresh-cut baby spinach grown under a floating trays system as affected by nitrogen fertilization and innovative packaging treatments, *J Sci Food Agric*, **90** (2010) 1089-1097.

129 Farber J M, Microbiological aspects of modified atmosphere packaging technology: a review, *J Food Prot*, **54** (1991) 58-70.

130 Day B, *Fresh Prepared Produce: GMP for High Oxygen MAP and Non-Sulphite Dipping Guideline No 31* (Campden and Chorleywood Food Research Association Group, Chipping Campden, Gloshister, UK) 2001, 76.

131 Ayala-Zavala J F, Wang S Y, Wang C Y & González-Aguilar G A, High oxygen treatment increases antioxidant capacity and postharvest life of strawberry fruit, *Food Technol Biotechnol*, **45** (2007) 169-173.

132 Allende A, Jacxsens L, Devlieghere F, Debevere J & Artés F, Effect of super atmospheric oxygen packaging on sensorial quality, spoilage, and *Listeria monocytogenes* and *Aeromonas caviae* growth in fresh processed mixed salads, *J Food Prot*, **65** (2002) 1565-1573.

133 Day B P F, Industry guidelines for high oxygen MAP of fresh prepared products, *Acta Hortic*, **599** (2003) ISHS**.**

134 Jacxsens L, Devlieghere F, De Rudder T & Debevere J, Designing equilibrium modified atmosphere packages for fresh-cut vegetables subjected to changes in temperature, *LWT Food Sci Technol*, **33** (2000) 178-187.

135 Angos I, Virseda P & Fernandez T, Control of respiration and colour modification on minimally processed potatoes by means of low and high O_2/CO_2 atmospheres, *Postharvest Biol Technol*, **48** (2008) 422-430.

136 Day B P F, Novel MAP for fresh prepared produce, *Euro Food Drink Rev*, **1** (1996) 73-80.

137 Pinelli L L, Moretti C L, Almeida G C, Santos J Z, Qnuki A C A *et al*, Chemical and physical characterization of fresh-cut potatoes, *Cienc Tecnol Aliment*, **26** (2006) 127-134.

138 Allende A, Luo Y, McEvoy J L, Artés F & Wang C Y, Microbial and quality changes in minimally processed baby spinach leaves stored under super atmospheric oxygen and modified atmosphere conditions, *Postharvest Biol Technol*, **33** (2004) 51-59.

139 Jacxsens L, Devlieghere F, Van der Steen, C & Debevere J, Effect of high oxygen modified atmosphere packaging on packaging on microbial growth and sensorial qualities of fresh-cut produce, *Int J Food Microbiol*, **71** (2001) 197-210.

140 Artes F, Gomez P, Aguayo E, Escalona V & Artes-Hernandez F, Sustainable sanitation techniques for keeping quality and safety of fresh-cut plant commodities, *Postharvest Biol Technol*, **51** (2009) 287-296.

141 Ballantyne A, Stark R & Selman J D, Modified atmosphere packaging of shredded lettuce, *Int J Food Sci Technol*, **23** (1988*)* 267-274.

142 Qadir A & Hashinaga F, Inhibition of postharvest decay of fruits by nitrous oxide, *Postharvest Biol Technol*, **22** (2001) 279–283.

143 Rocculi P, Romani S & Dalla Rosa M, Evaluation of physico-chemical parameters of minimally processed apples packed in non conventional modified atmosphere, *Food Res Int*, **37** (2004) 329-335.

144 Rocculi P, Romani S & Dalla Rosa M, Effect of MAP with argon and nitrous oxide on quality maintenance of minimally processed kiwifruit, *Postharvest Biol Technol*, **35** (2005) 319-328.

145 Gorris L G M, DeWitte Y & Bennik M J H, Refrigerated storage under moderate vacuum, *ZFL Focus Int*, **45** (1994) 63-66.

146 Cameron A C, Patterson B D, Talasila P C & Joles D W, Modeling the rick in modified-atmosphere packaging: A case for sense and respond packaging, in *Proc 6th Int Controlled Atmosphere Res Conf*, **vol 1** (Cornell University,) 1993, 95-102.

147 Patterson B D & Cameron A C, Modified atmosphere packaging, *Int Pat PCT/AU90/00267*, 1992.

148 Labuza T P & Breene W M, Applications of 'Active packaging' for improvement of shelf-life and nutritional of fresh and extended shelf-life foods, *J Food Proces Preser*, **13** (1989) 1-69.

149 Vermeiren L, Devlieghere F, Beest M V N, de Kruijf M & Debevere J, Developments in the active packaging of foods, *Trends Food Sci Technol*, **10** (1999) 77-86.

150 Pittia P, Nicoli M C, Comi G & Massini R, Shelf-life extension of fresh-like ready-to-use pear cubes, *J Sci Food Agric*, **79** (1999) 955-960.

151 Zhou T, Harrison A D, McKellar R, Young J C, Odumeru J *etal*, Determination of acceptability and shelf life of ready-to-use lettuce by digital image analysis, *Food Res Int*, **37** (2004) 875-881.

152 Siddiqui M W, Bhattacharjya A, Chakraborty I & Dhua R S, 6-Benzylaminopurine improves shelf life, organoleptic quality and health promoting compounds of fresh-cut broccoli florets, *J Sci Ind Res*, **70** (2011) 461- 465.