TRENDS IN POST HARVEST TECHNOLOGY
Journal homepage: www.jakraya.com/journal/tpht

REVIEW ARTICLE

Modified atmosphere packaging of minimally processed fruits and vegetables

Sanjaya Kumar Dash[1], Abhijit Kar[2] and Kalyani Gorrepati[3]*

[1]Deptt. of Agril. Processing and Food Engg., Orissa University of Agriculture and Technology, Bhubaneswar-751 003, Odisha, India.
[2]Division of Post Harvest Technology, Indian Agricultural Research Institute, New Delhi-110 012, India.
[3]Directorate of Onion and Garlic Research, Rajgurunagar, Pune, Maharashtra-410 505, India.

*Corresponding Author:

Kalyani Gorrepati
kalyanigorrepati@gmail.com

Received: 04/10/2013
Revised: 26/11/2013
Accepted: 27/11/2013

Abstract

The change in food consumption patterns from ensuring an adequate supply of calories and nutrients to an increased emphasis on quality and convenience and the demand of consumers on convenience as well as fresh texture, flavour and appearance have led to a relatively new area of food preservation - minimally processed or lightly processed foods. Mechanical damage to the cells during processing, however, is a major limitation to shelf life of minimally processed fruits and vegetables. The damages enhance the process of deterioration by increased microbial activity, respiration and senescence. Hence, in addition to storage and transportation under a low temperature environment, an additional barrier in the form of modified atmosphere packaging (MAP) has been tried extensively for increasing the shelf life of these products. Studies indicate that MAP can be adopted for different types of minimally processed fruits and vegetables such as broccoli, spinach, lettuce, melon, apple, cucumber, carrot and some others; either individually or in combination to increase the shelf life and maintain freshness for a relatively longer period. The cultivars of a specific produce, however, differ in their characteristics. Their respiration rate is also dependent on temperature, composition of storage atmosphere, degree of processing and storage life among other factors. Therefore, maintenance of proper concentration of oxygen and carbon-dioxide in the packages needs a thorough research about the produce and package characteristics.

Keywords: Modified atmosphere packaging, minimally processed foods, quality, safety, shelf life, modelling.

Introduction

Minimally Processed (MP), or lightly processed or otherwise called *"Grade 4',* foods are produced using a range of modern technologies, which aim to change the food as little as possible. At the same time, endow it with a shelf life sufficient for it to transport from the producer to consumer (Ohlsson, 1994). Over the last years, the market for *MP* vegetables is growing both in sales volume and assortment of vegetables, e.g. vegetable salads of endive, lettuce, carrots, pepper, potatoes, onions, cabbage, soybeans, both as single vegetables and in mixtures, completed with sauces and dressings, as well as vegetable mixtures for soups and stew. Consumers are increasingly demanding convenient, ready to use and ready to eat foods with a fresh like quality and containing only natural ingredients (Lund, 1989).

Minimal processing would encompass any procedure, short of the traditional complete preservation procedures (heat sterilization, freezing, etc.), that adds value (King and Bolin, 1989). It generally includes a minimum preparation procedure, peeling and cutting, which cause rupturing of the cell tissues and liberation of intracellular products such as oxidizing enzymes (Ahvenainen, 1996). Hence, *MP* produce deteriorates rapidly because of physiological ageing, biochemical changes and microbial spoilage, causing degradation in colour, texture and flavour of the produce (Varoquax and Wiley, 1994). It is well established that modified atmosphere packaging (MAP) extends the shelf life of fruits and vegetables through suppression of respiration, ripening and subsequent senescence, microbial activity due to diversity of effects caused by low O_2, elevated CO_2, by inhibition of ethylene induced effects, and by reduction of moisture loss due to the moisture barrier properties of the packaging film (Zagory, 1995). In case of the *MP* fruits and vegetables also, the creation of a low O_2 and high CO_2 atmosphere exhibit enough promise to extend their shelf life both at room temperature and at lower temperatures. The paper is an attempt to review the work done in this field.

Modified atmosphere packaging of minimally processed fruits and vegetables

As a result of peeling, grating and shredding, the produce changes from a relatively stable product with a shelf life of several weeks or months to a perishable one that has only a very short life, even as short as 1-3 days at chill temperatures (Ahvenainen, 1996). Microbial growth, oxidation (enzymatic browning) and moisture loss are the principal spoilage mechanisms affecting the prepared fresh vegetables (Willocx *et al.,* 1994; Varoquaux and Wiley, 1994). Ethylene production can also increase following minimal processing, and it may soften the fruit. The respiration activity of the minimally processed commodity will increase 1.2-7 folds, or even more, depending on the produce, cutting grade and temperature (King and Bolin, 1989; Varoquaux and Wiley, 1994; Mattila *et al.,* 1995).

Nguyen-the and Carlin (1994) stated that *MP* fresh fruits and vegetables are good media for growth of microorganisms. They are also sensitive to various spoilage microorganisms such as pectinolytic bacteria, saprophytic Gram-negative bacteria, lactic acid bacteria, and yeasts. Contamination of *MP* fruits and vegetables occurs at every stage of the food chain, from cultivation to processing. Polluted environments during cultivation or poor hygienic conditions in processing increase the risk of contamination with food-borne pathogens. Willcox *et al.* (1994) mentioned that most of the *MP* vegetables have pH between 5.8-6.0, which favors the growth of pathogenic bacteria. The high humidity and large number of cut surfaces can provide ideal conditions for the growth of microorganisms.

Modified atmosphere (MA) packaging and Controlled atmosphere (CA) storage are two methods for extending the shelf life of perishable foods by altering the proportions of atmospheric gases surrounding the food (O'Connor *et al.,* 1992). MAP, therefore, can also be applied efficiently to increase the shelf life of minimally processed fruits and vegetables (O'Connor and Shaw, 1998).

Heat processed foods are generally metabolically not active, while fresh and *MP* vegetables are active and may create a modified atmosphere when they are packaged. The metabolic activity will depend on the type of the product, type of processing and storage conditions (Gorris, 1994). Refrigeration is the most commonly used method to extend the durability of vegetable based ready-to-eat foods, i.e. fresh and *MP* preparations. However, due to the difficulty in maintaining sufficiently low temperature throughout the food chain from production and processing to retail, additional barriers to the growth of spoilage, and pathogenic micro-organisms are required. These barriers based on novel mild preservation techniques like biopreservation, MAP or Modified atmosphere coating, are used for the purpose. Ahvenainen *et al.* (1995) emphasized that suitable packaging materials and methods were the key requirements alongwith the raw material of good quality, strict hygiene and good manufacturing practices, low temperatures during working and storage, gentle peeling, careful washing before and after peeling, and use of proper additives for the minimally processed products. Niemira *et al.* (2005) reported that irradiation and modified atmosphere packaging can be combined to prevent the regrowth of *L. monocytogenes* during post-irradiation refrigerated storage, thereby improving product safety.

Shelf life and quality of MA stored *minimally processed* vegetables

With the increase in popularity of *MP* foods, several studies have been conducted in the last few years on the application of modified atmosphere for storage of fruits and vegetables. However, most of the studies dealt with different vegetables used in fresh like or salad form.

Barth *et al.* (1996) assessed a variety of postharvest storage treatments including MAP, vent-packaging (perforated film, VP) and automatic misting (AM) in broccoli (cv. *Iron Duke*) florets for storage over 6 days at 5°C. MAP resulted in the best retention of antioxidant vitamins, moisture and colour in lightly processed broccoli florets during postharvest storage. Jia *et al.* (2009) packaged Broccoli (*Brassica oleracea* var. italica) florets in polyethylene bags with no holes (M0), two microholes (M1), and four macroholes (M2), and then stored at 4 or 20°C. MAP treatments, especially with M0 and M1, extended the shelf life and reduced the postharvest deterioration of broccoli florets stored at 4 and 20°C. Ansorena *et al.* (2011) coated minimally processed broccoli with either chitosan or carboxymethyl-cellulose with or without a previous application of a mild heat shock of 1.5 min at 50°C, packaged in multilayered polyolefin bags and stored at 5°C for 18 days. Chitosan coating combined with a mild heat shock showed the best performance for long-term refrigerated storage of minimally processed broccoli.

Howard and Griffin (1993) observed lignin formation in carrot sticks stored at 2°C under MAP, which also corresponded with the development of white discoloration. Ethylene absorbents ($KMnO_4$) prevented accumulation of ethylene, but did not affect surface discoloration or lignification. Howard *et al.* (1994) reported that steam treatment retarded surface discoloration, soluble phenolic and isocoumarin production and lignin formation for MAP stored carrot sticks at 2°C. Heat inactivation of phenylalanine ammonia-lyase (PAL), peroxidase (POD) and syringaldazine oxidase (SOX) also occurred. Control of surface discoloration by steam appeared to be related to retardation of phenylpropanoid metabolism. Hurme *et al.* (1995) observed a considerable improvement of the shelf-life of grated carrots (cv. *Navarra*) by washing in chlorinated water after peeling and before grating, and by packing in microperforated film. Long-term storage before processing was detrimental to the quality of the prepared samples, but not to the fresh non-processed control samples. The use of an edible coating incorporating an acidulant inhibited white blush formation and maintained acceptable degree of microbial growth for up to 4 weeks at 4°C (Reyes *et al.*, 1996). Galetti *et al.* (1997) compared storage of carrot (cv. *Chantenay*) slices (0.5-cm thick) in various plastic films having different permeabilities to CO_2 and O_2 (films BB4, PD961 and BE) under vacuum at 450 mbar. Discoloration increased during storage, especially in more permeable packages (PD961 and BE) and ascorbic acid had no effect on O_2 or CO_2 concentrations in any of the packages tested and had no effect on superficial bleaching of carrot slices. CO_2 gas concentrations were highest in the BB4 pack. Carrot slices stored in BE packs were acceptable even after 14 days' storage. Li and Barth (1998) reported 15% greater carotene retention in peeled carrots packaged in polymeric film bag (70 g/pack) after dipping in cellulose-based edible coatings (pH 2.7 or 4.6) for 10 sec compared to the control during a storage period of 28 days at 1°C and 92% relative humidity (RH).

Low O_2 and high CO_2 atmospheres inhibited the quality deterioration, especially browning, of MP Chinese cabbage during storage at 5°C. Among the tested packaging materials PD961 (polyolefin type film, 50 µm thick) was found to be the best packaging material for MP Chinese cabbage (Kim, 1999). Pirovani *et al.* (1997) observed reduced weight loss for shredded white cabbage stored in mono-oriented polypropylene film (OPP bags) or in polyethylene (PE) trays overwrapped with a multilayer shrink polyolefin (RD106-PE tray) or with a plasticized poly vinyl chloride film (PVC-PE tray), all at 3°C and 70-80% RH for up to 13 days.

Heimdal *et al.* (1995) reported that PE-bags (80 µm), moderate vacuum packaging (MVP, 0.45 atm) for shredded Iceberg lettuce stored at 5°C for 10 days inhibited enzymatic browning over the 10-days storage period, and that storage time exceeding 10 days should be avoided due to increasing off-flavour in bags with good visual quality. CO_2 concentration below 5% improved the preservation of lettuce leaves (Varoquaux *et al.,* 1996). Berger *et al.* (1997) packed chopped lettuce (200 g) in Cryovac bags (BB4, PD961 or BE) differing in O_2 and CO_2 permeabilities and stored at 4°C, 85% RH. After 7 days' storage, quality was best in PD961 bags; the atmosphere in these packs consisted of 2-3% O_2 and 5-6% CO_2. Colour variation was least in the PD961 bags. Immersion of chopped lettuce in ascorbic acid (1% w/v, for one minute) prior to packing had no effect on sensorial quality. Castaner *et al.* (1997) stored white, green and red sections of Lollo Rosso lettuce in perforated or non-perforated PE film with active atmosphere modification at 5°C for 7 or 14 days. The quality of white and green tissues were best maintained in modified atmosphere storage whilst red tissue was better preserved in air. Gil *et al.* (1998a) observed a two-fold increase in the amount of soluble phenylpropanoids in the midribs of *MP* Lollo Rosso lettuce during storage in air at 5°C. When the lettuce was stored in 2-3% O_2 and 12-14% CO_2, this increase was not induced and no browning was observed. A marked decrease in the amount of phenylpropanoids was observed in MAP-stored green and red tissues. MAP storage proved useful in the prevention of browning. However, MAP was not so beneficial for the preservation of the quality of red tissues and, in fact, their overall visual quality, texture, aroma and macroscopic breakdown under MAP conditions were worse than those of air-stored tissues. No differences in texture and aroma were detected between the different treatments (two refrigeration temperatures (1 or 5°C), packaging film (perforated or non-perforated polypropylene, 35 µm) and passive or active modified atmosphere). Leaf edge browning was the worst problem in all treatments. The perforated film reduced this disorder but not completely (Artes *et al.,*1999). An *et al.* (2007) reported that aqueous ozone treatment (1 mg/l) and subsequent modified atmosphere packaging during storage at 3°C for 25 days inhibited the enzyme activities including phenylalanine ammonia lyase (PAL), superoxide dismutase (SOD), ascorbate peroxidase (APX) and glutathione reductase (GR) in fresh-cut green asparagus (*Asparagus officinalis* L.).

MAP (7%O_2+10%CO_2) had no effect on total flavonoid content of Swiss chard spinach beets leaves (cv. *Green*) after 8 days of storage, although it increased flavonoid extraction during cooking in boiling water. In contrast, ascorbic acid content decreased, especially in MAP-stored Swiss chard, to reach levels below 50% of the initial content after 8 days of cold storage (Gil *et al.,* 1998b).

Gil *et al.* (2002) stored Fresh cut '*Durinta*' tomato slices for 7 and 10 days at 0 and 5°C under active (12–14 kPa O_2 + 0 kPa CO_2) modified atmosphere packaging (MAP). After storage at 0°C no effect of gas composition on tomato keeping quality was shown. However, the best overall tomato slice quality was found at 5°C under higher CO_2. Hong and Gross (1998) investigated the effect of concentration (0, 0.26 or 1.05%) and duration (0, 20 or 60s) of sodium hypochlorite treatment on subsequent firmness, electrolyte leakage, respiration and methane production of light-red tomato fruit slices during storage at 5°C under modified atmosphere. The results suggested that routine surface sterilization of tomato fruit prior to postharvest treatments may lead to physiological and biochemical alterations in the behaviour of fruits.

Laurila *et al.* (1998) studied the effects of potato cultivar (*Van Gogh*, *Bintje* or *Fambo*), washing with browning prevention chemicals in place of sodium bisulfite, percentages of CO_2, O_2 and N_2 in the package headspace, and storage time (1, 4 or 7 days) on the sensory and microbiological quality of potato slices. After 7 days of storage, the best sensory quality of both raw and cooked Bintje slices was obtained with washing solutions containing 0.1 or 0.5% citric + ascorbic acids and with a gas mixture containing 20% CO_2 and 80% N_2. Potato strips stored in MAP decreased in L-ascorbic acid (AA) content by 14–34% compared to samples held in air. Frozen storage resulted in a reduced vitamin C content (23%) of 'Spunta' potato strips after 5 weeks while 'Agria' tubers did not show any change (Tudela *et al.,* 2002)

The Mature-green or red bell pepper fruits were diced/ sliced, rinsed with water containing 50 ppm NaCl, drained and centrifuged in a salad spinner and placed in glass jars either in air or CA (3% O_2 with 0, 5 or 10% CO_2) at 0, 5 or 10°C for up to 20 days. Atmospheres with 5 or 10% CO_2 increased the shelf-life of diced peppers at 5°C, but were not as effective as storage in air at 0°C (Lopez *et al.,* 1997a).

During storage of *MP* leek (cv. *Arkansas*) for up to 10 days at 4°C in pillow packs (22x19cm) with no perforations, 2, 4 or 8 perforations of 0.2 mm, or 8 perforations of 0.4 mm diameter, Keteleer *et al.* (1994) observed two main types of deterioration, viz. deterioration due to over modification of the atmosphere (anaerobic processes, CO_2 damage), primarily leading to olfactory quality loss; and deterioration due to senescence and oxidative processes, mainly leading to visual quality loss. It was further observed that at least 3 physiological measurements were necessary to compare materials of different sensory quality and with an appropriate selection of objective measurements, the quality of different products can be compared in a standardized, objective and reproducible manner.

The storage life of grated beetroots was observed to be 7 days at 0°C and 3-4 days at 4°C. There was a notable decrease in pigment content during storage. Quality was generally better in trays wrapped with PVC than with EVA (ethylene vinyl acetate) (Lopezosornio *et al.,* 1998).

Manzano *et al.* (1995) evaluated four packing systems for mixed fresh cut vegetables (parsley, celery, sliced courgette, sliced carrot, pieces of Savoy cabbage, sliced leek, white beans, garlic and onion), namely, (1) packing in trays with 50 ml O_2 + 30 ml CO_2 + 920 ml N_2/litre atmosphere, (2) packing in trays with 70 ml O_2 + 930 ml N_2/litre atmosphere, (3) packing in trays with 200 ml O_2 + 800 ml N_2/litre atmosphere, and (4) packing in trays with a perforated film at 4°C for 7 days. It was observed that vegetables packed in perforated film retained the best sensory characteristics.

Gomez and Artes (2005) reported that MAP treatments both in oriented polypropylene (OPP) and polyethylene-perforated bags improved the sensory quality, avoided the loss of green colour, decreased the development of pithiness and retarded the growth of microorganisms in celery sticks stored at 4°C for 15 days as compared to the control (air). Radziejewska-Kubzdela *et al.* (2007) reported that modified atmosphere with the content of 5% or 10% CO_2, 2% O_2 and balance N_2, applied in the packaging of celeriac flakes during storage for 12 days at 4 and 15°C, resulted in the inhibition of growth of mesophilic, psychrophilic and coliform bacteria in the tested minimally processed product.

Lu (2007) reported that modified atmosphere packaging (MAP) flushed with 5% O_2 and 2% CO_2 resulted in a reduction of respiration rate and ion leakage of minimally processed Bok Choy (*Brassica chinensis* L.) stored at 10°C. The shelf-life of minimally processed Bok Choy in MAP, sealed directly in polyethylene (PE) bag or in perforated oriented polypropylene (POPP) bag at 10°C were 10, 6 and 4 days, respectively, according to the sensory quality evaluation. Sliced mushrooms treatment with 3% H_2O_2 for up to 60 s prior to slicing followed by a spray application of 4% sodium d-isoascorbate monohydrate or 1% H_2O_2 subsequent storage under modified atmospheres at 4°C maintained quality and enhanced shelf-life (Cliffe-Byrnes and Beirne, 2008). Blanchard *et al.* (1996) stored diced, `ready-to-use' yellow onion (cv. *Blitz*) for 14 days at 4°C and high RH under a continuous stream of nitrogen containing (% O_2/% CO_2) 20/0, 2/0, 2/5, 2/10 or 2/15, and for 12 days at 4°C under (% O_2/% CO_2) 20/0, 2/0 or 2/10, and observed optimal sensory quality under the 2% O_2/10% CO_2 atmosphere. Xing *et al.* (2010) packed 100g of untreated and treated lotus root slices in trays (150×150 mm) and sealed with a microperforated polyethylene (30 µm thickness) and reported that chitosan-based coating along with MAP had a better inhibitory effect on the browning and extended the shelf life of fresh-cut lotus root stored at 4°C for 10 days. Onions were minimally processed to produce fresh-sliced onions and packed either in closed plastic cups (polyethylene terephthalate (PET) and polystyrene (PS)), or under vacuum conditions, taking into account the effect of light exposure and stored for 16 days at 1–2°C. In all cases, the commodity was acceptable after the storage period, with the exception of vacuum packaging (score 5, fair/poor, on a 1–9 scale), due to water loss (about 4%) colour loss and a glassy appearance. The best performance was obtained when the more transparent polystyrene cups were stored under light (Perez-Gregorio *et al.,* 2011). Siddiq *et al.* (2013) treated onion slices with mild heat by dipping in 50, 60, or 70°C water for one min each. The treated slices were packaged in polystyrene rigid containers and stored at 4 ± 1°C and reported that onion slices can be successfully heat treated at 50°C to preserve antioxidant properties while preserving the colour quality for 21 days when stored at 4°C.

Geraldine *et al.* (2008) evaluated the effects of three types of edible coatings: without additives agar-agar, incorporated with 0.2% of acetic acid and incorporated with 0.2% of chitosan (from 1% chitosan and 1% acetic acid distilled water solution) on coating of minimally processed garlic cloves. Peeled and sanitized garlic cloves were stored in polyethylene terephthalate (PET) boxes and coated with edible film. The edible coating, still liquid, was placed inside the boxes (15% of garlic mass) over the cloves and boxes were kept at 25°C for 9 days. Moisture loss of coated garlic cloves was, on average, three times lower when compared to the control samples (no coated garlic cloves). Coated garlic cloves, had a respiration rate (≈30 mg CO_2 h^{-1} kg^{-1}) halved compared to the non-coated garlic cloves.

Shelf life and quality of MA stored *minimally processed* fruits

Pretel *et al.* (1998) observed no significant change in weight loss, acidity, °Brix or carotenoid content for *MP* (enzymically peeled or manually segmented) orange (cv. *Salustiana*) during the first 11 days of storage in plastic bags with different permeabilities. The health-related characteristics (carotenoids, flavanones and vitamin C and antioxidant activity) of minimally processed oranges were retained during refrigerated storage at 4°C in darkness for 12 days, when oranges as whole fruits, hand-peeled fruits and manually separated segments were packed in antimist coated oriented polypropylene film (200 g of sample was placed on polystyrene trays, which were packaged in 20-30cm antimist coated oriented polypropylene film of medium oxygen permeability [5200 $cm^3/(m^2$ 24 h bar) at 23°C and 0% relative humidity (RH)]) under air atmosphere (Plaza *et al.,* 2011).

Dipping in 4% sodium erythorbate + 0.2% $CaCl_2$ + 50-100 ppm 4-hexylresorcinol, in conjunction with modified atmosphere (MA), controlled browning and maintained the quality of fresh-cut Bartlett and d'Anjou pears for 12-14 days at 4°C (Sapers and Miller, 1998). Perez-Cabrera *et al.* (2011) applied different isotonic solutions containing antibrowning compounds (EDTA, 4-hexylresorcinol, citrate and ascorbate), combined or not with calcium lactate to minimally processed pear samples (cv. *Blanquilla*) by using the vacuum impregnation (VI) technique. Pear samples (55-60 g/container) were packed in polypropylene containers (6.5 cm height, 6cm diameter), stored at 4°C and reported that VI treatments with ascorbate solutions and calcium lactate were the most effective to extend the shelf life of MP pear.

The use of superatmospheric O_2 atmospheres are proposed to reduce CO_2 production rates, avoid fermentative reactions and, maintain firmness and chewiness of fresh-cut 'Piel de Sapo' melon for 2 weeks of storage (Oms-Oliu *et al.,* 2008). Dip pretreatment to jackfruit bulbs (calcium chloride, ascorbic acid and sodium benzoate under mild acidified conditions) prior to MAP in 3 kPa O_2 + 5 kPa CO_2 gas mixture flushed PE bags was found to preserve the initial firmness value (about 44 N) with a minor loss of around 7% after 35 days compared to significantly higher loss in the control samples packaged in the same MAP (Saxena *et al.,* 2008). Gil *et al.* (1996) observed the effect of different washing treatments, temperature and packaging on anthocyanins in 'ready-to-eat' pomegranate seeds (cv. *Mollar*). There was no difference in anthocyanin composition after washing with different solutions, although a slight decrease in pigments occurred. Storage in perforated polypropylene bags preserved pigments and a slight increase in most anthocyanins occurred. During storage in modified atmosphere (MA), anthocyanins increased at 1°C, but decreased at 8 and 4°C. Chemical treatment of calcium chloride (1% w/v) and citric acid (2% w/v)) followed by MAP with polypropylene (PP) film in an atmosphere of 5% O_2,10% CO_2, 85% N_2 extended the shelf-life of fresh-cut papaya to 25 days at 5°C and retained sensory and quality characteristics (Waghmare and Annapure, 2013). Finnegana *et al.* (2013)

investigated the effects of intrinsic factors (origin, physiological age and seasonality) and extrinsic factors (cut-size, blade-sharpness and dipping treatments) on respiration rate of fresh-cut pineapple chunks. The target O_2 and CO_2 transmission rate required for optimal modified atmosphere packaging were 7300–12,500 and 13,900–23,500 ml/m^2 day atm covering variability in respiration rate due to intrinsic and extrinsic factors studied. The effect of MAP on minimally processed fruits and vegetables is shown in Table 1.

Safety of MA stored *minimally processed* fruits and vegetables

The reliance of minimally processed foods on low temperature for distribution with optimized CA/MA device to maintain safety and quality posed new challenges to the food microbiologists (Labuza *et al.*, 1992). In the case of MVP at 4°C improved sensory assessment and/or microbial quality compared with the controls, which were stored in air at ambient temperature. When mung beans and endive were challenged with *Yersinia enterocolitica, Salmonella typhimurium, Bacillus cereus and Listeria monocytogenes*, the pathogens did not survive storage at 4°C, with the exception of *L. monocytogenes* with endive, which grew at 4-10°C (Gorris *et al.,* 1994). Irradiation (2 kGy) strongly inhibited the growth of aerobic mesophilic and lactic microflora for shredded carrots stored at 10°C in microporous plastic bags (Chervin and Boisseau, 1994). A large number of different groups of microorganisms were found in the raw vegetables at packing but no pathogenic microorganisms were isolated from the prepacked vegetables (before or after storage). It was observed that the hygienic quality was similar in all packing systems used (Manzano *et al.,* 1995)

Bennik *et al.* (1996) observed that in modified atmosphere packaging of fresh cut endives at low temperature (8°C), growth of the psychrotrophic pathogen *Listeria monocytogenes*, inoculated on the product, was not inhibited. The extent to which the pathogen grew depended on its initial number, type of endive and size of the population of competitive spoilage microflora. Reducing the initial microbial load by disinfection could minimize microbial spoilage and improve the safety status of the product. However, *L. monocytogenes* grew better on disinfected produce than on non-disinfected or water-rinsed produce, indicating the practical importance of avoiding recontamination after disinfection. Minimally processed fresh broad-leaved endive (*Cichorium endivia* L.) stored in the MA containing 10% CO_2 +10% O_2 resulted in improved visual quality, without a marked effect on the growth of the aerobic microflora or of L. *monocytogenes* among the MA tested (Carlin *et al.,* 1996). Blanchard *et al.* (1996) observed delayed microbial development, particularly that of the psychrotroph flora, in diced, `ready-to-use' yellow onion (cv. *Blitz*) stored for 14 days at 4°C and high RH under a continuous stream of nitrogen containing oxygen and carbondioxide in the ratio of 20/0, 2/0, 2/5, 2/10 or 2/15 and for 12 days at 4°C under oxygen and carbondioxide ratios of 20/0, 2/0 or 2/10. When the shredded lettuce were inoculated with nalidixic acid-resistant *E. coli* (ATCC 35150) and placed at 13 or 22°C, and was continuously flushed with gas mixtures of 0/10/90, 3/0/97, 5/30/65, 20/0/80 (O_2/CO_2/N_2, v/v). It was observed that the aerobic plate count (APC) growth was inhibited in 5/30/65 (O_2/CO_2/N_2) at 13°C compared to all other atmospheres. However, the extended shelf-life in MA allowed *E. coli* to grow to higher numbers compared to air-held lettuce (Diaz and Hotchkiss, 1996).

Kakiomenou *et al.*(1996) reported that spoilage was delayed (as indicated by changes in texture, colour and odour) in shredded carrot samples stored under MA (5% CO_2/95% N_2) compared with samples stored under air or 4.9% CO_2/2.1% O_2/93% N_2.

Reports by Segall and Scanlon (1996) reveals that no effect of MAP on microbial (pectinolytic and lactic acid bacteria) growth during the storage of lettuce under three MAs (3% O_2 plus either 6, 10 or 14% CO_2) for 20 days. However, of the three CO_2 concentrations, 10% was slightly more effective than 6 and 14%. It was concluded that critical choice of packaging permeabilities combined with MAP could substantially increase shelf life. Izumi *et al.* (1997) monitored the physiology and quality of spinach (cv. *Sunbest*) leaves during storage in air and controlled atmospheres (0.5, 1 and 2% O_2) at 0°C (for 28 days), 10°C (for 9 days) and 20°C (for 5 days) and observed that low-O_2 atmospheres did not affect the development of decay, or populations of aerobic mesophilic and lactic acid bacteria at any of the storage temperatures tested. Pirovani *et al.* (1997) compared the storage of shredded white cabbage in bags of mono-oriented polypropylene film (OPP bags) or in polyethylene trays overwrapped with a multilayer shrink polyolefin (RD106-PE tray) or with a plasticized PVC film (PVC-PE tray), stored at 3°C and 70-80% RH for up to 13 days and reported that the microbiological quality during the storage period for all types of packaging was satisfactory.

When the shredded carrot and cabbage were packaged in polypropylene film (35 µm thick) and stored at 7°C, no pathogens were detected on vegetables in uninoculated packs (Finn and Upton, 1997). Hong and Gross (1998) observed an increase in methane and CO_2 production due to infection by *Alternaria alternata* on light-red tomato slices light-red

Table 1: Effect of MAP on minimally processed fruits and vegetables

S.No	Commodity	Pre-treatment	Packaging material	Storage Conditions	Observation	Reference
1.	Fresh-cut salad Savoy	Washed in 100 µl l^{-1} chlorine solution (NaOCl) for 1 min	Polyethylene bags prepared with films of selected OTRs at 8.0, 16.6, 21.4, and 29.5 pmol s^{-1} m^{-2} Pa^{-1}	5°C for 25 days	Packages prepared with 16.6 and 21.4 OTR films achieved the desired O_2 (1.4–3.8 kPa) and CO_2 (3.6–6.3 kPa)	Kim *et al.* (2004)
2.	Lightly-processed (LP) carrots	Two types of cellulose-based edible coatings, EC_1 (pH=2.7) and EC_2 (pH=4.6) were applied by dipping the carrots in the coating solution for 10 s	Polymeric film bags (OTR=5006 cm^3/m^2/24 h/atm at 25°C, 50% RH)	1°C, 92% RH, for 28 days in the absence of light.	Cellulose- based edible coatings have an overall beneficial effect on retention of carotenes, retardation of surface whitening, and extension of shelf-life of the LP carrots.	Li and Barth (1998)
3.	Tomato slices	Sodium hypochlorite solution (1.3 mM) for 1 min at 4°C before cutting	Polypropylene film (PP), composite film, bi-oriented polypropylene film (OPP)	7 and 10 days at 0 and 5 °C.	For keeping quality of 'Durinta' tomato slices up to 10 days the best storage conditions were obtained at 0°C independently of the kind of film used.	Gil *et al.* (2002)
4.	Tomato slices	0.26% (1:20; v:v) or 1.05% (1:5; v:v) sodium hypochlorite for 20 or 60 s before cutting	Plastic containers	5°C for 12 days	Routine surface sterilization of tomato fruit prior to postharvest experimentation may lead to physiological and biochemical alterations in the behaviour of fruit.	Hong and Gross (1998)
5.	Fresh-cut green asparagus	1 mg/l aqueous ozone pretreatment for 30 min.	Low-density polyethylene (LDPE)	3°C for 25 days	Increasing of the cell wall compositions under the aqueous ozone treatment or (and) MAP were significantly reduced	An *et al.* (2007)
6.	Sliced button mushrooms	-	Tray and covered with cellophane™ 335 PS film (23.3 µm thickness) perforated with a needle of diameter 0.33 mm.	7 days at four levels of temperature (0, 5, 10, and 15 °C)	The shelf-life of fresh sliced mushrooms in an optimum package was found to be 7.5 and 4 days when stored at 0 and 5°C, respectively	Oliveira *et al.* (2012)
7.	Broccoli florets	Washing with a	Polyethylene bag (40	4 or 20°C.	Polyethylene bag (40 µm thick) with no	Jia *et al.*

		solution of 50 ppm NaOCl for 1 min.	µm thick). Three types of bags were used: (1) without holes (M0), (2) with two microholes (750 µm in diameter, one on each side of the bag) (M1), and (3) with four macroholes (8.8 mm in diameter, two on each side of the bag) (M2)		hole (M0), two microholes (M1), and four macroholes (M2) extended the shelf life of broccoli florets from 10 days (control) to 28.5 days, 19.1 days and 15.2 days, respectively, at 4°C, and from 2.5 days (control) to 7.2 days, 5.6 days, and 4.8 days, respectively, at 20°C.	(2009)
8.	Sliced mushrooms	Immersed in an aqueous solution with 10 g/l citric acid for 5 min with slight shaking before slicing.	Polystyrene trays. The trays were overwrapped with two different PVC films: (a) perforated PVC film of 12 µm thickness (1 pore of 1 mm of diameter for every 2.5 cm^2 of film surface); and (b) non-perforated PVC film of 12 µm thickness	5°C and 80% RH for up to 17 days.	The effect of washing with citric acid combined with packaging in modified atmosphere resulted additive. The reduction of microbial counts avoided bacterial blotch in washed mushrooms.	Simon *et al.* (2010)
9.	Fresh-cut lotus root	Dipped into chlorinated water (7500 ppm active chlorine) for 5 min before cutting and chitosan-based coating after cutting.	Packaged in trays and sealed with a microperforated polyethylene (30 µm thickness).	4°C for 10 days	Chitosan-based coating+MAP treatment could provide a better inhibitory effect on the browning and extend the shelf life of fresh-cut lotus root.	Xing *et al.* (2010)
10.	Peeled white asparagus	Heat treatment by immersion in a hot water bath at 55°C for 3 min and cooling in water containing 150 µL L^{-1} chlorine at ambient temperature	Polystyrene trays hand wrapped with a 16 µm stretch film.	3°C for 6 days	The combination of heat treatment with modified atmosphere packaging (MAP) could be used to improve the storage life of this product.	Siomos *et al.* (2010)

		for 10 min				
11.	Peeled white asparagus	Immersed in an aqueous solution of sodium hypochlorite containing 150 mg/l of free available chlorine for 8 min with slight manual agitation	Polystyrene trays overwrapped with two polypropylene oriented micro-perforated films of 35 mm in thickness with different gas permeability. The film A had an O_2 transmission rate of 13200 ml m^{-2} day^{-1} atm^{-1} and film B had 45000 ml O_2 m^{-2} day^{-1} atm^{-1}	Two different temperatures, 5°C ±1 and 10°C±1, and 50% RH for up to 14 days.	Modified atmosphere generated with film A extended shelf life at 5°C, since spoilage was inhibited.	Simon and Gonzalez-Fandos (2011)
12.	Fresh-cut asparagus	Washed with tap water, with chlorinated water containing 100 mg/L free Cl_2 and with ozonated water at 0.10 mg/L O_3	OPP packaging Properties were 35mm thickness, 3500 cm^3mil/(m^2-day-atm) gas mixtures were 8.15±0.29 kPa CO_2 and 17.51±0.39 kPa O_2	4°C for 28 days	Washed fresh-cut asparagus with chlorinated water and storage in an active MAP of OPP bags containing 8.15 kPa CO_2 and 17.51 kPa O_2 maintained its quality for 23 days at 4°C	Sothornvit and Kiatchanapaibul (2009)
13.	Fresh-cut Cime di rapa	Washed in 0.25 g/L sodium hypochlorine solution for 1 min.	Oriented polypropylene (OPP) (20 mm), two biodegradable polyesters (NVT, 50 mm and 100 mm), nylon/ polyethylene (MF 95 mm)	5°C and 48.7% of relative humidity (RH) for 9 days	Samples packaged in the MF-based bag were compromised by off-odours, due to the higher gas barrier properties of the film; Cime di rapa stored in the biodegradable materials resulted very compromised by wilting, due to high water permeable bags. On the contrary, the OPP film considerably increased the shelf life of the fresh-cut produce, with a unique limitation represented by visible moulds.	Conte *et al.* (2011)
14.	Sliced onions	-	Wrapped with low density polyethylene (LDPE) (30μm) film	Different temperatures (−2, 4 and 10 °C) in dark and atmospheric	The microbial shelf lives of the tested onions in 40% CO_2 + 59% N_2 +1% O_2, or at −2, 4 and 10°C, were 12.5, 9.5, 7, 12, 9 and 6 days, respectively, and their sensory shelf lives were 12, 8, 5, 10.5, 7 and 5 days,	Liu and Li (2006)

				conditions (with or without 40% CO_2 + 59% N_2 +1%O_2)	respectively.	
15.	Minimally processed 'Hayward' kiwifruit	Sanitized with chlorinated water (200 mg/L) for 5 min at 15°C before cutting, kiwifruit slices were treated for 10 min by immersing them in different solutions of aloe-vera gel (15°C) 1, 5 and 15% (v/v).	Polypropylene trays (450 mL) and sealed with a composite film (PP-PET, 64 µm, O_2 permeability = $4.58x10^{-6}$ $mL/m^2/d/Pa$)	4 ± 1°C and 75% RH for 12 days	The sensory evaluation of the samples coated with 5% aloe also yielded the highest score for overall quality.	Benitez *et al.* (2013)
16.	Fresh-cut papaya	Immersion in a solution of calcium chloride (1% w/v) and citric acid (2% w/v) for 5 min	Packed in an atmosphere of 5% O_2, 10% CO_2, 85% N_2 with polypropylene (PP) film	5°C for 25 days	Chemical treatment followed by MAP, showed the best results among the treatment in terms of retaining sensory and quality characteristics and extending the shelf-life of 25 days for fresh-cut papaya.	Waghmare and Annapure (2013)
17.	Fresh-cut Jackfruit bulbs	Post-cutting phytosanitation wash followed by a dip pretreatment with calcium chloride, ascorbic acid and sodium benzoate under mild acidified conditions prior to MAP	3 kPa O_2 + 5 kPa CO_2 (balance of N_2) gas mixture flushed polyethylene (GFPE) bags, PET jars equipped with a silicon membrane (SM) window on the lid, PE bags.	6 °C	Dip pretreatment along with different MAP was found effective in establishing optimum O_2 and CO_2 concentrations. On the basis of sensory quality attributes, the shelf-life of pretreated jackfruit bulbs packaged in gas mixture flushed PE bags, in PET jars with silicon membrane window and in PE bag were 35, 31 and 27 days, respectively.	Saxena *et al.* (2008)

tomato slices treated with sodium hypochlorite than from control slices during storage at 5°C under modified atmosphere. Higher number of microorganisms were observed in potato slices stored in an atmosphere containing 5% O_2 than that in an atmosphere containing 0% O_2. Washing of potato slices with browning prevention chemicals (citric acid + ascorbic acid : 0.1% + 0.1% or 0.5% + 0.5%) decreased the number of microorganisms compared to potato slices not washed or potato slices washed with water after 7 days of storage (Laurila *et al.*, 1998)

Song *et al.* (1996) observed that hexanal vapour inhibited hyphal growth of Penicillium expansum and Botrytis cinerea on potato dextrose agar (PDA) and on *MP* apple slices (cv. *Jonagold* and *Golden Delicious*). The authors also examined the possibility of developing a system for treating apple slices with hexanal in modified-atmosphere packages.

Watada *et al.* (1998) monitored quality changes, microbial population and respiration rates in freshly sliced fruits and vegetables (spinach, broccoli, carrots, zucchini [marrows], peaches, honeydew melons and strawberries) stored in a low-O_2 controlled atmosphere (0.5-2.0% O_2, 5-10% CO_2). It was concluded that a low O_2 atmosphere in MAP can be beneficial, provided the minimum O_2 concentration is maintained.

To determine the safety of fresh-cut vegetables packaged in MA, Austin *et al.* (1998) performed challenge studies using both nonproteolytic and proteolytic strains of *C. botulinum* with a variety of fresh-cut packaged salads and vegetables stored at different temperatures and reported that the strict maintenance of low temperatures (<5°C) was recommended to control the potential growth of *C. botulinum* on fresh-cut vegetables packaged in a modified atmosphere. Vescovo *et al.* (1997) studied the effects and interactions of sixteen combinations of CO_2 concentration, *Lactobacillus casei* inoculum size and storage temperature on the growth of *Aeromonas hydrophila* and lactic acid bacteria in ready-to-use mixed salad vegetables packaged under modified atmosphere. The growth curve parameters, modelled according to the Gompertz equation, were analysed to generate polynomial equations. The model obtained emphasized the role of *L. casei* inoculum size in controlling A. *hydrophila* and permitted identification of appropriate combinations of the selected variables to reduce A. *hydrophila* survival. It was suggested that use of these hurdles may increase the shelf-life and the microbiological safety of ready-to-use vegetables. Washing with citric acid before slicing combined with packaging in modified atmosphere with PVC film resulted in reduced microbial counts of sliced mushroom when stored at 5°C for up to 17 days (Simon *et al.,* 2010). Moreira and Roura (2011) evaluated the antimicrobial effects of chitosan on the microflora (mesophilic, psychrotrophic, yeast and molds, lactic acid bacteria and coliforms) and on the survival of E. coli O157:H7 inoculated in broccoli. Broccoli florets were treated (with or without the pathogen inoculation) and placed in polymeric film bags (PD960, CRYOVAC, Argentina) of 25 mm of thickness with an O_2 permeability of 7000 cc/m^2/d, CO_2 permeability of 20,000cc/m^2/d, and water vapor permeability of 1 g/m^2/d, placing 3 broccoli florets per bag (approximately 60-90 g) and stored in a refrigerated chamber at 5-7°C for 20 days. Chitosan treatments resulted in a significant reduction in total mesophilic and psychrotrophic bacteria counts with respect to the control samples during the entire storage period. Microbial proliferation and sensory quality aspects of sliced onions (0.7 cm thickness) were tested by Liu and Li (2006) in low density polyethylene (LDPE of 30 µm) packages. Microbial shelf life of the tested onions at 2, 4 and 10°C, with or without 40% CO_2 + 59% N_2 +1% O_2, were 12.5, 9.5, 7, 12, 9 and 6 days, respectively, and their sensory shelf lives were 12, 8, 5, 10.5, 7 and 5 days, respectively.

Quality and safety of commercially available MA stored *minimally processed* produce

Some studies have also been conducted on the assessment of quality of some commercially available minimally processed fruits and vegetables. Lilly *et al.* (1996) determined the incidence of *C. botulinum* spores in commercially available, precut vegetables stored under MAP. Results indicated a low overall incidence rate (0.36%) of *C. botulinum* spores in commercially available precut MAP vegetables. The quality of four types of packaged salad products (retail and food service Garden salad, Caesar salad and European salad) manufactured by five major processors in the United states of America (USA) and stored at 5°C for 20 days was assessed by Lopez *et al.* (1997b). Total aerobic microbial load increased by an average of 2.5-3 log units over 20 days.

Peiser *et al.* (1997) observed that food service garden salad packages (containing commercially processed iceberg lettuce, carrot and red cabbage) obtained from 5 California processors had 0.2-1.0% O_2 and 5-20% CO_2 after over 15 days of storage at 5°C. Acetaldehyde and ethanol developed in the tissues at concentrations of 2-22 µl/kg and 50-1500 µl/kg, respectively, by the 'Best if used by Date' (BIUD). Packages from all processors were above the limit of salability for overall visual quality by the BIUD, although off-odours were detected.

Hagenmaier and Baker (1998) sampled five nationally and regionally distributed brands of ready-to-eat salads in sealed bags from major supermarket chains. During purchase, product temperature was 4-7°C; the mean mesophilic microbial population was 1x10^{7} CFU/g; the yeast population was 210 CFU/g; the mean headspace O_2 and CO_2 concentrations were 1.2 and 12%, respectively; and the ethanol content was 700 ppm. For samples analysed on the expiration date (14-16 days after packaging), the mean mesophilic microbial population was 6x10^{7} CFU/g; ethanol content was 1500 ppm; and the headspace gas had not markedly changed from time of purchase. Rodov *et al.,* (2000) reported that when retail packages of sweet corn (film-wrapped trays containing a pair of trimmed cobs) were stored at 2°C within additional plastic liners. The modified atmosphere (MA), generated in these nested packages by corn respiration, complied with the recommended range of 5–10 kPa CO_2 and inhibited mold growth. No *E.coli* were detected during the whole storage in grated carrots samples treated under MAP and irradiated at doses ≥ 0.3 kGy (Lacroix and Lafortune, 2004). Modified atmosphere packaging (MAP) enhanced the reduction of the total aerobic and coliform bacteria in cut Chinese cabbage, irradiated at doses up to 2 kGy with air, CO_2 or CO_2/N_2 packaging during a refrigerated storage for 3 weeks (Ahn *et al.,* 2005). Granado-Lorencio *et al.* (2008) reported that modified-atmosphere packaging does not affect significantly the *in vivo* bioavailability of carotenoids and tocopherols from broccoli, supporting its convenience for use by the food industry and consumers. The effect of MAP on yeasts is negligible, however, molds are aerobic microorganisms and therefore CO_2 can cause growth inhibition at concentrations as low as 10% (Molin, 2000).

Modelling and design of MAP for *minimally processed* fruits and vegetables

In case of the horticultural commodities, the composition of the atmosphere in a MAP system is a function of the initial gas composition, product:head space ratio, gas permeability characteristics of the packaging film and plant tissue, and respiration rate of the tissue (O'Connor *et al.,* 1992). However, depending on the product tolerances, the ideal equilibrium O_2 and CO_2 levels would be in the 1-3% and 3-10% range, respectively (Gorris and Peppelenbos, 1992). But, in many commercial MAP systems extremely low O_2 levels (<1-2%) and high CO_2 levels (>20-30%) have been found. In addition to the potential safety problem of low O_2 tolerant psychrotrophs, growth and toxin production by *C. Botulinum* becomes a serious hazard in these cases where O_2 has almost completely expired. Powrie and Skura (1991) reported that under anaerobic conditions of packaging, it leads to anaerobic respiration and thus the formation of ethanol, aldehyde and ketones.

Hence, the modified atmosphere package should be scientifically designed depending on the characteristics of the stored produce and the desired characteristics of the package. A number of studies have been conducted to model the atmosphere in fruits and vegetables stored under MA conditions depending on the product and packaging film characteristics (Sudheer, 1999). However, by minimal processing, the produce behaviour would change considerably and a reasonable determination of the respiration rate of the minimally processed fruits and vegetables under the MAP conditions is very much essential to determine the package volume and material characteristics. Cameron *et al.* (1995) have discussed about developing predictive models for modified atmosphere packaging, modeling O_2 uptake, gas permeation, steady state O_2, CO_2 and RH levels, measurement of respiration, film permeability, skin permeability, lower O_2 limits, estimating permeability requirements, predicting gas levels in MA packages, temperature effects of gas concentrations, and film requirements in relation to MAP of lightly processed fruits and vegetables. Day *et al.* (1994) described the methods of creating MA conditions together with the intrinsic properties of fresh produce that need to be considered and extrinsic factors that need to be optimized for successful utilization of MAP technology. In addition, the concept of mathematical modeling of MAP has been introduced, and information on commercial and future developments is provided. Oliveira *et al.* (1998) discussed the general aspects of MAP and concepts, advantages and limitations of perforations as a means of atmosphere modification. Design of perforated MAP, highlighting important factors and processes that influence the overall dynamic MAP system have also been outlined. Respiration rate models are discussed and a preliminary study on the respiration rate of shredded cabbage has been presented. Based on the isostatic method, Artes *et al.* (1998) determined the permeabilities to O_2 and CO_2, the Arrhenius constant and the activation energy (E_a) of permeation of some poly propylene (PP), poly vinyl chloride (PVC) and low density poly ethylene (LDPE) films, at 2, 12 and 20°C and 90% relative humidity. A low E_a was detected in LDPE and particularly in PVC. Changes in temperature during the marketing process slightly affected LDPE and PVC gas permeabilities. Selectivity of permeability to O_2 and CO_2 of the studied polymers, which is considered one of the most important parameters in the design of packages for respiring foods, ranged from 2.2 to 4.5 amol. mm/(m.s. Pa) at 2°C and from 2.4 to 4.3 amol. mm/(m.s. Pa) at 20°C. Consequently, these films were considered very suitable for making packages for modified atmosphere storage of fresh fruits and vegetables. In spite of their low E_a, PVC and LDPE could be recommended for conditioning commodities with a relatively high Q_{10} (temperature coefficient) in order to avoid risks of fermentation due to their high permeability to O_2 and CO_2 at 2-20°C. On the other hand, PP may be considered advantageous for generating favorable modified atmospheres for commodities with a moderate to low Q_{10}, due to its relatively low permeability to O_2 and CO_2 and high E_a. Beaudry *et al.* (1998) presented a method to describe O_2 concentrations in MAPs composed of polymeric films using relatively simple mathematical equations that incorporate film permeability, the respiratory response to O_2 and the temperature dependence of both processes. The authors mentioned that the impact of the atmosphere and the presence of packaging film on the aroma profile of *MP* fruits was unknown and the sorption and diffusion coefficients for aroma volatiles tend to be markedly different from those of O_2 or CO_2. Nevertheless, the rates of sorption, diffusion and permeation of aroma volatiles can, in some cases, be described mathematically such that the accumulation of aroma volatiles may be modeled in conjunction with O_2 and CO_2 concentration. An example using hexyl acetate production from a sliced apple product has been presented. The effect of O_2 on the rate of fermentative metabolism has been incorporated into the model, which might relate to the occurrence of off-flavours. The modeling approach can be used to predict O_2 concentration, hexyl acetate concentration and fermentation activity as a function of temperature and film thickness.

Bastrash *et al.* (1993) conducted experiments to compare the rates of respiration and ethylene production by intact broccoli (cv. *Green Valiant*) heads and florets and to determine the optimal atmosphere for preservation of florets at 4°C and reported that the minimal processing had little influence on optimal storage atmosphere, suggesting that recommendations for intact produce could be useful guidelines for MAP of *MP* vegetables.

Segall and Scanlon (1996) determined the oxygen consumption rates of commercially prepared lettuce in a closed system for 3% O_2 with 6, 10 or 14% CO_2. A linear model, which was found to be more suitable to describe the respiratory data than the enzymatic and quadratic mathematical models, was used to predict the O_2 consumption rate of the *MP* lettuce. The predicted O_2 consumption rate was used to determine the O_2 permeability for the packaging film. Packages (21.6X25.4 cm), made from a polypropylene-polyethylene- laminate film with appropriate O_2 permeability to develop the three modified atmospheres as mentioned above, were used for studying the shelf life of minimally processed lettuce. However, the O_2 consumption rate of the lettuce decreased with increasing CO_2 concentration, and the O_2 concentration in the MA packages equilibrated at 7-11%.

Lee *et al.* (1996) designed the MAP for a mixed vegetable salad, consisting of 75 g of cut carrot, 55 g of cut cucumber, 20 g of sliced garlic and 50 g of whole green pepper, combining the respiration data of all the components with film permeability data. The optimal package designed from above studies avoided minimum O_2 and maximum CO_2 tolerance limits, and chilling injury temperatures for any component. A pouch form package made of 27 µm LDPE developed a modified atmosphere of 2.0-2.1% O_2 and 5.5-5.7% CO_2, which was beneficial for all components and provided better quality retention than other test packages.

Pirovani *et al.* (1997) compared the atmosphere in bags of mono-oriented polypropylene film (OPP bags) or in PE trays overwrapped with a multilayer shrink polyolefin (RD106-PE tray) or with a plasticized PVC film (PVC-PE tray) with shredded white cabbage stored at 3°C and 70-80% RH for up to 13 days. The modified atmosphere in PVC-PE and RD106-PE trays did not change more than 3% when compared with normal atmosphere levels. However, in OPP bags, O_2 reached 2% and CO_2 increased to approximately 13% after 3 days.

MAP systems with head lettuce, cut broccoli, whole broccoli, tomatoes, sweet corn and blueberries were designed using the gas permeability coefficients. The gas composition in each biodegradable package including the fresh produce was simulated to be close to the optimal composition. As a result, the biodegradable laminate was considered suitable as a packaging material for storage of fresh produce (Makino and Hirata, 1997). Kim *et al.* (2004) conducted an experiment to develop a modified atmosphere packaging system for fresh-cut salad savoy (*Brassica oleracea* L.) and to evaluate the effect of film oxygen transmission rate (OTR) on package atmospheres, and consequently product quality changes during storage and reported that packages with 16.6 and 21.4 $pmol s^{-1} m^{-2} Pa^{-1}$ OTR films attained the desired O_2 (1.4–3.8 kPa) and CO_2 levels (3.6–6.3 kPa) on day 10 and throughout the storage period; products stored in these packages maintained freshness with high overall quality scores. Gonzalez-Buesa *et al.* (2009) compared the evolution of the gas composition inside the package predicted by the model with the results of experiments conducted at 4°C with minimally processed peach ('*Andross*' and '*Calante*' cultivars), fresh-cut cauliflower and whole black truffle, by using seven packages of different number (0–14) and size (from 90x50 µm to 300x100 µm) of microperforations. The experimental data and those predicted by the model showed a satisfactory agreement for the O_2, while the CO_2 is underestimated for products with respiration quotient (RQ) < 1 but in agreement when RQ > 1. Oliveira *et al.* (2012) developed a kinetic model to describe the influence of temperature on firmness and predict shelf-life of sliced mushrooms. Fresh sliced mushrooms had a shelf-life of 1, 2, 4, and 7.5 days at 15, 10, 5, and 0°C, respectively, under optimum MAP conditions. Waghmare *et al.* (2013) quantified the respiration rate of (RR) of three fresh-cut products viz. coriander, cluster beans and beetroot and a mathematical model was developed for prediction of RR as a function of both time and temperature. Temperature and the interaction of time and temperature had significant effects on RR. The dependence of respiration rate of fresh-cut produce on temperature and time was well described by Arrhenius and first order decay models.

Discussion

Though there have been several studies connected to the application of the MAP for minimally processed fruits and vegetables, still there exists a gap in the desired technology and available technology for the application of this system. Much research is still neded to develop minimally processed fruits and vegetables that have high sensory quality, microbiological safety and nutritional value. More information about the growth of pathogenic bacteria and the occurrence of nutritional changes in minimally processed fruits and vegetables with long shelf life is still needed.

There should be an accurate balance between the product respiration and the permeability characteristics of the packaging material. The respiration rate and other characteristics of the produce during storage will change with the produce, cultivar, period of storage and with change in temperature, among other factors. Besides as most of the salad products are not packed alone, but as a combination of several types of lightly processed vegetables, it is quite difficult to assess the respiration rate of the packed produce in group. It makes the package design of the minimally processed produce a tedious one. Day (1996) has also mentioned that maintaining the required concentrations of O_2 and CO_2 was very difficult as none of the packaging materials available in the market were permeable enough. Most films do not result in optimal O_2 and CO_2 atmospheres, especially when the produce has a high level of respiration. However, one solution is to make microholes of a defined size and of a defined number in the materials to avoid anaerobes (Exama *et al.* 1993). The use of composite materials have also been tried (Segall and Scanlon, 1996), which may prove to a suitable alternative.

With regard to the rationalization of production and utilisation of the peeling waste it is reasonable to aim for centralized processing of fruits and vegetables. Willocx *et al.* (1994) mentioned that though MAP was effective in inhibiting the spoilage mechanisms, as well as reducing respiration, delay ripening and decreasing ethylene production, MAP would not eliminate the need of refrigeration. Therefore, wherever, refrigeration facility is not available for storage and transportation, modified atmosphere packaging can not be considered as a solution to extend the shelf life of the minimally processed products.

Ahvenainen (1996) mentioned that hurdle technology that makes use of natural preservatives such as inhibitors produced by lactic acid bacteria, and the matching of correct processing methods and ingredients to each other are two approaches that should be applied more often to minimal processing and produce. Exama *et al.* (1993) proposed a safety valve system which prevents excessive depletion of O_2 and excessive CO_2 accumulation when a transient temperature increase occurs. Hence all these possibilities should be tried and suitable technologies need be recommended to the producers and consumers for more popularisation of minimally processed fruits and vegetables.

Conclusion

Minimally Processed fruits and vegetables are those prepared for convenient consumption and distributed to the consumer in a fresh like state. Shredded lettuce and cabbage, cut fruits, peeled and sliced potatoes, etc. are some common examples of minimally processed fruits and vegetables being produced now-a-days and which have gained enough popularity for reasons of expense, labor and hygiene. Though the minimally processed fruits and vegetables are supposed to be shipped under low temperature, but the growth of spoilage organisms and quick degradation of the produce by increased respiration, ethylene production, etc. need an additional barrier for the stored produce. Modified atmosphere packaging is one option which has been studied for the purpose. The studies indicate that MAP of minimally processed fruits and vegetables offer enough promise in the recent scenario with increased volume of handling of minimally processed fruits and vegetables. However, more work needs to be done for defining the behavior of mixed processed fruits and vegetables and design of the MAP for these products.

References

Ahn HJ, Kim JH, Kim JK, Kim DH, Yook HS and Byun MW (2005). Combined effects of irradiation and modified atmosphere packaging on minimally processed Chinese cabbage (*Brassica rapa* L.). *Food Chemistry*, 89(4): 589-597.

Ahvenainen R (1996). New approaches in improving the shelf life of minimally processed fruit and vegetables. *Trends in Food Science and Technology*, 7: 179-187.

Ahvenainen R, Hurme E, Mattila M, Pala M(ed.), Hohn E(ed.) and Somogyi Z (1995). Minimal processing and modified atmosphere packaging of vegetables. *COST 94*. The post harvest treatment of fruit and vegetables: modified atmosphere packaging. *Proceedings of a workshop, Istanbul, Turkey, 1, 2 October 1992*, 35-40.

An J, Zhang M and Lu Q (2007). Changes in some quality indexes in fresh-cut green asparagus pretreated with aqueous ozone and subsequent modified atmosphere packaging. *Journal of Food Engineering*, 78: 340–344.

Ansorena MR, Marcovich NE and Roura SI (2011). Impact of edible coatings and mild heat shocks on quality of minimally processed broccoli (*Brassica oleracea* L.) during refrigerated storage. *Postharvest Biology and Technology*, 59: 53–63.

Artes F, Martinez JA and Ben Yehoshua S (1998). Gas transmission characteristics of different films used for packaging intact and minimally processed fruits and vegetables. *14th International congress on plastics in agriculture, Tel Aviv, Israel, March 1997*, 481-486.

Artes F, Martinez JA, Marin JG, Hagg M(ed.), Ahvenainen R(ed.), Evers A M(ed.) and Tiilikkala K (1999). Quality changes in minimally processed 'Romaine' lettuce as affected by several treatments. *Agri, Food Quality II: quality management of fruits and vegetables, from field to table, Turku, Finland, 22, 25 April 1998*, 115-118.

Austin JW, Dodds KL, Blanchfield B and Farber JM (1998). Growth and toxin production by Clostridium botulinum on inoculated fresh, cut packaged vegetables. *Journal of Food Protection*, 61: 324-328.

Barth MM and Zhuang H (1996). Packaging design affects antioxidant vitamin retention and quality of broccoli florets during postharvest storage. *Postharvest Biology and Technology*, 9(2): 141-150.

Bastrash S, Makhlouf J, Castaigne F and Willemot C (1993). Optimal controlled atmosphere conditions for storage of broccoli florets. *Journal of Food Science*, 58(2): 338-341.

Beaudry RM, Deng WM, Lakakul R, Jun S and Yehoshua BS (1998). Packaging effects on respiratory and aroma volatiles of apples. *14th International congress on plastics in agriculture, Tel Aviv, Israel, March 1997. 1998*, 608-616.

Benitez S, Achaerandio I, Sepulcre F and Pujola M (2013). Aloe vera based edible coatings improve the quality of minimally processed 'Hayward' kiwifruit. *Postharvest Biology and Technology*, 81: 29–36.

Bennik MHJ, Peppelenbos HW, Nguyen TC, Carlin F, Smid EJ and Gorris LGM (1996). Microbiology of minimally processed, modified atmosphere packaged chicory endive. *Postharvest Biology and Technology*, 9(2): 209-221.

Berger H, Galletti L, Escalona V, Saenz C and Gorny JR (1997). Modified atmospheres and ascorbic acid for minimally processed lettuce. *7th* international controlled atmosphere research conference. CA '97. *Proc. volume 5: Fresh cut fruits and vegetables and MAP, Davis, California, USA, 13-18 July, Postharvest Horticulture Series-Department of Pomology, Univ. of California. 1997,* 19: 16-22.

Blanchard M, Castaigne F, Willemot C and Makhlouf J (1996). Modified atmosphere preservation of freshly prepared diced yellow onion. *Postharvest Biology and Technology*, 9(2): 173-185.

Cameron AC, Talasila PC and Joles DW (1995). Predicting film permeability needs for modified, atmosphere packaging of lightly processed fruits and vegetables. *Proc. of the colloquium on lightly processed fruits and vegetables held at the 90th ASHS Annual Meeting, Nashville, Tenessee, USA, 27 July 1993. Hort Science*, 30: 25-34.

Carlin F, Nguyen-the C, Silva AAD and Cochet C (1996). Effects of carbon dioxide on the fate of Listeria monocytogenes, of aerobic bacteria and on the development of spoilage in minimally processed fresh endive. *International Journal of Food Microbiology*, 32(1-2): 159-172.

Castaner M, Gil MI, Ferreres F, Artes F, Tomas Barberan FA and Gorny JR (1997). Effect of modified atmospheres on anthocyanin stability and other phenolic metabolites during storage of minimally processed red lettuce. 7th international controlled atmosphere research conference. CA '97. *Proc. volume 5: Fresh, cut fruits and vegetables and MAP, Davis, California, USA, 13-18 July, Postharvest Horticulture Series, Department of Pomology, Univ of California 1997*, 19: 134-138.

Chervin C and Boisseau P (1994). Quality maintenance of "ready to eat" shredded carrots by gamma irradiation. *Journal of Food Science*, 59(2): 359-361.

Cliffe-Byrnes V and Beirne DO (2008). Effects of washing treatment on microbial and sensory quality of modified atmosphere (MA) packaged fresh sliced mushroom (Agaricus bisporus). *Postharvest Biology and Technology*, 48(2): 283-294.

Conte A, Scrocco C, Brescia I, Mastromatteo M and Del Nobile MA (2011). Shelf life of fresh-cut Cime di rapa (*Brassica rapa* L.) as affected by packaging. *LWT - Food Science and Technology*, 44: 1218-1225.

Day BPF (1996). High oxygen modified atmosphere packaging for fresh prepared produce. *Postharvest News and Information*, 7: 31N-34N.

Day BPF, Ahvenainen R(ed.), Mattila ST (ed.) and Ohlsson T (1994). Modified atmosphere packaging and active packaging of fruits and vegetables. *Minimal processing of foods, 14-15 Apr. 1994, Kirkkonummi, Finland. VTT, Symposium. 1994*, 142: 173-207.

Diaz C and Hotchkiss JH (1996). Comparative growth of Escherichia coli 0157:H7 spoilage organisms and shelf life of shredded iceberg lettuce stored under modified atmospheres. *Journal of the Science of Food and Agriculture*, 70(4): 433- 438.

Exama A, Arul J, Lencki RW, Lee LZ and Toupin C (1993). Suitability of plastic films for modified atmosphere packaging of fruits and vegetables. *Journal of Food Science*, 58 (6): 1365-1370.

Finn MJ and Upton ME (1997). Survival of pathogens on modified atmosphere packaged shredded carrot and cabbage. *Journal of Food Protection*, 60(11): 1347-1350.

Finnegan E, Mahajan PV, O'Connell M, Francis GA and O'Beirne D (2013). Modelling respiration in fresh-cut pineapple and prediction of gas permeability needs for optimal modified atmosphere packaging. *Postharvest Biology and Technology*, 79: 47–53.

Galetti L, Berger H, Escalona V, Saenz C, Araya E and Gorny JR (1997). Modified atmospheres and ascorbic acid for minimum process of carrot slices. 7th international controlled atmosphere research conference. CA '97. *Proc. volume 5: Fresh, cut fruits and vegetables and MAP, Davis, California, USA, 13-18 July, 1997. Postharvest Horticulture Series, Department of Pomology, Univ of California. 1997,* 19: 139-144.

Geraldine RM, Soares NFF, Botrel DA and Goncalves LA (2008). Characterization and effect of edible coatings on minimally processed garlic quality. *Carbohydrate Polymers*, 72: 403–409.

Gil MI, Conesa MA and Artes F (2002). Quality changes in fresh cut tomato as affected by modified atmosphere packaging. *Postharvest Biology and Technology*, 25(2): 199-207.

Gil MI, Artes F and Tomas-Barberan FA (1996). Minimal processing and modified atmosphere packaging effects on pigmentation of pomegranate seeds. *Journal of Food Science*, 61(1): 161-164.

Gil MI, Castaner M, Ferreres F, Artes F and Tomas-Barberan FA (1998a). Modified atmosphere packaging of minimally processed 'Lollo Rosso' (*Lactuca sativa*): Phenolic metabolites and quality changes. Zeitschrift fur Lebensmittel Untersuchung und Forschung. *European Food Research and Technology*, 206(5): 350-354.

Gil MI, Ferreres F and Tomas-Barberan FA (1998b). Effect of modified atmosphere packaging on the flavonoids and vitamin C content of minimally processed Swiss chard (*Beta vulgaris* subspecies *cycla*). *Journal of Agricultural Food Chemistry*, 46(5): 2007-2012.

Gomez PA and Artes F (2005). Improved keeping quality of minimally fresh processed celery sticks by modified atmosphere packaging. *LWT - Food Science and Technology*, 38(4): 323-329.

Gonzalez-Buesa J, Ferrer-Mairal A, Oria R and Salvador ML (2009). A mathematical model for packaging with microperforated films of fresh-cut fruits and vegetables. *Journal of Food Engineering*, 95: 158–165.

Gorris LGM and Peppelenbos HW (1992). Modified atmosphere and vacuum packaging to extend the shelf life of respiring food products. *Hort Technology*, 2(3): 303-309.

Gorris LGM (1994). Improvement of the safety and quality of refrigerated ready, to, eat foods using novel mild preservation techniques. In: Minimal processing of foods and process optimisation, an interface.(R. Paul Singh and FAR Oliveria eds.) *CRC Press, Inc.*

Granado-Lorencio F, Olmedilla-Alonso B, Herrero-Barbudo C, Sanchez-Moreno C, de Ancos B, Martinez JA, Perez-Sacristan B and Blanco-Navarro I (2008). Modified-atmosphere packaging (MAP) does not affect the bioavailability of tocopherols and carotenoids from broccoli in humans: A cross-over study. *Food Chemistry*, 106(3): 1070-1076.

Hagenmaier RD and Baker RA (1998). A survey of the microbial population and ethanol content of bagged salad. *Journal of Food Protection*, 61 (3): 357-359.

Heimdal H, Kuhn BF, Poll L and Larsen LM (1995). Biochemical changes and sensory quality of shredded and MA packaged iceberg lettuce. *Journal of Food Science*, 60(6): 1265-1268, 1276.

Hong JH and Gross KC (1998). Surface sterilization of whole tomato fruit with sodium hypochlorite influences subsequent postharvest behavior of fresh cut slices. *Postharvest Biology and Technology*, 13(1): 51-58.

Howard LR and Griffin LE (1993). Lignin formation and surface discoloration of minimally processed carrot sticks. *Journal of Food Science*, 58(5): 1065-1067, 1072.

Howard LR, Griffin LE and Lee Y (1994). Steam treatment of minimally processed carrot sticks to control surface discoloration. *Journal of Food Science*, 59(2): 356-358.

Hurme E, Ahvenainen R, Skytta E, Heinio RL, Mattila M, Hagg M, Pala M(ed.), Hohn E(ed.) and Somogyi Z (1995). Effects of preparation procedures and long term storage on the shelf, life of prepared vegetables packed in polypropylene film. *COST 94.* The post harvest treatment of fruit and vegetables: modified atmosphere packaging. *Proceedings of a workshop, Istanbul, Turkey, 1-2 October. 1992*, 41-49.

Izumi H, Nonaka T, Muraoka T and Gorny JR (1997). Physiology and quality of fresh, cut spinach stored in low O_2 controlled atmospheres at various temperatures. 7th international controlled atmosphere research conference. CA '97. *Proc. volume 5: Fresh, cut fruits and vegetables and MAP, Davis, California, USA, 13-18 July, Postharvest Horticulture Series, Department of Pomology, Univ of California. 1997*, No. 19: 130-133.

Jia C, Xu C, Wei J, Yuan J, Yuan G, Wang B and Wang Q (2009). Effect of modified atmosphere packaging on visual quality and glucosinolates of broccoli florets. *Food Chemistry*, 114: 28–37.

Kakiomenou K, Tassou C and Nychas GJ (1996). Microbiological, physicochemical and organoleptic changes of shredded carrots stored under modified storage. *International Journal of Food Science and Technology*, 31(4): 359-366.

Keteleer A, Mulder C, Hermans A, Tobback P, De Mulder C, Hribar J (ed.), Johnson D S(ed.), Bohling H (ed.), De La Plaza J (ed.), Haffner K E (ed.), Hohn E (ed.) and Somogyi Z (1994). The use of multivariate data analysis techniques for identification of objective quality criteria for minimally processed leek stored under modified atmosphere. COST 94. *The post harvest treatment of fruit and vegetables: quality criteria. Proc. of a workshop, Bled, Slovenia, 19, 21 April 1994*, 25-37.

Kim B (1999). Freshness prolongation of minimally processed Chinese cabbage with active modified atmosphere packaging. *Acta Horticulture*, 483: 319-324.

Kim JG, Luo Y and Gross KC (2004). Effect of package film on the quality of fresh-cut salad savoy. *Postharvest Biology and Technology*, 32(1): 99-107.

King AD Jr and Bolin HR (1989). Physiological and microbiological storage stability of minimally processed fruits and vegetables. *Food Technology*, 43(2): 132-135, 139.

Labuza TP, Fu B and Taoukis PS (1992). Prediction for shelf life and safety of minimally processed CAP/MAP chilled foods: a review. *Journal of Food Protection*, 55(9): 741-750.

Lacroix M and Lafortune R (2004). Combined effects of gamma irradiation and modified atmosphere packaging on bacterial resistance in grated carrots (*Daucus carota*). *Radiation Physics and Chemistry*, 71(1-2): 79-82.

Laurila EK, Hurme EU and Ahvenainen RT (1998). Shelf life of sliced raw potatoes of various cultivar varieties-substitution of bisulfites. Journal of Food Protection, 61(10): 1363-1371.

Lee KS, Park IS and Lee DS (1996). Modified atmosphere packaging of a mixed prepared vegetable salad dish. *International Journal of Food Science and Technology*, 31(1): 7-13.

Li P and Barth MM (1998). Impact of edible coatings on nutritional and physiological changes in lightly-processed carrots. *Postharvest Biology and Technology*, 14(1): 51-60.

Lilly T, Solomon HM and Rhodehamel EJ (1996). Incidence of Clostridium botulinum in vegetables packaged under vacuum or modified atmosphere. *Journal of Food Protection*, 59(1): 59-61.

Liu F and Li Y (2006). Storage characteristics and relationships between microbial growth parameters and shelf life of MAP sliced onions. *Postharvest Biology and Technology*, 40: 262–268.

Lopez GG, El Bassuoni R, Nie X, Cantwell M and Gorny JR (1997a). Quality of red and green fresh, cut peppers stored in controlled atmospheres. 7th international controlled atmosphere research conference. CA '97. *Proc. volume 5: Fresh, cut fruits and vegetables and MAP, Davis, California, USA, 13-18 July, Postharvest Horticulture Series, Dept. of Pomology, Univ. of California 1997*, No. 19: 152-157.

Lopez GG, Peiser G, Nie X and Cantwell M (1997b). Quality changes in packaged salad products during storage. *European Food Research and Technology*, 205(1): 64-72.

Lopezosornio MM and Chaves AR (1998). Quality changes in stored raw grated beetroots as affected by temperature and packaging film. *Journal of Food Science*, 63(2): 327-330.

Lu S (2007). Effect of packaging on shelf-life of minimally processed Bok Choy (*Brassica chinensis* L.). *LWT-Food Sci and Technology*, 40(3): 460-464.

Lund D (1989). Food processing from art to engineering. *Food Technology*, 43: 242-247.

Makino Y and Hirata T (1997). Modified atmosphere packaging of fresh produce with a biodegradable laminate of chitosan, cellulose and polycaprolactone. *Postharvest Biology and Technology*, 10(3): 247-254.

Manzano M, Citterio B, Maifreni M, Paganessi M and Comi G (1995). Microbial and sensory quality of vegetables for soup packaged in different atmospheres. *Journal of the Science of Food and Agriculture*, 67(4): 521-529.

Mattila M, Ahvenainen R, Hurme E and Hyvonen L (1995). Respiration rates of some minimally processed vegetables. In: Procedings of Workshop on Systems and operations for post, harvest quality (De Baerdema, et al. Eds.) COST 94' Post harvest treatment of fruits and vegetables. *Commission of the European Community, Brussels*, 135-145.

Molin G (2000). Modified atmospheres. In: Lund BM, Baird-Parker TC, Gould GW, editors. The microbiological safety and quality of food. Gaithersburg, MA: *Aspen Publishers*, 214-234.

Moreira MR and Roura SI (2011). Effectiveness of chitosan edible coatings to improve microbiological and sensory quality of fresh cut broccoli. *LWT - Food Science and Technology*, 44: 2335-2341.

Nguyen-the C and Carlin F (1994). The microbiology and minimally processed fresh fruits and vegetables. CRC- *Critical Reviews in Food Science and Nutrition*, 34(4): 371-401.

Niemira BA, Fan X and Sokorai, KJB (2005). Irradiation and modified atmosphere packaging of endive influences survival and regrowth of *Listeria monocytogenes* and product sensory qualities. *Radiation Physics and Chemistry*, 72(1): 41-48.

O'Connor and Shaw R (1998). Shelf life and safety of minimally processed fruits and vegetables. In: Sous vide and cook, chill processing for the food industry(eds. S. Ghazala), *Aspen Publishers, Inc., Maryland*.

O'Connor RE, Skarshewski P and Thrower SJ (1992). Modified atmosphere packaging of fruits, vegetables, sea food and meat: state of the art. *ASEAN Food Journal*, 7: 127-136.

Ohlsson T (1994). Minimal processing preservation methods of the future: an overview. *Trends in Food Science and Technology*, 5(11): 341-344.

Oliveira F, Sousa-Gallagher MJ, Mahajan PV and Teixeira JA (2012). Development of shelf-life kinetic model for modified atmosphere packaging of fresh sliced mushrooms. *Journal of Food Engineering*, 111: 466–473.

Oliveira FAR, Fonseca SC, Oliveira JC, Brecht JK and Chau KV (1998). Development of perforation mediated modified atmosphere packaging to preserve fresh fruit and vegetable quality after harvest. *Food Science and Technology International*, 4(5): 339-352.

Oms-Oliu G, Soliva-Fortuny R and Martin-Belloso O (2008). Modeling changes of headspace gas concentrations to describe the respiration of fresh-cut melon under low or superatmospheric oxygen atmospheres. *Journal of Food Engineering*, 85(3): 401-409.

Peiser G, Lopez Galvez G, Cantwell M and Gorny JR (1997). Changes in off odor volatiles of salad products during storage. 7th international controlled atmosphere research conference. CA '97. *Proc. volume 5: Fresh, cut fruits and vegetables and MAP, Davis, California, USA, 13-18 July, 1997. Postharvest Horticulture Series Department of Pomology, Univ of California. 1997*, 19: 23-28.

Perez-Cabrera L, Chafer M, Chiralt A and Gonzalez-Martinez C (2011). Effectiveness of antibrowning agents applied by vacuum impregnation on minimally processed pear. *LWT - Food Science and Technology*, 44: 2273-2280.

Perez-Gregorio MR, Garcia-Falcon MS and Simal-Gandara J (2011). Flavonoids changes in fresh-cut onions during storage in different packaging systems. *Food Chemistry*, 124: 652–658.

Pirovani ME, Guemes DR, Piagentini AM, Pentima JH and Pentima JHD (1997). Storage quality of minimally processed cabbage packaged in plastic films. *Journal of Food Quality*, 20(5): 381-389.

Plaza L, Crespo I, de Pascual-Teresa S, de Ancos B, Sanchez-Moreno C, Munoz M and Cano MP (2011). Impact of minimal processing on orange bioactive compounds during refrigerated storage. *Food Chemistry*, 124: 646–651.

Portela S, Nie X, Suslow T, Cantwell M and Gorny JR (1997). Changes in sensory quality and fermentative volatile concentrations of minimally processed cantaloupe stored in controlled atmospheres. 7th international controlled atmosphere research conference. CA '97. *Proc. volume 5: Fresh, cut fruits and vegetables and MAP, Davis, California, USA, 13-18 July, 1997. Postharvest Horticulture Series, Department of Pomology, Univ of California. 1997*, 19: 123-129.

Powrie WD and Skura BJ (1991). Modified atmosphere packaging of fruits and vegetables. In: Modified atmosphere packaging of Food (OoraiStiles, MS. Ed.), *Ellis Horwood*, 169-245.

Pretel MT, Fernandez PS, Romojaro F and Martinez A (1998). The effect of modified atmosphere packaging on 'ready to eat' oranges. *LWT-Food Science and Technology*, 31(4): 322-328.

Radziejewska-Kubzdela E, Czapski J and Czaczyk K (2007). The effect of packaging conditions on the quality of minimally processed celeriac flakes. *Food Control*, 18(10): 1191-1197.

Reyes VG, Simons L and Tran C (1996). Preservation of minimally processed carrots by edible coating and acid treatment. *Proc. Australasian postharvest horticulture conference 'Science and technology for the fresh food revolution', Melbourne, Australia, 18-22 September 1995*, 451-456.

Rodov V, Copel A, Aharoni N, Aharoni Y, Wiseblum A, Horev B and Vinokur Y (2000). Nested modified-atmosphere packages maintain quality of trimmed sweet corn during cold storage and the shelf life period. *Postharvest Biology and Technology*, 18(3): 259-266.

Sapers GM and Miller RL (1998). Browning inhibition in fresh-cut pears. *Journal of Food Science*, 63(2): 342-346.

Saxena A, Bawa AS and Raju PS (2008). Use of modified atmosphere packaging to extend shelf-life of minimally processed jackfruit (*Artocarpus heterophyllus* L.) bulbs. *Journal of Food Engineering*, 87(4): 455-466.

Segall KI and Scanlon MG (1996). Design and analysis of a modified atmosphere package for minimally processed romaine lettuce. *Journal of the American Society for Horticultural Science*, 121(4): 722-729.

Siddiq M, Roidoung S, Sogi DS and Dolan KD (2013). Total phenolics, antioxidant properties and quality of fresh-cut onions (*Allium cepa* L.) treated with mild-heat. *Food Chemistry*, 136: 803–806.

Simon A and Gonzalez-Fandos E (2011). Influence of modified atmosphere packaging and storage temperature on the sensory and microbiological quality of fresh peeled white asparagus. *Food Control*, 22: 369-374.

Simon A, Gonzalez-Fandos E and Vazquez M (2010). Effect of washing with citric acid and packaging in modified atmosphere on the sensory and microbiological quality of sliced mushrooms (*Agaricus bisporus* L.). *Food Control*, 21: 851–856.

Siomos AS, Gerasopoulos D, Tsouvaltzis P and Koukounaras A (2010). Effects of heat treatment on atmospheric composition and color of peeled white asparagus in modified atmosphere packaging. *Innovative Food Science and Emerging Technologies*,11: 118–122.

Song J, Leepipattanawit R, Deng W and Beaudry RM (1996). Hexanal vapor is a natural metabolizable fungicide: inhibition of fungal activity and enhancement of aroma biosynthesis in apple slices. *Journal of the American Society for Horticultural Science*, 121(5): 937-942.

Sothornvit R and Kiatchanapaibul P (2009). Quality and shelf-life of washed fresh-cut asparagus in modified atmosphere packaging. *LWT - Food Science and Technology*, 42: 1484–1490.

Sudheer KP (1999). Development and testing of modified atmosphere package for banana using silicone membrane. *Ph.D. thesis, Indian Agricultural Research Institute, New Delhi, India*.

Tudela JA, Espin JC and Gil MI (2002). Vitamin C retention in fresh-cut potatoes. *Postharvest Biology Technology*, 26(1): 75-84.

Varoquaux P, Mazollier J and Albagnac G (1996). The influence of raw material characteristics on the storage life of fresh cut butterhead lettuce. *Postharvest Biology and Technology*, 9(2): 127-139.

Varoquax P and Wiley R (1994). Biological and biochemical changes in minimally processed refrigerated fruits and vegetables. In: Minimally processed refrigerated fruits and vegetables (R.C. Wiley Ed.), 226-268.

Vescovo M, Scolari G, Orsi C, Sinigaglia M and Torriani S (1997). Combined effects of Lactobacillus casei inoculum, modified atmosphere packaging and storage temperature in controlling Aeromonas hydrophila in ready to use vegetables. *International Journal of Food Science and Technology*, 32(5): 411-419.

Waghmare RB and Annapure US (2013). Combined effect of chemical treatment and/or modified atmosphere packaging (MAP) on quality of fresh-cut papaya. *Postharvest Biology and Technology*, 85: 147–153.

Waghmare RB, Mahajan PV and Annapure, US (2013). Modelling the effect of time and temperature on respiration rate of selected fresh-cut produce. *Postharvest Biology and Technology*, 80: 25–30.

Watada AE and Qi L (1998). Physiology, quality and microorganism population on fresh cut products stored under low O_2 controlled atmospheres. *14th International congress on plastics in Agriculture., Tel Aviv, Israel, March 1997*. 1998: 579-585.

Willcox F, Hendrickx M and Tobback P (1994). The influence of temperature and gas composition on the evolution of microbial and quality of minimally processed endive. In: Minimal processing of foods and process optimisation: an interface (R.P.Singh and F.A.R.Oliveria Eds.), 475- 492.

Xing Y, Li X, Xu Q, Jiang Y, Yun J and Li W (2010). Effects of chitosan-based coating and modified atmosphere packaging (MAP) on browning and shelf life of fresh-cut lotus root (*Nelumbo nucifera* Gaerth). *Innovative Food Science and Emerging Technologies*, 11: 684–689.

Zagory D (1995). Principles and packaging of modified atmosphere packaging of horticultural commodities. In: Principles of modified atmosphere and saus vide product packaging (J.M. Farber and K.L. Dodds eds.). *Technomic Publishing Co., Lancaster Publishing Co., Lancaster, PA*, 175-206.