REVIEW OF LITERATURE

2.1 INTRODUCTION

Fruit and vegetable consumption is growing rapidly in recent years. Associated with the new consumer profile, there is a high demand for ready-to-eat products. For this reason, the industry of fresh-cut fruits and vegetables is constantly growing and new methods for maintaining quality and inhibiting undesirable microbial growth are demanded in all the steps of the production and distribution chain. Therefore, a growing interest and efforts over the last few years regarding development of novel food packaging concepts for ‘fresh-cut’ or lightly processed or minimally processed (MP) fruits and vegetables offer suitable techniques for their preservation, shelf-life extension which suggests improvement in various post-harvest handling methods. Today’s society is characterized by an increasing health consciousness and growing interest in light processing of food without any hazardous treatments, for maintaining human well-being and consumer health. Active food packaging-promising technology- offer new opportunities for the food industry, in efficient preservation of minimally processed foods. Substantial work has been done on current know-how of all of the steps involved in minimal processing of fresh produce including literature regarding studies on shelf-life and their quality aspects are currently available till date but, information regarding application of active packaging concepts in quality determination with prolonged storage life of these products is very limited. Therefore, the research work done by various scientists worldwide the results reported by them were studied and the relevant information regarding various aspects of minimal processing and preservation of whole as well as cut/minimally processed fruits and vegetables by active packaging have been included and reviewed in this chapter under the appropriate headings.

Minimally processed fruits and vegetables (MPFV) are convenient, nutritious foods with additional benefit of reduced wastage for consumers. The consumption of fresh-cut fruits and vegetables is increasing tremendously, due to the changes in consumer lifestyle, increasing health consciousness and purchasing power. As a result, the maintenance of the quality of MPFV is becoming more challenging. Rapid quality deterioration is mainly due to the high metabolic rates as a result of cutting, trimming and peeling. Processing of fruits and vegetables results in loss of colour, texture, moisture, and microbial growth. If not controlled, these changes can lead to rapid senescence and quality deterioration of the product. The
techniques that are being used to preserve the quality of whole fruits are not effective for minimally processed produce. This is because of the physical stress and strain the fresh-cuts have to undergo increase in respiration rates, ethylene production, colour loss, firmness loss, weight loss and other physical, chemical, physiological and microbial changes during minimal processing. These reasons prompt the development of other improved technology, like Active Packaging. The concept of application of active packaging with whole as well as minimally processed fruits and vegetables are numerously growing. O₂ scavengers and antioxidant releasing systems can be used with most oxygen-sensitive foods to extend their shelf-life. CO₂ emitters would benefit most foods susceptible to mould spoilage. Desiccants and water vapour absorbers have been used extensively with dried and mould sensitive foods. Ethylene scavengers are finding their way into the horticultural produce industry, and antimicrobial release systems can be used with baked foods, cheese and other products. The literature on the present study has been reviewed in this chapter under the appropriate headings.

2.2 POST-HARVEST QUALITY ENHANCEMENT IN FRUITS AND VEGETABLES

Fruits and vegetables undergo biological, chemical and bio-chemical changes during development, maturation, ripening and storage. Maintenance of post-harvest quality depends upon various factors such as harvesting at optimal maturity, method of harvesting, proper handling, minimization of microbial load and proper ambience in terms of appropriate temperature and relative humidity during storage and transportation (Rai et al., 2002). Workneh and Osthoff (2010) examined some of the post-harvest handling methods and factors affecting quality of fruits and vegetables by including disinfecting, packaging and storage temperature and found that pre- and post-harvest treatments have an effect on post-harvest quality of the produce which should be assessed by quality improvement, maintenance and consumer safety point of view. Surendranathan (2005) defined ‘fruit ripening’ as a physiological process involving the induction/acceleration of a variety of metabolic processes, most of them are enzymatically regulated, and he further stated that the major degradation changes taking place during ripening are destruction of chloroplasts, breakdown of chlorophyll, catabolism of organic acids, inactivation of pectic compounds, break-down of starch, etc. whereas, the major synthetic changes involve formation of carotenoids and other pigments, inter-conversion of sugars, formation of ATP, flavour volatiles, etc. So, he visualized an urgent need to develop technologies to overcome post-harvest losses of fruits by achieving feasible technology and alternative value addition of the produce by developing innovative products of consumer interest. In recent years, considerable efforts have been directed to develop many packages of post-harvest practices in India as well as abroad to minimize post-harvest losses in fruits and vegetables (Arya, 2004).
However, a rapid growth of MAP (Modified atmospheric packaging) for preservation of fresh-cut (minimally processed) products are of great interest because of their greater susceptibility to water loss, cut surface browning, higher respiration rates, enhanced ethylene biosynthesis and action along with microbial growth (Lange, 2000).

2.3 MINIMAL PROCESSING (MP) OF FRESH-CUT FRUITS AND VEGETABLES

Tremendous growth in the ready-to-use (RTU) vegetable industry has been largely due to increasing demand for fresh, healthy and convenient foods. Mehyar and Han (2010) stated that most fresh-cut fruits and vegetables are usually consumed fresh and non-thermal preservation methods are applied before consumption; therefore, there is an increased consumption of these products due to the increased demand for better quality, fresh-like and convenient food products. As reported by Bruhn (2000), consumers have also become critical for the use of synthetic additives to preserve food or enhance characteristics such as colour and flavour whereas, Kader (2002) emphasized that customer usually judge the quality of fresh-cut fruit on the basis of appearance and freshness at the time of purchase. Ohlsson (2002) suggests that minimal processing techniques have emerged to meet the challenge of replacing traditional methods of preservation while retaining nutritional and sensory quality. The International Fresh-cut Produce Association (IFPA) defines fresh-cut products as fruits and vegetables that have been trimmed and/or cut into 100 per cent usable product that is bagged or pre-packaged to offer high nutrition, convenience and flavour while maintaining its freshness for the consumers (Wiley, 1994). Ahvenainen and Hurme (1994) stated that fresh-cut fruit attract consumers because they are fresh, nutritious, low priced and ready-to-eat, hence, a wide assortment of MP fruits has been developed and termed as ‘quick’ and ‘convenient’ products which can benefit from fruit’s healthy image. Manvell (1997) described MP as non-thermal technologies to process food in a manner to guarantee the food safety and preservation as well as to maintain fresh-like characteristics of fruits and vegetables as much as possible whereas, Jongen (2002) added that these products meet consumer’s need for ‘quick’ and ‘convenient’ products that preserve their nutritional value, retain a natural and fresh colour, flavour, texture and contain fewer additives. According to Ahvenainen (1996), the microbiological, sensory and nutritional shelf-life of MP vegetables or fruits should be at least 4-7 days, but preferably even longer, up to 21 days depending on the market; the loss of ascorbic acid and carotenes is the main limiting factor of nutritional quality and he further stated that as a result of peeling, grating and shredding, produce will change from a relatively stable product with a shelf-life of several weeks or months to a perishable one that has only a very short shelf-life, even as short as 1-3 days at chill temperature. Minimal processing operations alter the integrity of fruits bringing about the changes on product quality such as browning, off-flavour development and texture
breakdown and presence of microorganisms on the fruit surfaces may compromise the safety of fresh-cut fruits (Rojas-Grau et al., 2009). MP produce deteriorate because of faster biochemical changes and microbial spoilage, which may result in degradation of colour, texture and flavour of the produce (Varoquaux and Wiley, 1994) and during peeling/grating operations many cells are ruptured, and intracellular products such as oxidizing enzymes are liberated.

2.3.1 Steps for the Preparation of MP products

MP vegetables and fruits can be manufactured on the basis of the principle that the products which are prepared today are consumed tomorrow by adopting simple processing methods and a characteristic feature in minimal processing is an integrated approach were raw material handling, processing, packaging and distribution must be considered to make shelf-life extension possible (Ahvenainen, 1996). Prior to being packaged for consumption, minimally processed fruits are subjected to one or more mild unit operations which include washing/sanitizing, peeling, cutting and/or slicing, dicing, shredding, etc. as shown Fig. 2.1 each step during the production, packaging and storage, could potentially have an effect on nutrients and quality of the prepared produce and special attention is necessary for mechanical operations as they are considered very critical to delimit the shelf-life of fresh-cut fruit commodities (Gorny et al., 2000).

![Diagram showing the response results of minimally processed fruits and vegetables](image)
2.3.1.1 Raw Material Selection

The first step is the selection of raw material, it is self-evident that vegetables or fruit intended for pre-peeling and cutting must be easily washable and peelable, and their quality must be first class. Francis et al. (1999) revealed that the first step in preparing MP products is the selection of raw material by assessing correct and proper stage of the raw materials, followed by careful trimming, pre-peeling and cutting to retain good quality, and these steps may be followed by peeling, slicing or shredding based on customers need. The correct choice of variety is particularly important in the case of carrot, potato, rutabaga and onion, as studied by Ahvenainen (1996), who found that carrot and rutabaga varieties that give the juicier grated product cannot be used in the production of MP products with enhanced shelf-life of several days, whereas poor colour and flavour become problems if the variety of potato is wrong. Furthermore, his results showed that climatic and soil conditions, agricultural practices, including the use of fertilizers and the harvesting conditions can also significantly affect the behaviour of vegetables, particularly that of potatoes during minimal processing. Soliva-Fortuny and Martin-Belloso (2003) stated that, it becomes necessary to harvest fruits and vegetables at proper maturity stage because the state of maturity has been shown to greatly influence the damage inflicted by mechanical operations on the cut produce tissue, and they concluded that more advanced the ripeness stage, more susceptible the fruit is to wounding during processing.

2.3.1.2 Cleaning, Washing and Disinfection

It is clear that if incoming fruit or vegetables are covered with soil, mud or sand, they should be carefully cleaned before processing. Usually, a second washing step must be performed after peeling and/or cutting (Ahvenainen and Hurme, 1994). The main steps throughout the processing chain of MP fruits and vegetables are washing and disinfection and accordingly Sapers (2003) provided the guidelines for packing fresh or minimally processed fruits and vegetables by specifying a washing or sanitizing step to remove dirt, pesticide residues, and microorganisms responsible for quality loss and decay. During minimal processing (including peeling, cutting and grating operations), many cells are broken and intracellular products, such as oxidizing enzymes are released (Laurila and Ahvenainen, 2002), accelerating the decay process of the product which support better microbial growth, and they further mentioned that, just because of these reasons, the cutting and shredding must be performed with knives or blades as sharp as possible made from stainless steel. According to AR-USDA (2005), different solutions have been tested to avoid the acceleration of decay due to peeling, cutting or slicing and the newest technology mentioned as immersion therapy is being used for cutting a fruit while it is submerged in water to control turgor pressure, due to the formation of a water barrier that prevents movement of fruit fluids while the product is
being cut. Additionally, the watery environment also helps to flush potentially damaging enzymes away from plant tissues thereby reducing browning and injury of fresh-cut products (Lamikanra and Bett-Garber, 2005). Sapers (2003) suggested that any of the available washing and sanitizing methods, including some of the newest sanitizing agents such as chlorine dioxide, ozone and peroxy acetic acid, were not capable of reducing microbial population by more than 90-99 per cent. Therefore, washing and disinfection of the produce before preparation and consumption is recommended but does not guarantee that the fresh produce is pathogen free (Gorny and Zagory, 2002). Another alternative method of washing could be the use of water jet cutting, a non-contact cutting method which utilizes a concentrated stream of high-pressure water to cut a wide range of foodstuffs (Allende et al., 2006). Chlorine-based chemicals, particularly liquid chlorine and hypochlorite, are probably the most widely used sanitizers for decontaminating the fresh produce. Francis and O’Beirne (2002) determined that chlorine compounds usually used at levels of 50-200 ppm free chlorine and with typical contact time of less than 5 minutes, whereas Beuchat (2000) indicated that although chlorine is most effective in solution at acidic pH levels, in order to minimize the corrosion of processing equipment, chlorine-based sanitizers are usually used at pH values between 6.0 and 7.5. According to several researchers, 100-200 mg of chlorine or citric acid per litre is effective in the washing water before or after peeling and/or cutting to extend shelf-life and when chlorine is used, vegetable material should subsequently be rinsed to reduce the chlorine concentration for improving the sensory shelf-life of minimally processed vegetables up to 7-8 days (Hurme and Ahvenainen, 1994).

Chlorine dioxide has an antimicrobial activity (Han et al., 2000) and it is found to be effective in the inactivation of Listeria monocytogenes and Salmonella typhimurium (Lee et al., 2004). However, Bari et al. (2005) demonstrated that organic acids (e.g. lactic acid, citric acid, acetic acid, tartaric acid) can act as strong antimicrobial agents against psychrophilic and mesophilic microorganisms in fresh-cut fruits and vegetables. Parish et al. (2003) stated that hydrogen peroxide is a desirable sterilizing agent; he further observed that shredded lettuce was severely browned on dipping in H2O2 solution. Calcium treatments extend the shelf-life of fruits and vegetables which remain firmer than controls during storage. Rico et al. (2006) and Smout et al. (2005) reported that use of calcium based treatments effectively reduce chlorophyll and protein loss and thereby inhibit plant tissue senescence. Calcium-based solution as an alternative to chlorine, calcium lactate showed no differences in affecting the quality of the product and both treatments showed similar effectiveness in reducing the microbial load (Anion et al., 2006). Ozone is a strong antimicrobial agent with high reactivity, penetrability and spontaneous decomposition to a non-toxic product (Grass et al., 2003) and is effective in extending the storage life of fresh non-cut commodities such as
broccoli, cucumber, apples, grapes, oranges, pears, raspberries and strawberries by reducing microbial load and by ethylene oxidation (Skog and Chu, 2001). Beltran et al. (2005) stated that the application of ozonated water on fresh-cut vegetables for sanitation reduces microbial populations and thereby extending the shelf-life of these products. When compared to chlorine, ozone has a greater effect against certain microorganisms and rapidly decomposes to oxygen, leaving no residues (White, 1992). However, higher degree of corrosiveness and initial capital cost for generator are the main disadvantages compared to the use of chlorine (Smilanick et al., 1999).

2.3.1.3 Peeling, Cutting, Shredding and Moisture Removal

Wiley (1994) reported that some vegetables or fruit, such as potatoes, carrots or apples, require peeling and several methods for peeling are available; however, on an industrial scale, peeling is normally accomplished mechanically (e.g. using rotating carborundum drums), chemically or in high-pressure steam peelers. O’Beirne (1995) demonstrated that the ideal method is hand peeling using a sharp knife and he found that peeling of carrots by this method increased the respiration rate over that of unpeeled carrots by approximately 15 per cent, whereas abrasion peeling (both fine and coarse) of new season Irish carrots almost doubled the respiration rates compared with the rate for hand-peeled carrots. In the case of stored carrots, the respiration rates recorded for coarse abrasion-peeled carrots were almost threefold higher than those recorded for hand-peeled carrots. Further, he had also obtained similar results with carrot discs. Carrots cut with a razor blade were more acceptable from both a microbiological and a sensory point of view than carrots cut using various commercial slicing machines and it was clear that slicing with dull knives impairs the retention of quality because it ruptures cells and releases tissue fluid to a great extent. Mats and blades that are used in slicing operations can be disinfected, for example, with a 1% hypochlorite solution. Varoquaux and Wiley (1994) observed that sensory shelf-life of grated carrot improves markedly if whole carrots are washed in a citric acid or chlorine solution after peeling. Wiley (1994) recommended that the washing water removed gently from the product. Bolin and Huxoll (1991) suggested the method of centrifugation for moisture removal but the centrifugation time and rate should be chosen carefully.

2.3.1.4 Browning Inhibition

Adams and Brown (2007) stated that browning reactions that occur in fruits and vegetables may be due to abiotic stress and enzymatic oxidation of phenolic compounds. Poly-phenoloxidase (PPO) enzyme catalyses the hydroxylation of monophenols to o-diphenols (monophenolsae activity) and the oxidation of o-diphenols to o-quinones (catecholase activity) in the presence of oxygen (Soliva-Fortuny et al., 2002). Dong et al.
(2000) suggested that quinones further react non-enzymatically with amino acids and proteins leading to formation of brown (melanin), red or black pigments.

Fruit browning causes a particularly poor appearance; washing with water is not effective enough to prevent discolouration. Traditionally, sulphites have been used to prevent browning in fruits and vegetables, such as pre-peeled and sliced apple and potato but their use has some disadvantages. In particular, they can cause dangerous side effects for people with asthma. For this reason, the US Food and Drug Administration (FDA) partly restricted the use of sulphites. At the same time, interest in substitutes for sulphites is increasing (Ahvenanien, 1996). Citric acid (CA) combined with ascorbic acid (AA), alone or in combination with potassium sorbate in the case of potato or 4-hexyl resorcinol in the case of apple, seems to be promising alternatives for sulphites, particularly when hand peeling is used. Further, Sapers and Miller (1995) have obtained promising results by treating pre-peeled (abrasion or high-pressure steam peeled) potatoes with a heated solution of AA and CA. Potatoes were heated for 5-20 min in a solution containing 1 per cent AA and 2 per cent CA at 45-55°C cooled and then dipped for 5 min in a browning inhibitor solution containing 4 per cent AA, 1 per cent CA and 1 per cent sodium acid pyrophosphate. The combined treatment inhibited potato discolouration for 14 days at 4°C, compared with 3-6 days with the browning inhibitor treatment alone. The most attractive methods to inhibit browning would be ‘natural’ ones, such as the combination of particular salad ingredients with each other. Lozano-de-Gonzales et al. (1993) have obtained promising results with pineapple juice, which appears to be a good potential alternative to sulphites for the prevention of browning in fresh apple rings. Rojas-Grau et al. (2006) suggested that N-acetyl-L-cysteine (NAC) and reduced glutathione (GSH) can act to reduce o-quinones back to o-diphenols or react with o-quinones to yield colourless substances. Further, Rojas-Grau et al. (2007) used N-acetyl-L-cysteine (NAC) and reduced glutathione (GSH) as effective browning inhibitors in fresh-cut pears. Dong et al. (2000) reported that dipping of fresh-cut pears and apples in NAC and GSH prevented browning.

2.3.1.5 Packaging, Refrigeration and Storage

Packaging is an important step in producing minimally processed fruits and vegetables and highly permeable packaging materials are required for minimally processed produce (Mohamed et al., 1996). Ayhan et al. (2008) observed that minimally processed carrots retained better quality while stored in high oxygen (80 per cent oxygen and 10 per cent carbon dioxide) atmosphere than low oxygen (5 per cent) atmosphere. Day (2008) suggested active packaging plays an effective role in maintaining the quality and safety of fresh-cut produce. Rico et al. (2007) suggested that minimally processed products being
highly perishable in nature, required chilling storage (<5°C) and good packaging system to ensure reasonable shelf-life.

2.3.2 Quality Changes in MP Fruits and vegetables

Ahvenainen (1996) reported that minimally processed produce deteriorates because of physiological ageing, biochemical changes and microbial spoilage, which may result in degradation of the colour, texture and flavour of the produce. During peeling and grating operations, many cells are ruptured and intracellular products such as oxidizing enzymes are liberated.

2.3.2.1 Physiological and biochemical changes

Consumers take product appearance into consideration as a primary criterion (Kays, 1999); colour has been considered to have a key role in food choice, food preference and acceptability, and may even influence taste thresholds, sweetness perception and pleasantness (Clydesdale, 1993). Colour is one of the main attributes, along with texture, that characterises the freshness of most vegetables. Lettuce and carrot can undergo changes in colour due to different bio-chemical processes, mainly chlorophyll degradation and browning appearance in the case of the lettuce, and carotene degradation, whiteness and browning in the case of the carrot (Ihl et al., 2003). Wounding and other minimal processing procedures can cause physiological effects, including ethylene production, increase in respiration, membrane deterioration, water loss, susceptibility to microbiological spoilage, loss of chlorophyll, formation of pigments, loss of acidity, increase in sweetness, formation of flavour volatiles, tissue softening, enzymatic browning, lipolysis and lipid oxidation (Rico et al., 2007). The most important enzyme with regard to minimally processed fruit and vegetables is polyphenol oxidase, which causes browning. In some fruits such as melon, watermelon and citrus fruits, enzymatic colour changes are primarily affected by peroxidase (POD) enzymes (Soliva-Fortuny and Martin-Belloso, 2003). Apples contain sufficient amount of polyphenols that cause rapid enzymatic browning while lettuce contains a far lower amount of these compounds. Lettuce presents two types of browning, edge browning and russet spotting. Wounding (e.g. cutting, cracking or breaking) of lettuce produces a signal that migrates through the tissue and induces the synthesis of enzymes in the metabolic pathway responsible for increased production of phenolic compounds and browning. Research for controlling lettuce browning has been focused on the control of phenylalanine ammonialyase (PAL) activity, which is the rate-limiting enzyme of the phenylpropanoid pathway and is generally induced by wounding (Rico et al., 2007). Another important enzyme is lipooxidase, which catalyzes peroxidation reactions, causing the formation of numerous bad-smelling aldehydes and ketones. Ethylene production can also increase following minimal processing
and because ethylene contributes to the biosynthesis of enzymes involved in fruit maturation. It may be partially responsible for bringing about physiological changes in sliced or shredded fruits and vegetables, such as softening. Furthermore, the respiration activity of minimally processed produce will increase 1.2-7.0 fold or even more depending on the produce, cutting grade and temperature. If packaging conditions are anaerobic, this leads to anaerobic respiration and thus the formation of ethanol, ketones and aldehydes (Ahvenainen, 1996).

Minimally processed vegetables that maintain firm, crunchy texture are highly desirable because consumers associate these textures with freshness and wholesomeness (Bourne, 2002). Indeed, the appearance of a soft or limp product may give rise to consumer rejection prior to consumption. Textural changes in vegetables are related to certain enzymatic and non-enzymatic processes. (Van Buren, 1979) reported that enzymatic degradation of pectins is catalysed by pectin methylesterase (PME) and polygalacturonase (PG). Pectin is first partially demethylated by PME, and later depolymerised by PG to polygalacturonic acid causing a loss of firmness (Vu et al., 2004). Roy et al. (2001) studied that the controlled activation of PME results in improvement of the texture, as it increases the cross-linking between pectin chains and cations. Minimally processed vegetables are living tissues even after treatment. Damaged plant tissues exhibit an increase in respiratory rate (Laties, 1978). Practical experience has demonstrated that tissues with high respiratory rates and/or low energy reserves have shorter postharvest lives (Eskin, 1990). Modifying the atmosphere composition in which the produce is stored is usually done to slow down the respiration rate, to reduce product metabolism and maturation (Kader et al., 1989), losses in fresh weight and in dry matter (Bottcher et al., 2003). Del Nobile et al. (2006) stated that the treatments applied after or before wounding can affect the respiration rate and they suggested a practical approach to evaluate the respiration rate by comparing similar samples which can be carried out by monitoring the composition of the headspace in the packages. The concentration of oxygen and carbon dioxide inside the headspaces is related to the metabolic state of the samples. The levels of oxygen can have other effects on quality, e.g. inactivating enzymatic reactions. Because PPO requires O2 to induce cut surface discolouration, reducing the amount of O2 in the package of fresh-cut product by vacuum, MAP or gas flushing may reduce cut surface discolouration, although not completely stop it.

2.3.2.2 Microbiological changes

During peeling, cutting and shredding, the surface and nutritious internal tissue fluid of produce is exposed to microorganism, thereby resulting in their accelerated growth and spoilage. According to Garg et al. (1990) major sources of in-plant contamination are the shredders used to prepare chopped lettuce and cabbage for coleslaw. In particular, in the case of minimally processed vegetables, most of which fall into the low-acid category (pH 5.8-
the high humidity and the large number of cut surfaces can provide ideal conditions for the growth of microorganisms (Willocx et al., 1994). The bacterial populations found on fruit and vegetables vary widely. The predominant microflora of fresh leafy vegetables are *Pseudomonas* and *Erwinia* species, with an initial count of approximately $10^5$ colony-forming units (cfu) per g, although low numbers of moulds and yeasts are also present. During cold storage of minimally processed leafy vegetables, pectinolytic strains of *Pseudomonas* are responsible for bacterial soft rot (Varoquaux and Wiley, 1994). Manzano et al., 1995 found that an increase in storage temperature and carbon dioxide concentration in the package will shift the composition of the microflora such that lactic acid bacteria tend to predominate. He also concluded that the initial total counts of various bacteria were high in vegetables for soup packed in modified atmospheres, approximately $10^8$ cfu/g, $5.6 \times 10^6$ cfu/g, $1.5 \times 10^7$ cfu/g and $10^6$ cfu/g for aerobic bacteria, *Pseudomonas* species, and lactic acid bacteria, respectively, moreover, the high level of initial microbial flora of vegetables for soup was probably due to the machinery, the environment, as well as human and natural contamination. Marchetti et al. (1992) also found that high initial counts for psychrotrophic bacteria and total mesophilic bacteria, exceeding even $10^8$ cfu/g, in various commercial vegetable salads. Mixed salads and carrots were on average found to be more contaminated than either red or green chicory. Because minimally processed fruit and vegetables are not heat treated, regardless of the use of additives or packaging, they must be handled and stored at refrigeration temperatures to achieve a sufficient shelf-life and ensure microbiological safety. However, some pathogens such as *Listeria monocytogenes*, *Yersinia enterocolitica*, *Salmonella* species and *Aeromonas hydrophila* may still survive and even proliferate at low temperatures (Ahvenainen, 1996). It can be easily inferred that the microbiological shelf-life of the fresh-cut commodities depends on the composition and physico-chemical properties of the raw fruit. However, processing is crucial because it determines the sources of spoilage caused by the presence of cut surfaces and increased moisture content and by the active metabolism of plant tissue. As these products are minimally processed, sterility or microbial stability cannot be ensured longer, thus far many techniques have been studied in order to extend their shelf-life, acting on processing or, more usually, on packaging (Corbo et al., 2009).

### 2.3.2.3 Nutritional changes

Most studies on fresh and minimally processed fruit and vegetables have been concerned with market quality as determined objectively and subjectively by colour, flavour and texture measurements as well as by microbiological determinations. Little is known about the nutritive value, that is, the vitamin, sugar, amino acid, fat and fibre contents of minimally processed produce (Ahvenainen, 1996). The ascorbic acid in kiwifruit slices is influenced by various atmosphere conditions. Vitamin content of slices stored under 0.5, 2
and 4 kPa O₂ decreased by 7, 12 and 18 per cent respectively after 12 days storage. Studies in fresh cut pears, apples, kiwifruit and melon found that sugar level do not vary substantially under refrigerated storage. No significant changes were observed in citric acid, malic acid and amino acid content of fruit samples stored under refrigeration (Soliva-Fortuny and Martin-Belloso, 2003). Gunes and Lee (1997) studied the inhibition of browning in minimally processed potatoes when treated with L-cysteine (0.5 per cent) and citric acid (2 per cent) and the shelf-life of MP potatoes could be extended to 3 weeks by using different treatments in combination with MAP under refrigerated storage. Aguila et al. (2006) studied the effects of different types of cuts (sliced and shredded) and storage temperatures on fresh-cut radish stored up to 10 days and found that whole roots stored at 1°C showed the lowest respiration rate while the highest rate was observed in shredded roots stored at 10°C whereas, shredded radishes had lower soluble solids during storage compared to other cut types and the temperatures of 1 and 5°C are recommended for maintenance of quality in fresh-cut radishes. Agar et al. (1999) studied the effect of wounding, C₂H₄ addition or removal, and chemical treatments like calcium, ascorbic acid, citric acid on fresh-cut Kiwifruit slices and investigated the rate of deterioration and found that fresh-cut kiwifruit slices had a shelf-life of 9-12 days when treated with 1 per cent CaCl₂ or 2 per cent Calcium lactate, and stored at 0-2°C and >90 per cent relative humidity in an C₂H₄ free atmosphere of 2 to 4 kPa O₂ and/ or 5 to 10 kPa CO₂. (Oliu et al., 2007) studied the effect of ripeness on the shelf-life of fresh-cut melon preserved by modified atmosphere packaging and found that ripeness stage at processing is a limiting factor for the shelf-life of fresh-cut melon. Green-mature fresh-cut melon exhibited lower rates of CO₂ and ethanol accumulation than mature melon and low O₂ atmospheres in combination with AA and CaCl₂ treatments significantly reduced CO₂ accumulation and ethylene production as well as the maximal growth rate of bacteria, yeasts and moulds, except for fully ripe melon which exhibited the highest initial counts.

2.4 ACTIVE PACKAGING (AP) FOR WHOLE AND MP FRUITS AND VEGETABLES

An innovative and recent technique of modifying the atmosphere pack is by using ‘Active Packaging’; moreover any packaging is termed as ‘Active’ when it performs some desired role other than to provide an inert barrier to the external environment. The goal of developing such packaging is to create a more ideal match of properties of the package to the requirements of the food which also plays an additional role in maintaining the quality and safety of fresh-cut produce compared with traditional packaging systems (Day, 1994). The AP systems are specifically designed to control produce deterioration reactions by utilizing active ingredients that have been deliberately included in the packaging material or the head.
space (Day, 2008). Ozdemir and Floros (2004) commented that today’s trends initiated a vast amount of research in the field of active and intelligent packaging to provide the market with packaging technologies designed to keep produce fresh, since it is impossible to attain the optimum quality characteristics with passive plastic package for a highly deteriorative and metabolically active produce. According to Han and Floros (2007), the AP technologies that have been especially developed for fruits and vegetables are oxygen scavengers, carbon dioxide absorbents/emitters, moisture scavengers, ethylene scavengers, antimicrobial agent releasers including film coatings, time temperature indicators (TTIs), aroma emitters/odour absorbers, gas and volatile indicators and radio-frequency indicators. Such new employed technologies modify the gas environment (and may interact with the product surface) by removing gases from or adding gases to the package headspace, thus the internal atmosphere may be controlled by use of the active ingredients that absorb (scavenge) or release (emit) gases or vapours as overviewed by Lopez-Rubio et al. (2004) and they commented that the first designs in AP was made by use of a small pouch (sachet) containing the active ingredient inserted inside the permeable package as an additional step which yields some attractive characteristics to the packaged produce. As suggested by Floros et al. (1997), recent technological innovations for controlling specific gases within a package involve the use of active substances are either contained in a gas permeable sachet, which is then placed into a package, or incorporated directly into plastic packaging films, adhesives or other package components which should allow slow release of the active components on to the surface of the food, where it would exercise its desired function. They further added that systems containing gas scavengers must not allow the scavenger to diffuse into the food, but they should allow head-space gases to permeate readily and be absorbed by the scavenger. Major AP systems are reviewed and discussed here.

![Diagram of Active Packaging](image)

**Fig: 2.2: Properties of foods amenable to active packaging (Rooney, 1995)**
2.4.1 Oxygen Scavengers

Excessive oxygen causes the oxidation of ingredients such as vitamins, pigments (by enzymatic and non-enzymatic browning), flavour compounds, lipids and facilitates the growth of aerobic microorganisms in the cut tissue along with high levels of oxygen in the package headspace accelerate quality and safety deterioration of high respiring produce that may lead to an increase in ethylene production in MP fruits and vegetables such as potatoes, apples, banana and peaches where their processing increases the oxidation-reduction potential by accelerating the formation of the reactive oxygen species such as peroxide ions and superoxide anions that promote colour oxidation (Sanjeev and Ramesh, 2006) and therefore, controlling the oxygen concentration provides benefits in protecting the produce against the quality deterioration associated with oxygen, such as off-flavour formation, colour change, nutritional value reduction and safety losses. Furthermore, Oms-Oliu et al. (2008) suggested that low available oxygen helps in reducing respiration and ethylene production and keeps the produce fresh longer. Mehyar and Han (2010) defined oxygen scavengers as active additives used in the packaging system to absorb residual oxygen that remains after the package is sealed and that originated from the product respiration and the package permeability, whereas, Smith et al. (1986) indicated that the oxygen present may derive from oxygen permeability of the packaging material, air enclosed in the food and packaging material, small leakages due to poor sealing and inadequate evacuation and/or gas flushing. Ozdemir and Floros (2004) suggested that high levels of oxygen present in food packages may facilitate microbial growth, off-flavours and off-odours development, colour change and nutritional losses, thereby causing significant reduction in the shelf-life of foods. Therefore, the control of oxygen levels in food packages is important to limit the rate of this deteriorative and spoilage reactions in foods. Further, they concluded that typical oxygen absorbing systems are based on the oxidation of iron powder by chemical means or scavenging of oxygen through the use of enzymes and the sachet material is highly permeable to oxygen and in some cases, to water vapour in order for the sachet to be effective. The type and amount of absorbent that needs to be used in a sachet is determined by initial oxygen level in the package, the amount of dissolved oxygen present in the food, the permeability of the packaging material, the nature (size, shape, weight etc.), and the water activity of the food. According to Smith et al. (1995) these iron-based oxygen absorbing systems have the ability to scavenge oxygen in many foods, including high, intermediate, or low moisture foods, and foods containing lipids and they can also work at refrigerated and frozen storage conditions even with microwaveable food products. Day (2000) generalised that existing oxygen scavenging technologies utilize one or more of the following mechanisms: iron powder oxidation, ascorbic acid oxidation, photosensitive dye oxidation, enzymatic oxidation
(e.g. glucose oxidase/catalase and alcohol oxidase), ferrous salts, unsaturated fatty acids (e.g. oleic and linoleic acids) and combinations of these. The majority of currently available oxygen scavengers are based on the principle of iron oxidation (Smith et al., 1990).

\[
Fe \rightarrow Fe^{2+} + 2e^- \\
\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2OH^- \\
Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2 \\
Fe(OH)_2 + \frac{1}{4} O_2 + \frac{1}{2} H_2O \rightarrow Fe(OH)_3
\]

Most commercially available oxygen absorbers have reaction mechanisms based on iron oxidation to iron oxide, with this mechanism they can reduce the oxygen concentration in headspace to less than 100 ppm as studied by Sanjeev and Ramesh (2006) and they have also listed non-metallic oxygen scavengers such as ascorbic acid, ascorbate salts, catechol, glutathione, enzymes and unsaturated fatty acids which are used safely with packaging materials contacting with foods.

### 2.4.2 Carbon dioxide Scavengers/Emitters

Carbon dioxide concentration inside the package increases in some foods due to deterioration and respiratory reactions. In general, the permeability of plastic packages is too low to evacuate the excess CO₂ produced by some products hence; a possible solution to the problem would be the design of packaging technologies capable of absorbing the excess of CO₂ that could affect the quality of certain food stuffs (Brody et al., 2001). The use of CO₂ absorbers and emitters is a technology that goes beyond the simple modified atmosphere packaging systems that use gas permeability of material passively. This technology involves the absorption/emission of the specific gas by/from the packaging material and eventually control of the gas concentration (Del-Valle et al., 2004).

Ozdemir and Floros (2004) reported that multiform desiccants incorporated inside a CO₂ absorbing sachet is composed of a porous envelope containing calcium oxide and a hydrating agent on which water is adsorbed and in this system, water reacts with calcium oxide to produces calcium hydroxide, which the reacts with CO₂ to form CaCO₃.

\[
CaO + H_2O \rightarrow Ca(OH)_2 \\
Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O
\]

Therefore, the active CO₂ scavenger is generally Ca(OH)₂, which reacts with the CO₂ producing CaCO₃, which may be used as commercial CO₂ scavenger to make the perfect use of the sachet technology, whereas, zeolite and other finely divided minerals can also be employed as CO₂ absorbers (Lee et al., 2001). They also named these substances as CO₂ controllers which adversely, do not reduce headspace CO₂ concentration exclusively, but almost all volatiles present in the internal atmosphere. A mixture of calcium oxide and
activated charcoal has been incorporated in polyethylene-lined coffee pouches to scavenge carbon dioxide but dual-action oxygen and carbon dioxide scavenger sachets and labels are more common and are commercially used for canned and foil pouched coffees in Japan and the USA (Day, 2003). Sometimes, for many food products, the presence of CO₂ inside the package may have several beneficial effects (Labuza, 1996). High levels of CO₂ usually plays a beneficial role in retarding microbial growth on meat and poultry surfaces and in delaying the respiration rate in fruits and vegetables and since, CO₂ is more permeable than O₂ through many plastic films used for the food packaging, most of the carbon dioxide inside the package usually permeates through the film as reported by Ozdemir and Floros (2004), and they further concluded that the use of a dual function system consisting of an O₂ scavenger and a CO₂ emitter is the usual practice for increasing the shelf-life of highly perishable foods. CO₂ partial pressures above 0.1 atmosphere are claimed to reduce the respiration rate of fresh produce and to inhibit microbial growth on the surface of the product and hence, there is a potential field of application for another kind of active packaging technology- the CO₂ emitters which basically contain sodium bicarbonate. Vermeiren et al. (1999) commented that the release of CO₂ can also be used to overcome pack collapse or partial vacuum caused by the depletion of O₂ when using O₂ scavengers hence, to avoid this problem, sachets containing combinations of O₂ scavengers/CO₂ emitters have been commercialized. This double effect can be attained by placing ascorbic acid plus sodium bicarbonate in the sachet (Ronney, 1995).

2.4.3 Moisture Scavengers

It is important to control the atmospheric relative humidity during the storage of fresh fruits and vegetables for maintaining high quality because fruits and vegetables produce water by transpiration. The rate of transpiration is temperature dependent and also varies between day and night (Chakraverty, 2001). The amount of moisture in a food package is a net result of product transpiration and the package permeability to water vapour that is why minimal processing of fruits and vegetables may increase the relative humidity inside the package due to the increased water release of cut tissue and this excessive relative humidity inside the package promotes fungal and bacterial growth, while excessive water loss from packaged fruits and vegetables leads to shriveling and loss of quality and sensory properties (Rico et al., 2007). Various moisture scavengers can modify package humidity, including silica gel, natural clays (e.g., montmorillonite), calcium oxide, calcium chloride, and modified starch (Day, 2008). Further, Powers and Calvo (2003) reported that silica gel, clay, calcium sulphate, or molecular sieves, which retain increasing amounts of water as humidity increases. Silica gel, for instance, presents a nearly proportional relationship between water gained and relative humidity within the range 0-60 per cent. Lopez-Rubio et al. (2004)
suggested a package that includes a desiccant or any other active substance into its structure; some precautions have to be taken into account: The desiccant additive must maintain its properties after the package processing and should not affect plastic properties, and the polymer containing the desiccant has to be, to some extent, water permeable, whereas the package structure should contain a water-impermeable outer layer to limit water passage from the surrounding atmosphere. Commercial systems with desiccant capacity are available in adsorbent sheets (Thermarite, Pty Ltd. Australia; Toppan Sheet™, Toppan Printing Co. Japan; Peaksorb, Peakfresh Products Australia). These materials are basically a super absorbent polymer placed between two polyolefin layers (PE or PP). These absorbent sheets are placed, for example, under chicken pieces to absorb the condensate, avoiding the discolouration of the product or the tray (Brody et al., 2001a). Ozdemir and Floros (2004) stated that antifogging films allow the consumer to clearly see the product through the packaging films, which incorporate humidity absorbers, hydrophilic liners, or microperforations in the film. These films are usually used for respiring products such as fresh-cut fruits and vegetables to reduce the internal vapour pressure and prevent water condensation. Microporous sachets of desiccant inorganic salts such as sodium chloride have been used for the distribution of tomatoes in the USA (Rooney, 1995). Yet another example is an innovative fibreboard box that functions as a humidity buffer on its own without relying on a desiccant insert. It consists of an integral water vapour barrier on the inner surface of the fibreboard, a paper-like material bonded to the barrier, which acts as a wick and an unwettable but highly permeable to water vapour layer next to the fruit or vegetables. This multilayered box, patented by CSIRO Plant Industries, Australia, is able to take up water in the vapour state when the temperature drops and the relative humidity rises. Conversely, when the temperature rises, the multilayered box can release water vapour back in response to a lowering of the relative humidity (Scully and Horsham, 2005). Moisture absorbers are the best selling active packaging technology for all applications but oxygen scavengers are commercially more valuable for strictly food applications.

### 2.4.4 Ethylene Scavengers

Ethylene (C₂H₄), the growth-stimulating hormone, is responsible for initiating fruit ripening especially in the climacteric fruits but has detrimental effect after complete maturation. During the senescence stage, ethylene causes an increase in fruit respiration rate and textural and colour changes in climacteric fruits more than in non-climacteric fruits. It also accelerates chlorophyll degradation in leafy vegetables (Toivonen and Brummell, 2008). Therefore, controlling the concentration of the ethylene in the package headspace extends the shelf-life (Martinez-Romero and Bailen, 2007). Adequate ventilation has been used traditionally to alleviate ethylene concentration in the headspace using open boxes for fresh
fruits and vegetables (Terry, 2008). Day (2003) stated that activated carbon-based scavengers with various metal catalysts can also effectively remove ethylene and they have been used to scavenge ethylene from produce warehouses or are incorporated into sachets for inclusion into produce pack, and embedded into paper bags or corrugated board boxes for produce storage. A dual-action ethylene scavenger and moisture absorber has been marketed in Japan by Sekisui Jushi Limited. Neupalon™ sachets contain activated carbon, a metal catalyst and silica gel and are capable of scavenging ethylene as well as acting as a moisture absorber.

Potassium permanganate is the most extensively studied and commercially used ethylene absorber. Effective systems utilise potassium permanganate immobilised on an inert mineral substrate such as alumina or silica gel and in the process changes colour from purple to brown, and hence indicates its remaining ethylene scavenging capacity. It removes the exogenous ethylene from the atmosphere surrounding the produce by oxidizing it to ethylene glycol, which later decomposes to carbon dioxide and water (Martinez-Romero and Bailen, 2007). Both the carbon dioxide and water produced have a secondary effect on extending the shelf-life. Carbon dioxide reduces the fruit respiration rate and blocks the synthesis of endogenous ethylene and high concentration of water vapour inside the package lowers the transpiration rate (Day, 2008). Potassium permanganate cannot be used in contact with food products due to its toxicity, but only 4-6 per cent concentration of KMnO₄ is usually imbedded in silica gel, perlite, vermiculite, activated carbon that is incorporated inside devices (sachets, films, or filters) that have a high permeability to ethylene and the ethylene diffuses through these devices, is quickly absorbed by the potassium permanganate (Vermeiren et al., 1999 and Sammi and Mausd, 2008). Sammi and Masud (2008) further stated that it can also be impregnated into polymeric films used to wrap fruits and vegetables and they found that plastic films incorporated with potassium permanganate were effective in delaying tomato ripening as determined by colour development and the shelf-life and quality properties were improved for up to 84 days. Howard et al. (2006) reported that potassium permanganate removed ethylene effectively from the headspace of packaged diced onions and reduced the levels of sulfur volatiles and carbon dioxide produced by the produce. These diced onions were kept at 2°C for 10 days without spoilage. Palladium (Pd) and light-activated titanium dioxide (TiO₂) are metal catalysts used to accelerate the oxidation reaction of potassium permanganate, thus increasing its adsorption capacity about 6-fold higher (Martinez-Romero and Bailen, 2007). The use of activated carbon with palladium chloride (as a catalyst) prevented the accumulation of ethylene in the headspace of packaged tomato, delayed the deterioration of the quality parameters (including weight loss, colour, and fruit firmness), and improved sensory properties (Bailen et al., 2006).
stored at 20°C (Abe and Watada, 1991). Various dispersing materials (clays, zeolites, and carbons) were incorporated into commercial plastic films and utilized for fruit and vegetable packaging. Commercial examples are Evert-Fresh (USA), Peakfresh (Australia), Orega (Korea), and Bio-fresh (Israel). The use of 1-methylcyclopropene (1-MCP) also blocks the ethylene receptors in plant tissues and prevents the activity of ethylene (Scully and Horsham, 2007).

2.4.5 Antimicrobial Films

Surface microbial spoilage is the primary cause of shelf-life termination of fresh-cut produce (Jay et al., 2005). Uncontrolled harvesting, transportation, packaging, and processing operations are the main reasons for microbial contamination (Erdogrul and Sener 2005). Although freshly harvested fruits and vegetables contain mixed initial flora of coliforms especially *Escherichia coli*, lactic acid bacteria, *Pseudomonas* and *Erwinia*; yeasts, moulds, and *Pseudomonas* are the primary causes of the spoilage of fresh-cut fruits and vegetables, especially when stored aerobically under refrigeration (Ahvenainen 1996; May and Fickak, 2003). Adding antimicrobial agents such as hydrogen peroxide, peroxyacetic acid, ozone, chlorinated water, and plant extracts into the washing water demonstrates effective antimicrobial activity but is not successful for the total elimination of the microbial spoilage on fruit surfaces (Alegria et al., 2009). This direct application of antimicrobial agents has a limited effectiveness because most agents interact quickly with food compounds and reduce their effectiveness (Mehyar et al., 2006). Antimicrobial active packaging has controlled release of antimicrobial agents and keeps the surface concentration of the agent above the MIC (minimum inhibitory concentration) of the target microorganisms (Han 2003; Suppakul et al., 2003). This could be achieved by choosing packaging materials and proper antimicrobial substances with structural compatibility. The antimicrobial substances should be of materials with intermediate polarity (hydrophilicity/hydrophobicity) without strong interaction with the packaging materials or quick release from the packaging materials as a result of being binned or repelled, respectively (Han and Floros, 2000). The antimicrobial agent in active films may either migrate to the food surface or bond chemically to the surface of the film (called immobilized films) (Han, 2003). Blending antimicrobial substances into packaging materials or using multilayer films, in which only one layer is impregnated with antimicrobial substances, improved microbial stability of raw chicken, apple cuts, and strawberry (Rojas-Grau et al., 2007). In the case of edible coating systems, the coating materials should be colourless, tasteless, and stable to high relative humidity, and made of generally recognized as safe components (Krochta and De Mulder-Johnston, 1997). The coating should also adhere well and spread uniformly on the food surface (Ribeiro et al., 2007). The effect of antimicrobial packaging materials and edible coatings on produce shelf-
life is still under investigation. Rojas-Grau et al. (2007) found that lemongrass, oregano and vanillin essential oils in alginate coatings reduced the growth of psychrophilic aerobes, yeast, and moulds on apple cuts by more than 2 log cfu/g. Natamycin in a bilayer coating of chitosan significantly decreased fresh melon decay caused by two strains of spoilage fungi (Cong et al., 2007). Clove, cinnamon, and oregano essential oils totally inhibited the growth of Candida albicans, Aspergillus flavus, and Eurotium repens in vitro when they were used in paraffin coating of paper packaging materials and completely protected strawberry from visible fungal growth during storage for 7 days at 4°C (Rodriguez et al., 2007). Chitosan is an aminopolysaccharide prepared by deacetylation of chitin, which is one of the most abundant natural polymers in living organisms such as crustaceans, insects and fungi and it has been proved to be nontoxic, biodegradable, and biocompatible (Kim et al., 2003) and is capable of forming stable coatings on fresh-cut papaya that suppress microbial growth (Gonzalez-Aguilar et al., 2009). Park et al. (2004) developed Lysozyme-chitosan composite films for enhancing the antimicrobial properties of chitosan films by incorporating 10 per cent lysozyme solution into 2 per cent chitosan film forming solution, the composite films prepared enhanced the inhibition efficacy of chitosan films against bacteria and thus broadening their applications in ensuring food quality and safety. Quattara et al. (2000) observed that the release of acetic acid from chitosan film in water was faster than that of propionic acid, being both affected by temperature according to the Arrhenius law. They further studied the synergistic effect of chitosan with diverse organic acids and cinamaldehyde and they found that all formulations were effective against various endogenous microorganisms in meat except for lactic acid bacteria, with the films with aldehyde presenting the highest efficiency. The greatest limitation of chitosan as a film material is its relatively poor mechanical properties and by cross linking chitosan films with dialdehyde starch, their mechanical properties are significantly improved and the films still retained obvious antimicrobial effects toward S. aureus and E. coli (Tang et al., 2003).

2.4.6 Aroma emitters/absorbers

The commercial use of flavour/odour absorbers and releasers is controversial due to concerns arising from their ability to mask natural spoilage reactions and hence mislead consumers about the condition of packaged food. For this reason, flavour/odour absorbers and releasers have been effectively banned in Europe and the USA (Anon, 2006b). The interaction of packaging with food flavours and aromas has long been recognised, especially through the undesirable flavour scalping of desirable food components (Rooney, 1995). Commercially, very few active packaging techniques have been used selectively to remove undesirable flavours and taints, but many potential opportunities exist. An example of such an opportunity is the debittering of pasteurised orange juices. Some varieties of orange, such
as Navel, are particularly prone to bitter flavours caused by limonin that is liberated into the juice after orange pressing and subsequent pasteurisation. Processes have been developed for debittering such juices by passing them through columns of cellulose triacetate or nylon beads. A possible active packaging solution would be to include limonin absorbers (e.g. cellulose triacetate or acetylated paper) into orange juice packaging material. Two types of taints amenable to removal by active packaging are amines, which are formed from the breakdown of fish muscle proteins, and aldehydes, which are formed from the autoxidation of fats and oils. Unpleasant smelling volatile amines, such as trimethylamine, associated with fish protein breakdown, are alkaline and can be neutralised by various acidic compounds. In Japan, Anico Co. Ltd has marketed Anico™ bags that are made from film containing a ferrous salt and an organic acid such as citrate or ascorbate. These bags are claimed to oxidise amines as they are absorbed by the polymer film (Rooney, 1995). Removal of aldehydes such as hexanal and heptanal from package headspaces is claimed by Dupont’s Odour and Taste Control (OTC) technology that is based upon a molecular sieve with pore sizes of around 5 nanometres. Dupont claims that their OTC technology removes or neutralises aldehydes although evidence for this is lacking. The claimed food applications for this technology are snack foods, cereals, dairy products, fish, poultry and fish (Day, 2003). A similar claim of aldehyde removal has been reported by Swedish company EKA Noble, in collaboration with the Dutch company Akzo, who developed a range of synthetic aluminosilicate zeolites which they claim absorb odorous gases within their highly porous structure. Their BMH™ powder can be incorporated into packaging materials, especially those that are paper-based, and apparently odorous aldehydes are absorbed in the pore interspaces of the powder (Day, 2003).

2.5 CHANGES IN FRUITS AND VEGETABLES TREATED WITH ACTIVE PACKAGING DURING STORAGE

Another way of modifying the atmosphere pack is by using “Active Packaging”. Packaging is termed as “Active” when it performs some desired role other than to provide an inert barrier to the external environment. The goal of developing such packaging is to create a more ideal match of the properties of the package to the requirements of the food. Active Packaging can be created by using oxygen scavengers, carbon dioxide absorbents, ethanol emitters and ethylene absorbents. Ethylene scavengers are mostly used in packaging of minimally processed fruits and vegetables. The appropriate absorbent material is placed along side the fresh produce. It modifies the headspace in the package and thereby contributes to the extension of shelf-life of the fresh produce.

Ripening can also be checked by using controlled atmosphere storage (CAS) and/or active or passive modified atmosphere packaging (MAP) or with edible coatings. A modified
atmosphere can be defined as one that is created by altering the normal composition of air (78 per cent nitrogen, 21 per cent oxygen, 0.03 per cent carbon dioxide and traces of noble gases) to provide an optimum atmosphere for increasing the storage length and quality of food/produce (Phillips 1996). In all cases an atmosphere of low oxygen (1-5 per cent) and high carbon dioxide is created to help reduce the respiration rate of fruits and vegetables and depress ethylene production, thus preventing ripening (Lee et al., 1998). Reducing the rate of respiration by limiting \( \text{O}_2 \) prolongs the shelf-life of fruits and vegetables by delaying the oxidative breakdown of the complex substrates which make up the product. However, at extremely low \( \text{O}_2 \) levels (<1 per cent), anaerobic respiration can occur, resulting in tissue destruction and the production of off-flavours and off-odours (Zagory, 1995), as well as the potential for growth of food borne pathogens such as \textit{Clostridium botulinum} (Austin et al., 1998). Therefore, several different systems are being investigated to scavenge oxygen at appropriate rates for the requirements of different foods including fruits and vegetables, the oxygen scavenging sachets have been used in some countries to protect the colour of packaged cured meats from oxygen in the headspace and to slow down staling and mould growth on baked products, e.g. pizza crusts.

Carbon dioxide generators may be used in packaging for fresh produce where an increased concentration of \( \text{CO}_2 \), combined with decreased \( \text{O}_2 \) concentration, reduces the respiration rate thus increasing the product shelf-life. Another application for carbon dioxide emitters is the packaging of meat products where a high level of \( \text{CO}_2 \) may inhibit microbial growth. There are other situations however, where the removal of carbon dioxide is needed, as in the case of roasted ground coffee. Substantial quantities of carbon dioxide are released on grinding coffee, which must be removed from the package to avoid pressure build up and bursting, in the case of flexible pouches. Commercial solutions commonly used are the incorporation of a one-way valve and more recently, the inclusion of a \( \text{CO}_2 \) absorbing sachet.

\( \text{CO}_2 \) can inhibit ethylene action as well as autocatalytic production of ethylene by climacteric products such as apples and tomatoes (Lee et al., 1996). The rate of respiration of a fruit or vegetable is inversely proportional to the shelf-life of the product; a higher rate decreases shelf-life. Ethylene accumulation can cause yellowing of green vegetables and may be responsible for a number of specific postharvest disorders in fresh fruits and vegetables. To prolong shelf-life and maintain an acceptable visual and organoleptic quality, accumulation of ethylene in the packaging should be avoided. Different studies have shown that these sachets effectively remove ethylene from packages of pears, bananas, kiwifruit, diced onions, apples, grapes, mango, tomato and other fruits (Vermeiren, 2003). Kudachikar et al. (2007) found that MAP of optimally matured (75-80 per cent) banana with low density polyethylene film in combination with ethylene absorbent stored under 13°C could be
extended shelf-life up to 42 days without affecting initial fruit quality. Another type of ethylene scavenger is based on the adsorption of ethylene on activated carbon and subsequent breakdown by a metal catalyst. Use of charcoal with palladium chloride prevented the accumulation of ethylene and was effective in reducing the rate of softening in kiwifruits and bananas and chlorophyll loss in spinach leaves, but not in broccoli (Abe and Watada, 1991).

Condensation or 'sweating' is a problem in many kinds of packaged fruit and vegetables. It is of particular concern in cartons of fresh flowers for which there is important export trade. Unless the relative humidity around flowers is kept at about 98 per cent, water will be lost from the bunches. Such high humidity levels mean there is a very real risk of condensation occurring during transport as the temperature of the flowers may fluctuate by several degrees. When one part of the package becomes cooler then water is likely to condense in the cooler areas. If the water can be kept away from the produce there may be little harm. However when the condensation wets the produce, nutrients leak into the water encouraging rapid mould growth. When the condensation inside packages is controlled, the food remains dry without drying out the product itself. Therefore sensitive fruits like table grapes are protected from contact with water and thus help to reduce growth of mould. Desiccants have been successfully used for moisture control in a wide range of foods, such as cheese, meat, chips, nuts, popcorn, candies, gums and spices. Silica gel, molecular sieves, calcium oxide (CaO) and natural clays (such as montmorillonite) are often provided in Tyek™ sachets (Brody et al., 2001).

Another possible ‘packaging’ method for extending the post-harvest storage life of fruit and vegetables is the use of edible coatings, that is, thin layers of material that can be eaten by the consumer as part of the whole food product. Edible films/coatings can control migration of gas, moisture, oil and fat, and solutes, as well as retain volatile flavour compounds. They can also improve structural integrity and mechanical handling properties and carry food additives so that they help to maintain the quality of foods during marketing and even after packaging is opened. Polysaccharides (such as cellulose, starch, chitosan, pectin, guar gum, alginate, carrageenan and pullulan), proteins (whey protein, collagen, gelatin, corn zein, wheat gluten, soya protein isolate and casein) and lipids (wax) are the major substances used to form a continuous matrix for edible coating formation. The choice of the substance depends on the specific application, i.e. type of food product and main deterioration mechanisms (Min and Krochta, 2005). They also studied that use of edible coatings with antimicrobial properties or with incorporation of antimicrobial compounds is another potential alternative to enhance the safety of fresh-cut produce. Application of antimicrobial agents directly on the food surface may have limited benefits because the active substances are neutralised on contact with the surface or diffuse rapidly from the surface into
the product (Min and Krochta, 2005). Han (2000) selected some additives which can be incorporated into edible films and coatings can be selected to improve general coating performance such as strength, flexibility and adherence, to enhance product colour, flavour and texture, and to control microbial growth. As an example whey protein films/coatings can incorporate effective amounts of edible antimicrobial agent such as potassium sorbate, ethylenediaminetetra-acetic acid (EDTA), nisin and lysozyme (Han, 2000).

A more sophisticated way of extending the shelf-life of packaged foods with active packaging systems is to use multiple function active systems. For example, the combination of oxygen scavengers with carbon dioxide and/or antimicrobial releasing systems significantly improves the storage stability of packaged foods. Oxygen scavengers containing ethanol or antimicrobial releasing systems inhibit microbial growth more effectively than an oxygen absorber alone. Active packaging systems developed to scavenge both oxygen and ethylene from the packages of fresh produce is of great value not only in reducing the growth of spoilage microorganisms, but also in limiting the rate of respiration. Nakamura and Hoshino (1983) reported that an oxygen-free environment alone is insufficient to retard the growth of *Staphylococcus aureus*, *Vibrio* species, *E.coli*, *Bacillus cereus* and *Enterococcus faecalis* at ambient temperatures. For complete inhibition of these microorganisms in foods, a combined treatment involving O\textsubscript{2} scavenging with thermal processing, or storage under refrigeration, or by using a CO\textsubscript{2} enriched atmosphere, they further found that an O\textsubscript{2} and CO\textsubscript{2} absorber inhibited the growth of *Clostridium sporogenes* while an O\textsubscript{2} absorber and a CO\textsubscript{2} generator enhanced the growth of this microorganism.

In general, the chitosan-based antimicrobial films had no or little effect on the lactic acid bacteria, whether inoculated or indigenous. Chen *et al.* (1996) and Ouattara *et al.* (2000) reported that chitosan films made in dilute acetic acid solutions are able to inhibit the growth of *Rhodotorula rubra* and *Penicillium notatum* by direct application of the film on the colony-forming organism. Chitosan in organic acids have displayed antagonistic effects against *Escherichia coli*, *Staphylococcus aureus*, *Saccharomyces cerevisiae*, *Enterobacteriaceae* and *Serratia liquefaciens*, whereas lactic acid bacteria were not affected.