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*Review*

# A review on integrated agro-technology of vegetables

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**The aim of this review was threefold: First, to explore the effect of different preharvest treatments on postharvest quality of fruits and vegetables. Second, the principles of biological, chemical and biochemical changes in fruits and vegetables during development, maturation, ripening and storage were reviewed. Third postharvest handling and factors affecting quality of fruits and vegetables were examined. These include disinfecting, packaging and storage temperature. Pre- and postharvest treatments were found to have an effect on postharvest quality of fruit and vegetables, suggesting that postharvest quality of produce subjected to preharvest treatments should be assessed from a quality improvement, maintenance and consumer safety point of view. Literature recommends an integrated agro-technology approach towards improving quality at harvest and maintenance of qualities of fruits and vegetables.**

**Key words:** Agro-technology, vegetables, fruits, preharvest treatments, ripening, postharvest handling, storage.

## INTRODUCTION

An understanding of the changes of fruits and vegetables during storage entails more than just knowledge of packaging methods. Preharvest as well as postharvest physiological properties have to be understood. Therefore, in this chapter, the survey on the effect of preharvest treatments on postharvest quality of fresh commodities is presented first. This is followed by the survey of post-harvest handling and storage including pre-packaging treatments and storage methods available for fresh commodities. Since tomatoes and carrots were selected for this study, the survey will mainly concentrate on these vegetables.

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**Abbreviations: IAA,** Indoleacetic acid; **MAP,** modified atmosphere packaging; **CAS,** controlled-atmosphere storage; **CAP,** controlled-atmosphere packaging; **LDPE,** low density polyethylene; **LLDPE,** linear low density polyethylene; **MDPE,** medium density polyethylene; **HDPE,** high density polyethylene; **PP,** polypropylene; **PVC,** polyvinylchloride; **PS,** polystyrene; **VA,** ethylene vinyl acetate; **PVDC,** polyvinylidine chloride.

## DEVELOPMENT PHYSIOLOGY OF FRUIT AND VEGETABLES

### Development physiology of tomatoes

Tomato physiology begins with fertilisation of the ovules of the blossom (Salunkhe et al., 1991). Hormone production by the developing seeds and young ovary walls are highly responsible for growth. The period from the end of flowering to and including the ripening stage, during which chemical changes take place and new tissue is formed and brought to morphological completion, is known as the development period (Salunkhe et al., 1991). It includes stages of permutation, physiological maturation, ripening, and senescence (Kader et al., 1985). These stages are followed by continued changes in the chemical composition, which in turn is governed by a range of enzyme activities (Kader et al., 1985).

Tomatoes are commercially mature at a fully developed fruit stage. Endogenous ethylene is present in measureable quantities during the entire development of the tomato fruit (Lyons and Pratt, 1964). It has been reported that soluble peroxidase activity increases dramatically during the early stages of tomato fruit development, reaching a maximum at the green mature stage (Thomas et al., 1981). The soluble peroxidase activity remained higher during the breaker and light pink stages, but decreases in the later stages of development (Thomas et al., 1981). Simultaneously IAA (indoleacetic acid) oxidase activity in the soluble fraction followed a parallel pattern to the peroxidase activity (Frenkel, 1972; Thomas et al., 1981). Frenkel (1972) reported that the induction of the major isozyme component of peroxidase and IAA oxidase was enhanced as the tomato fruit ripens. The amount of auxin protectors also increased as the fruit developed (Thomas et al., 1981).

A relationship between nicotinamide adenine dinucleotide phosphate ($NADP^+$)-malic enzyme and organic acid levels exists in tomatoes from flowering through to ripening, and both increase during develop-ment, reaching maximum levels at the green mature stage (Knee and Finger, 1992). However, a decline in malate concentration is followed by a decrease in NADP-malic enzyme activity and citrate concentration. Their data reported demonstrated that, it is possible that an enzyme is involved in cytoplasmic pH regulation. The sugar content of tomato fruits increases progressively throughout maturation and ripening, with a pronounced increase with the appearance of yellow pigmentation (Winsor et al., 1962a, b, in Hobson and Davies, 1971). The starch content of tomatoes also increases with maturation, reaching a maximum at 8 weeks after fertilisation, but is not detected in young fruit up to 10 days. Results on the ascorbic acid content of tomatoes during the development and ripening seemed inconsistent. However, recent studies have indicated an increase in ascorbic acid contents of tomato fruit during maturation, with either a continuing increase or a slight decrease during the final stages of ripening (Dalal et al., 1965; Mohammed et al., 1999). The malic acid concentration decreases as tomatoes ripen, while citric acid increases up to the green-yellow stage and then generally decreases (Hobson and Davies, 1971).

## Development physiology of carrots

Phan et al. (1973) gathered comprehensive information on the carrot roots during growth up to harvest. The main constituents of carrot roots are soluble carbohydrates comprising of non-reducing sugars, mostly sucrose, and reducing sugars, mostly glucose. Their data showed that there was active biosynthesis of carbohydrates, mainly sucrose, and carotenes, such as β-carotene (Phan et al., 1973). The sugars and carotene contents of carrot roots consistently increase during the 3 months after seeding and reach their maxima at the end of 3 months. After 3 months of the development period, the sugar content of both groups of substances remains almost constant. The total soluble carbohydrate concentration increases rapidly a few days after the initiation of an entire ring of cambium in the carrot roots (Hole and McKee, 1988). Their data concerning the relationship between enzyme activity and carbohydrates during the development of carrot roots revealed the existence of little correlation.

The amount of organic and amino acids increases slowly with age during root development and these components are present in rather low concentrations (Phan et al., 1973). However, pyruvic acid occurs in high amounts in growing carrot roots up to 3 months, which is followed by isocitric acid and malic acid (Phan et al., 1973). These results indicated that a 3-month growth period for carrots could be sufficient before harvest, after which there is no more increase in chemical components responsible for good quality characteristics. However, this “biochemical maturity” is reached while carrots are still growing in diameter and can therefore not be taken as a criterion for determining the harvest date (Phan et al., 1973).

# PREHARVEST TREATMENTS OF VEGETABLES

## Effect of preharvest factors on storage quality of vegetables

Preharvest treatments of fruits and vegetables are primarily aimed at increasing yields, while postharvest storage performance is normally neglected. Several research results were reported on methods to increase harvest yield and qualities of fruits and vegetables (Mitchell et al., 1997). Most research work has been targeted on cultural practices, such as rootstock/plant age, soil management, nutrition, training and pruning practices, crop loads, product size, and growth regulators (Rosenfeld, 1999). Bramlage (1993) in Watkins and Pritts (2001) highlighted the almost overwhelming number of preharvest variables that contribute to the variety of postharvest responses of the crops.

Watkins and Pritts (2001) hypothesise that the diversified postharvest responses of fruits and vegetables during storage are in part due to preharvest cultural practice. A literature review has shown that the major factors affecting yield and quality of vegetables are cultivars, soil plant systems and fertiliser practices, and the environmental factors such as temperature, relative humidity, light intensity and rainfall during production (Rosenfield, 1999).

## Soil plant system and fertiliser practice

From a literature review on the effect of cultural practice on quality of vegetables with emphasis on tomatoes, carrots and lettuce (Rosenfeld, 1999), it was deduced that in general, the objectives of optimal fertilisation strategy were maximization of yield, the maximization of fruit and vegetable quality, minimization of environmental pollution caused by fertilisers and the minimisation of fertiliser expenses. The yield of potatoes, soybeans, cabbages, carrots, onions, cucumbers, strawberries, and eggplants oscillated because of the different soil and climatic conditions (Data given by Polus, in Schnabl et al., 2001). These could also suggest that there could be changes in postharvest quality based on different soil and climatic conditions.

Postharvest quality parameters of tomatoes and carrots vary with the fertilisation practice during production. Even under unfavourable climatic conditions, application of phosphorous-potassium (PK) fertiliser could be used to increase carotene content in carrots (Evers, 1989a). Photosynthetic products like sugar are slightly affected with fertilisation (Evers, 1989a). However, Evers (1989a) showed that seasonal variations and genetic variations are often larger than variations caused by soil and fertiliser practices.

Qualities of carrots are reduced as a result of increased use of mineral fertiliser, but are not affected by measured fertilizers (Lieblein, 1993) whereas increased use of composted manure had no effect on quality of carrots. The postharvest response of carrots is often dependent on the level of fertiliser applied during the growth period (Petrichenko et al., 1996).

Vitamin B concentrations are higher in plants grown with organic fertilisers as compared with plants grown with inorganic fertilisers (Mozafar, 1994). Nitrogen fertilisers, especially at high rate, seem to decrease the concentration of vitamin C in different fruits and vegetables, among them are potatoes, tomatoes and citrus fruits (Mozafar, 1994).

Positive and negative effects of preharvest treatments on tomatoes, either to increase yield or improve nutritional quality, have been reported (Gao et al., 1996; Carmer et al., 2001). Carmer et al. (2001) sup-plied tomato plants with either low electric conductivity (EC = 0.25 $Sm^{-1}$) nutrient solutions or with nutrient solutions supplied with 55 mM NaCl to generate at high electric conductivity (0.75 $m^{-1}$). Their results showed that high electric conductivity increased the total soluble solids (TSS) by ca. 18% and titratable acids by ca. 32% relative to low electric conductivity treatments. The report also indicted that after storage of 2 weeks at 15°C, fruits of high electric conductivity treated plants were 12% less firm than those of low electric conductivity plants, and no difference in TSS or acidity were found.

Salunkhe et al. (1971) has shown the effect of Telone (1,3-dichloropropene and other chlorinated hydropropane) and Nemagon (1,2-dibromo-3-chloropropane) on essential nutritive components and the respiratory rates of carrots and sweet corn seeds. The respiration of carrots treated with Telone and Nemagon was below 94 µl $O_2$ $h^{-1}$ $g^{-1}$ and 82.8 µl $O_2$ $h^{-1}$ $g^{-1}$, respectively, while that of untreated carrots was 108.8 µl $O_2$ $h^{-1}$ $g^{-1}$. This result clearly showed that preharvest treatments could affect the physiology of carrots at harvest. A significant increase in the content of total carotene, β-carotene and total sugars, was observed, with a simultaneous decrease in respiratory rates in carrots (Salunkhe et al., 1971). The low respiration rates indicated that the metabolic activities of the treated carrots were low, which lead to increased shelf life without quality deterioration. Pre-planting soil fumigation with Telone and Nemagon also resulted in increased carotene, β-carotene and total sugars, and decreased the respiratory rates in carrot roots (Singh et al., 1970).

Most researchers reported that there are either positive or negative effects of any type of preharvest practices on quality of carrots and tomatoes, especially at harvest (Watkins and Pritts, 2001; Tittonell et al., 2001; Ozeker et al., 2001; Sen et al. 2001). Salt concentrations of nutrient solutions were shown to affect quality of celery more than yield (Pardossi et al., 1999), and preharvest Ethephon (2-chloroethylphosphonic acid) spray directly onto pepino fruits advanced colour changes (Maroto et al., 1995; Lopez et al., 2000). Nutritional treatments had a positive effect in reducing the peel disorder of fruits under commercial conditions (Zilkah et al., 2001). More research is needed on the storage of fresh produce subjected to various preharvest practices. It is also recommended that after each preharvest practice a study on the quality of vegetables and their storability needs to be conducted in order to secure favourable storage conditions for these products and maintain freshness and nutritional quality.

## Effect of environmental factors on vegetable quality

The effect of climate on quality of vegetables is normally mostly higher than the effect of fertiliser on photosynthetic products such as sugar (Rosenfeld, 1999). Temperature is the major environmental factor affecting quality of vegetables. Vegetables like carrots and tomatoes respond to various levels of temperature. Carrots grown at high temperature were shown to have a higher total sugar content, whereas those grown at low temperature were sweeter, specifically due to a higher sucrose content (Rosenfeld, 1999). Apple watercore, ethylene evolution, flesh firmness, membrane permeability and sorbitol levels were shown to be affected by preharvest fruit temperature (Yamada and Kobayashi, 1999).

Hao and Papadopoulos (1999) have shown that supplemental lighting during growth of cucumber increases biomass allocation to fruits, fruit dry matter content and skin chlorophyll content. Leonardi et al. (2000) grew tomato plants in two glasshouse compartments under two vapour pressure deficit (vpd) levels, showing that fruit growth and transpiration rates greatly varied during daylight hours, which has enhanced under high vpd conditions. As a result a significant reduction in fruit weight and in fruit water content, and an increase in soluble solids was found. Environmental vapour pressure increases can therefore affect not only growth but also quality of tomato fruits. It was shown that air humidity has effects on growth, flowering, and finally on keeping quality of some greenhouse species (Mortensen, 2000).

## Water management

Sørensen et al. (1997) showed the effect of drought stress on carrot quality. Glucose, fructose and sucrose concentrations in carrots exposed to drought stress at different growth stages were not affected in any consistent manner. The results also indicated that the concentration of dry matter was low when drought was induced at an early growth stage in coarse and sandy soil. Averaging the effect of drought periods and cultivars, drought stress was observed to increase the concentration of sucrose in taproots from the coarse, sandy soil. It was also shown that drought stress increased storage losses due to the development of disease (Sørensen et al., 1997).

Research on deficit-irrigating micro-irrigated tomatoes showed that occurrence of early blight disease (caused by the fungus *Alternaria solani*) was increased by 50%, while blossom end rot incidence was five times more severe compared with full irrigation (Obreza et al., 1996). This result indicated that deficit irrigation could cause substantial economic loss of tomatoes through decreased crop marketable quality.

Dodds et al. (1996) studied the influence of water table depth and found that 0.6 m depth gave the best yield and largest fruit size, however, a higher incidence of catfacing, cracking, sunscald and loss of firmness of tomatoes were found. A balance between yield and quality at a water table depth between 0.6 and 0.8 m was recommended for tomato production on sandy loam soils.

On the other hand, irrigation deficit in the first growth period of tomato reduced the number of flowers leading to a decrease in the number of fruits and in the marketable yield (Colla et al., 1999). The soil moisture deficit resulted in increased soluble solids and acidity of the fruit. However, reducing irrigation by 25% before fruit onset and by as much as 50% in the fruit development and ripening stages resulted in no significant decrease of soluble solid yield.

## Hormone treatment

Hormones are essential for plant growth and development. The quality of hormone present and tissue sensitivity to hormones has an effect on plant physiology. Plant hormones are responsible for cell elongation, cell division, inhibition of senescence, abscission of leaves and fruits, dormancy induction of buds and seeds, promotion of senescence, epinasty and fruit ripening. The preharvest as well as postharvest physiological processes in fruits and vegetables are responsible for changes in composition and qualityof these horticultural crops and depend on the plant species. The major classes of plant hormones include auxins, gibberelins, cytokinins, abscisic acid, brassinosteroids and ethylene (Mauseth, 1991; Raven et al., 1992; Salisbury and Ross, 1992; Davies, 1995).

Gibberellins are known to stimulate the physiological processes such as stem elongation, bolting, breaking seed dormancy, enzyme production, induce maleness in dioecious flowers, cause parthenocarpic (seedless) fruit development and can delay senescence in leaves and citrus fruits (Mauseth, 1991; Raven et al., 1992; Salisburg and Ross, 1992; Davies, 1995). Cytokinin stimulates cell division, morphogenesis in tissue, the growth of lateral buds, release of apical dominance, leaf expansion resulting from cell enlargement, enhances stomatal opening in some species and promotes the conversion of etioplasts into chloroplasts via stimulation of chlorophyll synthesis (Mauseth, 1991; Raven et al., 1992; Salisbury and Ross, 1992; Davies, 1995). The functions of abscisic acid are to stimulate the closure of stomata, inhibition of shoot growth, induction of seeds to synthesise storage proteins, induction of gene transcription, especially for proteinase inhibitors in response to wounding, which may explain an apparent role in pathogen defence (Mauseth, 1991; Raven et al., 1992; Salisbury and Ross, 1992; Davies, 1995). Ethylene has been the most studied plant hormone in relation to fruit ripening and postharvest storage. Some of the functions of ethylene are to stimulate the release of dormancy, shoot and root growth, and differentiation of adventitious root formation, leaf and fruit abscission, bromiliad flower induction, induction of femaleness in dioecious flowers, flower opening, flower and leaf senescence and fruit ripening (Mauseth, 1991; Raven et al., 1992; Salisbury and Ross, 1992; Davies, 1995).

The other growth regulating compounds are brassinosteroids, salicylates, jasmonates and polyamines. An abundance of research has been devoted on the chemistry and physiology of natural growth regulators resulting in the recognition of brassinosteroids as a new class of phytohormones (Schnabl et al., 2001). Some of the effects of brassinosteroids include stimulation of stem elongation, inhibition of root growth and development and promotion of ethylene biosynthesis and epinasty. Recently, the brassinosteroids has gained a broad spectrum of application and extremely low toxicity and mutagenicity have received increasing attention (Schnabl et al., 2001). Previous work showed that brassinosteroids are plant growth promoting regulators, which are effective in cell elongation and division, source/ sink metabolism, chlorophyll synthesis and reproductive and vascular development (Clouse, 1996; Mandalla, 1988). Sasse et al. (1995) and Takatsuto et al. (1996) reported that they enhance nutrient contents, improve shape and taste of fruits, have beneficial effects on germi-nation, growth and seed quality. Much research has been conducted on the potential performance and investigations of the potential applications of brassinosteroids in agriculture (Schnabl et al., 2001).

## Communication catalization (ComCat®) treatment

Recently, a hormone containing treatment has been introduced as an alternative agricultural input to the use of chemicals to increase production of vegetables and other crops. ComCat® is a natural biocatalyst, which is extracted from seeds of plants and mainly consists of amino acids, gibberellin, kitenins, auxin (indole-3-acitic acid), brassinosteroids, natural metabolites, pathogen-related PR-proteins with defence reactions, terpenoids, flavonoids, vitamins, inhibitors, other signal molecules, biocatalysts and cofactors. The yields of ComCat® treated vegetables were shown to be increased for cabbage (8%), tomato (16 to 19%), potato (9 to 19%), soybeans (26 to 30%), eggplants (37%), cucumbers (25 to 32%), carrots (32%), onions (49%) and strawberries (50%), compared to control vegetables and fruits (Schnabl et al., 2001). These vegetables were also shown to have better root development, improved resistance induction, less chance of deficiencies with fertiliser, higher resistance to pathogens prior to harvest and they seem to have a slightly better resistance to environmental stress, and increased protein content (Hüster, 2001; Schnabl et al., 2001).

A reduction of plant disease symptoms of up to 45% in comparison to untreated control plants has been found. This is the result of induction of the PR-proteins (pathogenesis-related proteins) namely peroxidase, chitinase and 1-3 gluconase. These enzymes protect cell walls and prevent infection by fungi (Hüster, 2001). Advantages of ComCat® treatment are that only low doses are necessary to show measurable effects of these brassinosteroids containing plant extract in crop plants, their environmental safety and the possibility of reducing the amount of pesticides needed (Schnabl et al., 2001). Apart from studies on yield increase, no data is yet available on the effect of preharvest ComCat® treatment on quality of fruits and vegetables at harvest, as well as during storage.ComCat® was approved by, and registered with the Federal German Biological Centre of Agriculture and Forestry (BBA), Institute for Integrated Plant protection, as a harmless plant strengthening substance of plant origin. It is also licensed for use in ecological farming, according to the EU-regulation 2092/91.

As discussed, the effects of ComCat® include (a) serving the plant as a general strengthening agent for the organic development, (b) inducing resistance through activating plant own defence mechanisms against pathogens, and biotic and abiotical stress factors, (c) improve root development, (d) increase yield in agricultural cash crops as well as horticultural crops and (e) increase protein content.

## POSTHARVEST PHYSIOLOGY OF FRUIT AND VEGETABLES

### Respiration

Respiration is defined as a process by which stored organic materials (carbohydrates, proteins, and fats) are broken down into simple end products with a release of energy. In the process, $O_2$ is used and $CO_2$ is liberated. Vegetables continue to respire after harvest and during storage. Each type of vegetable and cultivars requires a specific range of $CO_2$ and $O_2$ concentration levels for safe storage without the occurrence of physiological disorder. The level of physiological activity and potential storage life can be indexed by the rate of respiration. Respiration is one of the basic physiological factors, which speeds up ripening of fresh commodities and is directly related to maturation, handling, and ultimately to the shelf life (Ryall and Lipton, 1979; Ryall and Pentzer, 1982). Generally, the loss of freshness of perishable commodities depends on the rate of respiration. An increase in respiration rate hastens senescence, reduces food value for consumers, and increases the loss of flavour and sellable dry weight.

Stored intact fruits and vegetables face desiccation and chilling injury after harvest and during storage. Due to wounding stress, as a result of chilling or mechanical injuries, respiration rate and overall metabolic activities usually increase. The main physiological manifestation of metabolic activities include increased respiration rate and, in some cases, ethylene production (Rosen and Kader, 1989).

The index of physiological activity and potential shelf life have a direct relationship with respiration of fruits and vegetables. Since sugars in fruits and vegetables play a role in the respiration process, the quantity of sugars in fruits and vegetables available for respiration is the dominant factor for the shelf life of these commodities at a given temperature (Paez and Hultin, 1972). For normal respiration, removal of respiratory $CO_2$ needs more emphasis than supply of $O_2$, because some fruits and vegetables are highly sensitive and could be suffocated with a high level of $CO_2$ (Duckworth, 1966; Kader et al., 1985). Removal of respiratory heat requires attention because it increases the product temperature and surrounding air temperature, which in turn is responsible for increasing respiration and causes acceleration of substrate utilization, predominantly sugars (Ryall and Lipton, 1979; Ryall and Pentzer, 1982). The rate of respiration depends on the quantity of available $O_2$ as well as the storage temperature. A decrease in rate of respiration increases the shelf life of fruits and vegetables. In order to achieve long storage life of fruits and vegetables, the rate of respiration should be reduced through decreasing the $O_2$ level, slightly increasing the $CO_2$ level, and decreasing the storage temperature, which includes removal of respiratory heat (Duckworth, 1966; Kader et al., 1985). The optimum gas composition is the range of $O_2$ and $CO_2$ levels that would minimise physiological disorder, reduce respiration rate and reduce ethylene production during storage. The limit of tolerance to low $O_2$ and high $CO_2$ levels depends on several parameters including temperature, physiological conditions, maturity, and previous treatment.

## Temperature quotient of respiration

Temperature highly affects the metabolic activities of fruits and vegetables. Relatively higher temperatures increase the rate of respiration and ethylene production during storage. The rate of chemical reactions in fruits and vegetables is also controlled by temperature. It was reported that theoretically, the rate of respiration doubles for each 10°C increase in temperature. Depending on the maturity and anatomical structure of the fruits or vegetables, the temperature quotient of respiration may be more than double (Ryall an Lipton, 1979; Ryall and Pentzer, 1982; Sargent et al., 1991). These researchers showed that the respiration rate of topped carrots increased by 79% at 25 to 27°C, when compared to topped carrots at 0°C. Similarly, the rate of respiration (rate of $CO_2$) of bunched carrots increased by about 71% at 25 to 27°C, compared to those at 0°C (Hardenburg et al., 1986), and the respiration rate of mature green tomatoes increased by 100% when stored at 25 to 27°C compared to storage at 0°C (Hardenburg et al., 1986).

Preharvest treatments on a farm, or in an orchard, affects postharvest physiology of fruits and vegetables, such as the respiration rates. Physiology of fruits and vegetables begins at the time of blossoming or bud formation and is affected by preharvest factors such as fertilisation, variety, and irrigation, and by environmental factors such as sunlight duration and quality, temperature, humidity etc., as well as preharvest spray of hormones and growth regulators (Ryall and Lipton, 1979; Ryall and Pentzer, 1982; Schnabl et al., 2001). These treatments could possibly have positive or negative effects on the postharvest quality and shelf life of fruits and vegetables, indicating the importance of further integrated research on pre-and postharvest physiology when implementing new preharvest treatment agents or methods.

## Ethylene production and effects

Ethylene advances the onset of an irreversible rise in respiration rate in climacteric fruit and increases the ripening process. The effect of low $O_2$ and high $CO_2$ levels on the production of ethylene adds to the nature of the ethylene production or inhibition process. Fruits and vegetables are classified into five groups according to ethylene production rates within the ranges of 0.1 ml ethylene $kg^{-1}h^{-1}$ at 20°C to 100.0 ml ethylene $kg^{-1}h^{-1}$ at the same temperature (Kader et al., 1985). In general, the ethylene production rates of tomatoes range from 1.0 - 10 ml $kg^{-1}h^{-1}$ at 20°C, which classifies them in the moderate class according to ethylene production rate (Ryall and Lipton, 1979; Kader et al., 1985). Tomato is one of the few vegetables to which a known phytohormone, ethylene, is applied commercially to influence the rate of ripening. Ethylene plays a significant role in the physiological and biochemical changes that occur with the climacteric onset. Lyons and Pratt (1964) reported that endogenous ethylene was present in measurable quantities during the entire growth phase of the tomato fruit. The concentration of ethylene increased 10-fold when fruit growth reached 70 to 93% of its total fruit growth (Lyons and Pratt, 1964).

It was also shown that the concentration of ethylene increased 400 times that of the average measured during growth, at the climacteric onset of ethylene production and onset of ripening. External introduction of ethylene to tomatoes at all stages of development induces ripening and climacteric onset along with phenotypic changes common to normal ripening, such as red color development, fruit softening, and characteristic flavour (McGlasson, 1978 and 1985). However, the acceptable edible quality of tomatoes can only be attained with those that were 93% mature (McGlasson, 1978 and 1985).

In shelf life improvement, maintaining low ethylene concentration and reducing ethylene biosynthesis plays a significant role. Adams and Yang (1977) have shown that aminoethoxyvinylglycine (AVG) block the conversion of s-adenosyl-methionine to 1-aminocyclopropane-1-carboxylic acid. Aminoethoxyvinylglycine was also effective in inhibiting ethylene synthesis in slices of green tomatoes, but was only relatively effective in pink and red tomato fruits. Low temperature also reduces induction of ethylene in tomato fruits during storage, so that the shelf life of tomatoes is increased, when stored at low temperature. Higher temperatures increase ethylene production and result in advanced physiological and biochemical changes in fruit (Wiley, 1994).

Ethylene-induced formation of isocoumarin was also characterised in relation to ethylene-enhanced respiration in whole or cut carrots (Lafuente et al., 1996). Sarker and Phan (1979) reported that ethylene induces the formation of isocoumarin (8-hydroxy-3-methyl-6-methoxy-3,4-dihydro-isocomarin) in carrots, a compound associated with bitterness in carrots (Carlton et al., 1961; Simon, 1985). Concentrations of ethylene ranging from 0.1 to 5 ppm, and temperatures from 1 to 15°C, increased respiration, resulting in a more rapid formation of isocoumarin (Lafuente et al., 1996). It was also shown that exposure to low levels of ethylene (0.5 ppm) for 14 days at 1 or 5°C resulted in isocoumarin contents of 20 and 40 mg/100 g peel, respectively. These levels were sufficient to bring a detectable bitter flavour in intact carrot roots. These results clearly indicated that carrot quality is highly sensitive to ethylene during storage and transportation, suggesting that ethylene concentration as well as its biosynthesis should be controlled during commercial storage of carrots.

The presence of the commonly identified phytohormones and various growth regulators are believed to have an inductive effect on ethylene production of fruits and vegetables during ripening (Abdel-Rahman et al., 1975; Davey and Van Staden, 1978; Ryall and Lipton, 1979; Ryall and Pentzer, 1982). Some chemicals applied to bring about abscission of fruits and vegetables that are important in fruit thinning and mechanical harvesting have been shown to induce ethylene production. These can cause premature ripening in fruits and bitterness in carrots.

## Transpirational loss

Storage temperature and relative humidity play an important role in the physiological changes of fresh produce including physiological weight loss. Water loss is rapid at low relative humidity, since the vapour pressure difference between the commodity and surrounding air is a driving force for moisture transfer from the wet product to the air. In most of the cases moisture content of fresh fruits and vegetables are very high (usually greater than 70%). Therefore, the air inside the flesh is nearly saturated that is, close to 100% relative humidity. Berg and Lentz (1966) noted that the lower humidity ratio causes desiccation and marked softening of carrots, together with some increase in decay. High relative humidity is therefore desirable for reducing physiological weight loss during storage of fruits and vegetables.

Temperature is the other major environmental factor that considerably affects the postharvest physiological weight loss of stored vegetables (Salunkhe et al., 1991). The commodity temperature is highly dependent on the surrounding air temperature. Usually weight loss from perishable commodities is high if surrounding air temperature, flesh moisture content and temperature are high. Vapour pressure increases as air, flesh temperature and moisture content increases. Depending on the magnitude of temperature gradients and relative humidity of the surrounding air the physiological moisture loss varies. In summary, the most important ways to reduce physiological weight loss are by increasing relative humidity and decreasing storage temperature.

## Postharvest physiological disorder

Postharvest physiological disorders affect mainly fruits. Susceptibility to disorders was shown to be dependent on a number of factors, such as maturity at harvest, cultural practices, climate during the growth season, produce size, harvesting, and handling practices. Adverse environmental conditions or a nutritional deficiency during growth and development of fruits and vegetables cause postharvest physiological disorders (Brown, 1973; Eckert et al., 1975; Eckert, 1978a, b and c). They may be classified as low temperature disorders, postharvest physiological disorders and mineral deficiency disorders. Low temperature storage is beneficial because it reduces respiration and metabolic activities. Tropical and subtropical fruit and vegetables require specific ranges of storage temperature. On the other hand, low temperature does not reduce all aspects of metabolism to the same extent as it reduces respiration. This could lead to a metabolic imbalance due to an accumulation of reaction by-products and possibly a shortage of substrates. Chilling injury is a disorder long observed in plant tissues, especially those of tropical or subtropical origin. This injury is due to the exposure of plant tissue to temperatures below their critical temperature, which is usually below 15°C (Ryall and Lipton, 1979; Bramlage, 1982; Couey, 1982; Wills et al., 1989). The physical symptom of chilling injury and the lowest safe storage temperature for some fruits and vegetables varies. Pitting of the skin due to the collapse of cell beneath the surface and browning of flesh tissues are some of the common symptoms of chilling injury. Therefore, selection of a proper storage temperature range for fruits and vegetables is a critically important factor in order to maintain the best quality and increase shelf life. The approximate lowest safe storage temperature for tomato fruit varies between 7.2-12.8°C (Hardenburg et al., 1986), while carrot roots are not susceptible to chilling injury when stored at temperatures as low as 0°C.

## Chemical and biochemical changes during ripening and storage

During ripening of fruits, several biodegradation processes take place, such as depolymerization, substrate utilization, loss of chloroplasts, and pigment distraction, mainly due to the action of hydrolytic enzymes (esterases, dehydrogenases, oxidases, phosphatases and ribonucleases) (Baker, 1975; Mattoo et al., 1975). There are also some biosyntheses associated with these processes such as syntheses of proteins and nucleic acids, maintenance of mitochondria, oxidative phosphorylation, phosphate ester formation and syntheses linked to the metabolic pathway (Baker, 1975; Mattoo et al., 1975).

## Carbohydrates

Among the changes that may occur during ripening of flesh fruits, such as tomatoes, is a change in the carbohydrates composition mainly due to substrate utilization and action of hydrolytic enzymes (Pratt, 1975). The presence of free or combined sugars with other constituents plays an important role in flavours of vegetables through a sugar to acid ratio balance. During ripening of fruit, carbohydrates undergo metabolic transformations, both qualitatively and quantitatively. Starch is completely hydrolysed into glucose, and fructose and sucrose formed as ripening progresses (Mattoo et al., 1975). However, structural carbohydrates are decreased slightly. Mattoo et al. (1975) reported that pentosans and cellulose are stored carbohydrates, which may also serve as potential sources of acids, sugars, and other respiratory substances during ripening.

In tomatoes natural sugars such as arabinose, rhamnose, and galactose are steadily decreased in cell walls as the color changes (Campbell et al., 1990). Several studies have also shown that changes in cell wall carbohydrates similar to those reported for intact fruits occurred in cell walls from pericarp discs (model for intact tomato fruits) (Gross and Wallner, 1979; Gross, 1984; Campbell et al., 1990). Other studies showed that the total sugar content of tomatoes increased during ripening, and may be followed by no further changes or a slight decrease during ripening (Baldwin et al., 1991). Similar findings were reported by other researchers, who showed that sucrose content in tomatoes also decreased with the progress of ripening (Goodenough et al., 1982; Baldwin et al., 1991).

During storage of fruit and vegetables, free sugars show a general initial increase followed by a decrease. The increase in free sugars in some fruit and vegetables are due to the breakdown of polysaccharides. In some fruits approximately equal quantities of glucose and fructose are formed due to hydrolysis of starch. However, as storage time advances, especially in fruit, the content of all three free sugars (sucrose, glucose and fructose) declines. Several factors contribute towards the excessive decline of sugars during storage, such as fruit maturity, storage temperature, concentration of $O_2$, $N_2$, ethylene and $CO_2$. Higher temperature favours faster utilisation of sugars as substrate in the respiration process (Wiley, 1994).

In carrots, the ratio of nonreducing to reducing sugars exhibits a sharp decrease after 14 to 18 weeks of storage at 1.1°C. Simultaneously an active synthesis of reducing oligosaccharides as raffinose together with the formation of new rootlets is observed (Phan et al., 1973). Temperature also regulates the rate at which biochemical changes occur during storage. Higher temperature activetes enzymatic catalysis and leads to chemical and biochemical breakdown of chemicals in fruits and vegetables during storage. As a result, fruits and vegetables loose firmness faster at higher temperature due to high enzymatic activities (Yoshida et al., 1984).

## Organic acids

Common acids found in fruit includes citric, malic and ascorbic acid. During ripening, organic acids are among the major cellular constituents undergoing changes (Salunkhe et al., 1991). Studies have shown that there is a considerable decrease in organic acid during ripening of fruits. Modi and Reddy (1966), in Salunkhe et al. (1991), showed that concentrations of citric, malic and ascorbic acids declined 10, 40 and 2.5 fold, respectively, in fruits such as tomatoes. The titratable acidity decreases with storage time, especially at higher temperatures (Mohammed et al., 1999). Higher storage temperatures are known to have an increasing effect on the rate of decrease in ascorbic acid content in tomatoes during storage (Salunkhe et al., 1991). However, Mohammed et al. (1999) showed that the ascorbic acid content in tomatoes slightly increased during ripening during storage at 20°C for 14 and 21 days. In general, the ascorbic acid content decreases rapidly after full ripening of tomatoes stored at higher storage temperatures.

In carrots, titratable organic acidity decreases slowly during storage (Phan et al., 1973). However, Phan et al. (1973) reported that stored carrots had high contents of iso-citric and malic acids, which they could not explain. Pyruvic and oxaloacetic acids were not detected in these stored carrots.

## Enzyme activity

As was mentioned above, the biochemical changes are responsible for development of off-flavours, discoloration and loss of firmness of fruit and vegetables and are affected by enzymes. The most important enzymes related to food quality include lipolytic acyl hydrolase, lipoxygenase, peroxidase, catalase, protease, polyphenol oxidase, amylase, pectin methylesterase, polygalacturonase, ascorbic acid oxidase and thiaminase (Svensson, 1977). Lipolytic acyl hydrolase, lipoxygenase, peroxidase, catalase and protease are responsible for the changes in flavour of minimally processed as well as intact fruits and vegetables, while polyphenol oxidase is responsible for the changes in colour, especially during ripening of fruits and vegetables (Wiley, 1994). The changes in softness of fruits and vegetables are due to the activities of amylase, pectin methylesterase and polygalacturonase, which result in loss of texture. The reaction catalysed by ascorbic acid oxidase and thiaminase leads to the loss of nutritional quality of food in terms of vitamins C and B content (Wiley, 1994). Catalase and peroxidase are also known for their oxidative activity during ripening and their activity levels increases considerably during ripening of fruit and vegetables (Mattoo et al., 1975).

Glycolytic enzymes are groups of enzymes responsible for the glycolytic breakdown of sugars, and they increase considerably during ripening of fruits. Other classes of enzymes active during storage of fruit and vegetables include hydrolytic enzymes, invertase, transminases, citrate cleavage enzymes, enzymes of the tricarboxylic acid cycle and chlorophyllase (Mattoo et al., 1975), which are responsible for the hydrolysis of starch, flesh softening in most fruits, the degradation of sucrose, liberation of monosaccharides, turnover of amino acids, and ensuing chlorophyll degradation during ripening.

El-Zoghbi (1994) reported effects of enzyme activity on alcohol-insoluble solid dietary fibres, and texture and firmness changes during ripening of tropical fruit such as mango, guava, date and strawberry. The results showed that alcohol-insoluble solid, dietary fibres, texture and firmness declined in these fruit during ripening. However, both polygalacturonase as well as cellulase activities of the fruits increased markedly, during ripening.

The pectin-degrading polygalacturonase (PG) iso-enzymes are highly responsible for softening of fruit (Hobson, 1964; Tigchelaar et al., 1978; Marangoni et al., 1995). Bruinsma et al. (1990) demonstrated that these enzymes are highly responsible for most chemical and biochemical changes associated with deterioration of fruit and vegetable quality during ripening and storage. Postharvest treatment had also an effect on biochemical changes related to enzymatic activities during storage (Marangoni et al., 1995; Yoshida et al., 1984; Dodds et al., 1996; Assi et al., 1997). PG normally accumulates to high levels in ripe tomatoes (Kramer et al., 1992). Similarly, Brummell and Harpster (2001) reported that polygalacturonase activity is largely responsible for pectin depolymerization and solublization of polysaccharides. The loss of firmness of tomatoes during ripening is due to the increased activities of PG and pectinesterase (El-Zoghbi, 1994).

In tomato it was shown that ethylene production was induced prior to polygalacturonase production and that it is responsible for triggering PG synthesis indirectly (Grierson and Tucker, 1983). Extracted PG activity in non-chilled tomato fruit significantly correlated with softening of the fruit. However, chilling-associated softening correlated with higher initial extracted pectin-methylesterase (PME) activity. It was suggested that loss of turgor from translocation of water to the PME-modified cell walls was responsible for loss in firmness as a consequence of chilling. Heat treatment, on the other hand, strongly reduces PG activity of tomatoes during ripening and storage (Yoshida et al., 1984). In general, relatively higher temperatures (about 22°C) favour development of PG activity in tomatoes and high temperature treatment suppresses this enzyme activity (Yoshida et al., 1984).

Biochemical processes are also responsible for colouration and loss of firmness of fruits and vegetables (Kertesz, 1951; Doesburg, 1965; Hildebrand, 1989). As a result of increased enzymatic activity occurring due to storage temperature, postharvest quality of tomatoes such as red colour formation, firmness, titratable acidity and decay during ripening are affected (Batu, 1998). Changes in colour from green to red are delayed in the case of tomatoes stored at lower temperature as compared with relatively higher temperature, since the lower storage temperature reduces enzymatic activity. This could lead to increased acidity during storage.

## Postharvest microbiology of fruit and vegetables

The freshness quality and consumer safety of fruits and vegetables depend on the microbial population at harvest, as well as during storage (Brackett, 1992). Fruit and vegetables are highly susceptible to microbial contamination during growth, harvest and postharvest operations (Madden, 1992). Most fruits have pH values below 4.5. Consequently, under such acidic conditions most of the microorganisms cannot grow easily. Conversely, most vegetables have pH's above 4.5, which creates favourable conditions for various types of microorganisms. Carrots have pH values varying from 4.9-6.3 while tomatoes have lower pH values ranging between 3.9 and 4.7 (Banwart, 1989). Microorganisms account for up to 15% of postharvest decay of fruits and vegetables. Bacteria, yeast and moulds are the three important groups of microorganisms that affect the quality of fruits and vegetables during storage. The sources of these microorganisms could be from environmental air, soil, and poor sanitation during postharvest unit operations.

Several distinct mechanisms for preharvest infection are known. Lesions on stems, leaves and flower parts of infected plants as well as dead plant materials are sites for sporulation of pathogenic fungi (Nelson, 1965; Salunkhe et al., 1991). Rain and wind transport spores of these fungi to flowers and fruits at every stage of their development. When free water is present and the climatic conditions favourable, these spores germinate and rapidly increase the microbial population. The population and type of microorganisms associated with fruit vegetables are different from those of stem and root vegetables, the reason being the differences in chemical composition such as moisture content, titratable organic acid, and free sugar content. Usually the microbial population is higher on stem and root vegetables than in most fruits mainly due to acidity and may be due to the contact with soil.

The most important postharvest diseases of tomatoes include alternaria, rhizopus, buckeye, grey mold, soft rot, acid rot, bacterial soft and ripe rot, which are caused by *Alternaria alternata, Phytophthora* species, *Botrytis cinerea, Rhizopus stolonifer, Alternaria tenuis, Geotrichum candidum, Erwinia cartovora or Pseudomonas* species and *Colletotrichum* species, respectively (Senter et al., 1987; Splittstoesser, 1987; Buick and Damoglou, 1987; Brackett 1988a; Bulgarelli and Brackett, 1991; Salunkhe et al., 1991). The major postharvest diseases of fresh carrots are gray moulds rot, centrospora rot, watery soft rot and bacterial soft rot which is due to *Botrytis cinerea, Centtrospora acerina, Sclerotinia sclerotiorium* and *E. cartovora,* respectively. Similarly, losses of other vegetables in general are due to watery soft rot, cottony leak, fusarium rot, and bacterial soft rot that are caused by *Sclerotinia, Pythium butleri, Fusarium and Erwinia or Pseudomonas* species, respectively.

As ripening of fruits and vegetables progresses, the firmness decreases and the intrinsic factors, which confer resistance during development, can no longer protect against microbial decay (Eckert et al., 1975, 1978). The high moisture and nutrient content of fruits and vegetables adds to susceptibility to invasion by specific pathogenic microorganisms (Eckert, 1978 a, b and c).

The microbial deterioration of fruits and vegetables are highly influenced by environmental factors, such as temperature, moisture content of crops, relative humidity of air, and storage air gas composition. In general, control of postharvest decay of fruits and vegetables are based upon the prevention of infection before as well as after harvest, eradication of incipient infections and retarding the progress of the pathogen in the host by postharvest treatments such as disinfection (Eckert et al., 1975).

## POST-HARVEST HANDLING AND STORAGE

### Pre-packaging treatments

### Postharvest disease control

As mentioned above, the postharvest quality and safety of fresh fruits and vegetables mainly depends on their microbial population (Brackett, 1992). Different approaches have been used to reduce postharvest loss, classified in chemical and non-chemical methods. Various synthetic fungicides and bactericides have been used alone or in combination with chlorination to limit the growth and transmission of diseases caused by microorganisms during storage of fresh commodities. However, chemicals may have a negative impact on agriculture in developing countries (Eckert, 1990; Conway et al., 1999; Qadir and Hashinaga, 2001). Biological products such as Aspire, BioSave, and Yield Plus are now available in the marketplace of developed countries to control growth of bacteria or fungi. *Pseudomonas syringae van Hall* (strain ESC-11) is sold commercially under the names BioSave-11 and BioSave-110 (EcoScience Corp., Orlando, Florida), and is currently being used to control decay on apples and pears caused by *B. cinerea*, *Mucorpiriformis fischer*, and *Pseudomonas expansum* (Janisiewicz and Marchi, 1992; Janisiewicz and Jeffers, 1997).

Other methods used to control postharvest diseases are modification of pH, chemical treatments or a combination (Huxsoll and Bolin, 1989; King and Bolin, 1989). The success of these products, however, remains limited (Wisniewski et al., 2001). The reason may include the following: (a) there is an increasing consumer concern over the use of pesticide as a postharvest decay control of food (Wisniewski and Wilson, 1992), (b) the use of fungicides may result in predominance of fungicide resistant strains (Elmer and Gaunt, 1994), (c) the variability experienced in the efficiency of these products, and lack of understanding of how to adapt "biological approaches" to a commercial setting (Wisniewski et al., 2001). Researchers and industries have come up with some noble ideas such as using combinations of different antagonists. However, these approaches seem to meet with consumer resistance (Wisniewski et al., 2001).

Much work as been done on non-chemical approaches and efficient postharvest disease control methods including various physical treatments such as biocontrol agents, heat, ultra-violet light and ionising radiation. Some novel heat treatment approaches to postharvest decay control of fruits and vegetables were developed and applied in Israel (Rodov et al., 1995; Afeke et al., 1998; Fallik et al. 1999, Fallik et al., 2000). The postharvest decay of bell pepper was significantly decreased by hot water treatment dipping at temperatures of 45 and 53°C for 15 and 4 min, respectively (Gonzalez et al., 1999). Heat treatment, when combined with fungicide treatments, was also reported to be effective and can be an useful alternative method to control postharvest decay (Conway et al., 1999). In this case the effect of fungicide residues on human health and costs associated with combinations of treatments has to be considered. However, the application of some of these methods, such as heat treatment, require equipment that is complex and costly for use in under-developed countries (Rodov et al., 1996).

Intensive research was conducted on the efficiency of chlorine solutions to control the growth of pathogenic microorganisms on fresh produce and minimally processed "ready-to-eat" fruits and vegetables (Wei et al., 1995; Zhuang et al., 1995; Park et al., 1995; Velazques et al., 1998; Beuchat et al., 1998; Delaguis et al., 1999; Escudere et al., 1999; Li et al., 2001; Beuchat et al., 2001; Ukuku and Sapers, 2001; Prusky et al., 2001). These studies were carried out on the survival of inoculated spoilage fungi such as *Alternaria hydrophila* (Velazquez et al., 1998; Beuchat et al., 2001), *A. alternata* (Prusky et al., 2001) and human pathogenic bacteria such as *Salmonella montevideo* (Zhuang et al., 1995), *Salmonella stanley* (Ukuku and Sapers, 2001) and *Yersinia enteroocolitica* (Escudero et al., 1999). Similarly, studies on the normal microbial populations of harvested vegetables were also reported (Beuchat et al., 1998; Prusky et al., 2001). The concentration of free chlorine in these studies varied from 50 to 2000 and ppm and dipping times from 1 to 10 min.

Chlorination, when used in combination with non-chemical methods, is effective in reducing postharvest disease losses. Warm chlorinated water was shown to reduce microbial loads by 3 log cfu. $g^{-1}$ in lettuce washed in chlorinated water at 47°C, and 1 log cfu. $g^{-1}$ at 4°C (Delaquis et al., 1999). Similarly, the combination of different chlorine concentrations (50 to 400 mg/ml NaOCl, pH 7.0) with 52.5°C water were shown to be more effective than use of water or chlorine solutions at 20°C for reducing initial microbiological flora in minimally processed green onions Park et al. (1995) reported that the microbial load of the minimally processed watercress and onion was effectively reduced with chlorine (100 ppm). However, high concentrations of chlorine resulted in greater microbial proliferation after 7 days of storage, loss of ascorbic acid and significant colour changes in stored cut vegetables.

Preharvest dipping treatment in the organic chlorine compound troclosene sodium extended the storage life of fruit by delaying development of black-spot disease (Prusky et al., 2001). All the research work cited here, has been devoted to the control of pathogens and postharvest decay by microorganisms without any emphasis on the effect of free chlorine on the quality, or the physiological and biochemical quality changes.

In general, chlorination is an effective method especially in reducing microbial load in intact fruits and vegetables. For several reasons, such as availability of chlorinated solutions and cost, chlorine disinfection seems to be a good method for application in developing countries. The efficacy of chlorine solution on postharvest physiological as well as chemical and biochemical changes still needs to be explored.

### Electrochemically activated water (anolyte water)

Anolyte water is prepared from an aqueous solution of NaCl and this electrochemically-activated water is known to be a powerful, non-toxic, non-hazardous disinfectant. Two kinds of electrochemically activated water are produced, anolyte and catholyte. The anolyte water is described as having an oxidation-reduction potential (ORP) in the region of +1000 mV and catholyte an ORP of –800 mV, and the pH value of catholyte is in the alkaline region while the pH value of anolyte is in the acidic region. Current thinking around the concept is that the ORP of both solutions fluctuates between these values at a rate too rapid to measure. Some of the biocidal agents (free radicals) in the solutions are $ClO_2$, HClO, $Cl_2$, $ClO^-$, $H_2O_2$, $HO_2^-$, NaHO, $O_2$, $O_3$, $H^\bullet$ and $^\bullet OH$. Prilutski and Bakhir (1997) investigated properties of anolyte and catholyte produced by diaphragm electrolysis of aqueous solutions. Their results showed that catholyte and anolyte have different physical-chemical properties. Anolyte is thought to have the antimicrobial effect and catholyte a detergent or cleaning effect (Popova et al., 1999). The presence of the free radicals with their oxidising effects in the solutions is considered of great importance. It is the free radicals (working substances), which gives anolyte bactericidal and sporicidal activity (Aquastel, 2000), since higher organisms possess antioxidant defence systems, whereas microorganisms generally do not.

The electrochemically produced anolyte water was effectively used in drinking water disinfecting units (Aquastel, 2000). The determination of organic chlorine compounds and trihalogenmethanes showed significantly less formation of these by-products. Moreover, the formation of halogens were significantly less than defined standard requirements and the pH-value only slightly decreased (Aquastel, 2000). Anolyte attracts interest since it is an environmentally and ecologically friendly substance for use as a postharvest fruit and vegetables disinfectant. Based on these and the antimicrobial action of anolyte, its potential to be used as a postharvest disinfectant of fruit and vegetables should be explored.

## Packaging

### Controlled atmosphere packaging

Controlled atmosphere storage refers to storage of food in a gas atmosphere that is different from the normal composition of air. In controlled atmosphere the headspace gas is precisely adjusted to the atmosphere composition required by a specific fruit or vegetable (Perry, 1993). Controlled atmosphere storage is mostly used for the long-term storage of whole fruits and vegetables in warehouses, bulk storage and transportation.

Over 4000 research papers have been published giving information on the optimal modified atmosphere conditions for cultivars of fruits and vegetables (Zagory and Kader, 1988; Kader et al., 1989). These literatures have built good basic principles of controlled atmosphere storage and significantly contributed towards the success of this technology in developing countries (Lioutas, 1988).

The major influence on the choice of controlled atmosphere conditions is the susceptibility of particular cultivars to superficial scald (Johnson, 1999). Using controlled atmosphere storage methods, the gas compositions have to be adjusted to a certain level specific to each fruit and vegetable type, and it is unlikely that there will be benefits from further adjustment of the compositions of oxygen and carbon dioxide without risking the damage to certain fruits and vegetables (Johnson, 1999).

The controlled atmosphere gas compositions required by a given commodity is obtained by mixing appropriate volumes of gases. Certain machinery are needed to mix and control the gas composition of the air during the storage period. In controlled-atmosphere storage packaging, atmospheric conditions (level of gases) are continuously controlled and adjusted to maintain the optimal concentrations required by specific fresh produce. As a result of this, it is capital intensive and expensive to operate for short-term storage (Kader et al., 1989). The factors that could probably determine the success of controlled atmosphere technology in developing countries are the cost and complexity (multidisciplinary nature) of the technology. However, controlled atmosphere storage is not appropriate for some commodities. For example, Lipton (1977) has shown that controlled atmosphere storage was not advantageous for carrot storage, and recommended the use of modified atmosphere packaging.

Low $O_2$ or high $CO_2$ levels may be of benefit for very short-term preservation of vegetables, as for example, with asparagus (Torres-Penarada and Saltveit, 1994), banana (Wills et al., 1990) and some vegetables (Wills et al., 1979). Low $O_2$ or high $CO_2$ conditions result in partial or full anaerobic respiration and produce volatile compounds (acetaldehyde and ethanol) responsible for aroma of fresh fruits (Morris et al., 1979; Paz et al., 1981). However, excessive accumulation of volatile compounds may lead to off-flavours and some physiological disorders (Ke and Kader, 1989). A study on the effects of low $O_2$ and high $CO_2$ levels on tomato physiology and composition showed that fruits treated with low $O_2$ or high $CO_2$ had skin injury and blotchy ripening (Klieber et al., 1996). The incidence of fruits showing disease when ripe, increase with increasing treatment time with $O_2$ and $CO_2$ (Klieber et al., 1996). Sozzi et al. (1999), on the other hand, reported that keeping tomatoes in controlled atmospheres, even in the presence of ethylene, had marked residual effects. These results suggested an antagonism between elevated $CO_2$ or low $O_2$, and exogenous ethylene levels, which could determine most of the physiological behaviour under controlled atmosphere storage, though a direct regulatory mechanism by $O_2$ and/or $CO_2$ should not be discarded. The literature cited indicated that controlled atmosphere storage of tomatoes in conditions of low $O_2$ and $CO_2$ atmosphere might have economic benefits for very short-term storage of a few days.

## Modified atmosphere packaging (MAP)

Historically, modified atmosphere packaging (MAP) has been erroneously described as synonymous with controlled-atmosphere storage (CAS) or controlled-atmosphere packaging (CAP). Modified atmosphere packaging (MAP) is defined as the "packaging of perishable products in an atmosphere which has been modified so that its composition is other than that of air" (Hintlian and Hotchkiss, 1986). MAP storage implies a lower degree of control of gas concentrations as compared with controlled atmosphere and vacuum packaging. Typically, initial atmospheric conditions are established for a transient period, and the interplay of the commodity physiology and the physical environment maintain those conditions within broad limits (Zagory and Kader, 1988). Modified atmosphere is depletion of oxygen ($O_2$) and emanation $CO_2$, occurring within a sealed plastic packaging headspace. This happens when fruit and vegetables are respiring.

Modified atmosphere packaging can be created either as a result of commodity respiration (passive) or intentionally through active packaging (Zagory and Kader, 1988). Passive modified atmosphere can be achieved in hermetically sealed packages due to commodity respiration. Levels of $O_2$ and $CO_2$ concentrations then adjusted themselves to the commodity-desired range as a result of $O_2$ consumption and $CO_2$ evolution during storage. If a commodity's respiration characteristics are matched to the film permeability value, the optimum favourable modified atmosphere can be created for a specific product (Smith et al., 1987).

The atmosphere created by modified atmosphere packaging (MAP) depends on product, environmental and packaging film factors. Product factors include respiration rate, respiration quotient, quantity of the product, and $O_2$ and $CO_2$ concentrations necessary to approximately achieve optimum reduction of product aerobic respiration rate. Packaging film factors consists of permeability of polymeric packaging materials to $O_2$ and $CO_2$, and water vapour at a selected storage temperature. Temperature, relative humidity, light and sanitation represent the environmental factors. This indicates that as many factors as possible should be included during MAP of fresh vegetable trials (Zagory and Kader, 1988). A proper understanding of the basic principles of the physiology, chemical, biochemical and microbiological properties of vegetables during MAP storage is required for the use of this technology.

Physiological changes: The beneficial effect of modified atmosphere packaging on increasing shelf life of perishable products is partially due to the decrease in $O_2$ and the increase in $CO_2$ levels, and partially to the decrease in physiological loss in weight (Biale, 1946, 1960; Fidler et al., 1973; Isenberg, 1979; Smock, 1979; Ben-Yehoshua et al., 1983). The role of MAP is to primarily reduce respiration rate of fruit and vegetables by retarding metabolic activities. Reduced respiration also retards softening, and slows down various compositional changes associated with ripening (Kader, 1986).

It is obvious that plant tissue responds quickly to low $O_2$ or high $CO_2$ levels during MAP storage. Low $O_2$ levels were shown to reduce the rate of respiration and resulted in a delay in climacteric onset of the rise in ethylene levels and a decrease in the rate of ripening (Fidler et al., 1973; Kader, 1986; Kannelis, et al., 1990; Yang and Chinnan, 1988a, b; Kannelis et al., 1991). Hypoxia conditions (low $O_2$ levels) have shown to inhibit the accumulation of RNA, protein, and DNA synthesis associated with the wounding of vegetables (Butler et al., 1990). The lowest limit of $O_2$ level, which can be tolerated by vegetables, is a critical factor that must be taken into consideration in selecting proper MAP for fruits and vegetables such as carrots and tomatoes (Butler et al., 1990).

Burg and Burg (1967) have shown that the $CO_2$ level is a competitive inhibitor of ethylene production during storage, and metabolic activities are reduced through an increase in $CO_2$ levels in the headspace. Low $O_2$, high $CO_2$ or both decreases the production of ethylene during modified atmosphere packaging (MAP) storage, which means lower rates of respiration, and prolongs the shelf life of produce (Blackman, 1954; Aligue, 1995; Agar and Streif, 1996; Petracek et al., 2002). This is for the benefit of both climacteric and non-climacteric fruits and vegetables during storage. The levels of $CO_2$ and $O_2$ in the headspace of packages balance each other and have a coupled effect on the metabolic activities of fresh produce during storage. The effect of lower $O_2$ and higher $CO_2$ levels on respiration is additive and can reduce respiration more than effected separately (Kader et al., 1989).

These means high levels of $CO_2$, when coupled with low $O_2$ levels have a cumulative effect on the respiration rate.

Oxygen and $CO_2$ levels below or above the optimum levels specific to each fruit or vegetable can cause physiological damage. Exposure of fresh commodities to extreme levels of $O_2$ and $CO_2$ below and above that required for normal respiration, may initiate anaerobic respiration and lead to the development of off-flavours due to the accumulation of ethanol and acetaldehyde (Zagory and Kader, 1988). Increased $CO_2$ is also associated with an increase of acidity in plant tissues with a subsequent reduction in pH. This acidification could lead to inactivation of enzymes, or phytotoxicity by $CO_2$.

Chemical and biochemical changes: The loss in firmness, development of off-flavours, and discoloration of fresh and minimally processed commodities after harvest or during ripening or storage, is the result of various biochemical changes. A review on the biochemical basis for effects of modified atmosphere packaging (MAP) on fruits and vegetables by Kader (1986) indicated that biochemical and compositional changes such as color, texture (firmness), flavour, and nutritive value can be reduced due to the modified atmosphere created by MAP during storage. MAP may inhibit enzymatic activities responsible for the deterioration in the mentioned quality parameters of fresh commodities during storage. The loss of chlorophyll and lycopene synthesis is reduce when tomatoes are stored in a modified atmosphere of less than 4% $O_2$ and 4% $CO_2$ for 2 months (Goodenough and Thomas, 1980). The appearance of PG is delayed for up to 8 weeks in green mature tomatoes stored in 5% $O_2$ and 5% $CO_2$ at 12.5°C (Goodenough et al., 1982), suggesting delayed fruit softening. Burton (1974) reported that the changes in starch to sugar conversion is slower in packaged fruit and vegetables with a headspace containing 5 to 20% $CO_2$ or less than 3% $O_2$ at 2°C.

Under MAP the effect of polyphenoloxidase and tyrosinase, the enzymes responsible for browning of plant tissue, decreases as a result of limited availability of $O_2$ as a substrate (Anese et al., 1997). A reduction in $O_2$ levels or increase in $CO_2$ levels in the microenvironment of a crop by modified atmosphere packaging (MAP) could reduce enzymatic activities responsible for quality deterioration (Duckworth, 1966; Ruall and Lipton, 1979; Ryall and pentzer, 1982; Kader et al., 1985). However, the effect of low $O_2$ created during MAP on biochemical changes cannot be separated from the effect of increased $CO_2$ (Murr and Morris, 1974; Bown, 1985; Siriphanich and Kader, 1986; Ballantyne et al., 1988b). Barth et al. (1993) reported that MAP of broccoli stored at 20°C for 96 h resulted in a significant decrease of peroxidise (POX) activity after 24 h compared to POX activities in unpackaged samples. The chemical compositions such as ascorbic acid and total chlorophyll also remained higher in packaged broccoli, but $O_2$ levels below 3% increases the concentrations of ethanol and acetaldehyde, and activities of pyruvate decarboxylase and alcohol dehydrogenase, which results in ethanolic fermentation in fresh-cut carrots (Kato-Noguchi and Watada, 1997).

This review shows that MAP has an effect on the biochemical as well as chemical changes in fruits and vegetables during ripening and storage through reducing the levels of $O_2$ and increasing the levels of $CO_2$ in the headspace. Generally, the lower the $O_2$ concentrations achieved by the MAP the lower the rate of chemical as well as biochemical changes, resulting in reduced respiratory metabolism and other biochemical processes, and leading to retention of chemical quality characteristics. However, maintenance of optimum minimum $O_2$ concentration inside the packages is very important to avoid accumulation of excessive volatile compounds responsible for off-flavour and physiological disorder. This entails the need for selection of appropriate packaging material for the specific fruits and vegetables.

Microbiological changes: The extended shelf life of many MAP may allow extra time for microorganisms to reach dangerously high levels in a food. Even in the case of slow growing photogenic microorganisms, extended shelf life using MAP gives them sufficient time to multiply, if not properly managed during storage. Additional research in the microbial control on MAP foods is still needed.

Hao et al. (1999) studied microbiological quality and production of botulinum toxin in MAP of broccoli, carrots, and green beans. Types of packaging material affected the quality of vegetables without noticeably influencing the growth of microorganisms. These results created awareness that the use of modified atmosphere packaging (MAP) could have both positive as well as negative effects on the microbial flora associated with fruits and vegetables during storage based on the pre-packaging treatment and storage conditions. However, their result showed that the toxin was not detected in the vegetables under study.

Microorganisms require certain conditions to grow and reproduce. These conditions are either properties of food such as nutrients, pH and water activity or extrinsic properties of food associated with storage environment such as oxygen, light, temperature and time. The most important environmental factors are gaseous composition and temperature. Modified atmosphere packaging, in principle, controls these factors to reduce or suppress spoilage and extend shelf life of fresh produce. Anese et al. (1997), studying the effect of modified atmosphere packaging on microbial growth, have shown that $CO_2$ and $N_2$ levels were the most effective in inhibiting microbial growth. Concentrations of $CO_2$ in excess of 5% inhibit the growth of microorganisms of most foods. However, the pH of MAP foods increases with increase in carbon dioxide concentration in packages. Direct suppression of microorganisms by MAP has only been possible with the horticultural commodities that can withstand carbon dioxide levels at 20% or above without development of off-flavours, odours, and colours (Harvey, 1982; Aaron, 1989). The ability of modified atmosphere alone is not sufficient to limit the incidence of spoilage of fruits and vegetables. The necessity of pre-packaging treatments to reduce initial microbial load, as well as limiting their growth during storage, is critical.

Conversely, unsuitable MAP can prevent wound healing, speed up senescence, or incidence of physiological breakdown, making fruits and vegetables more susceptible to postharvest pathogens. EL-Goorani and Sommer (1981) suggested that $O_2$ levels below 1% of $CO_2$ levels above 10% could be utilised to limit the growth of yeasts and moulds.

In summary, the growth of microorganisms is likely to continue inside MAP vegetables and fruits, especially for those that need higher $O_2$ and lower $CO_2$ levels. Additional pre-packaging treatments are therefore still required.

## Postharvest factors affecting map

The microenvironment created and maintained in the headspace of a package is the net result of the interaction of commodity factors, environmental factors and packaging material characteristics. Zagory and Kader (1988) described the effects and development of modified atmospheres in the packaging of fresh produce. In order to maintain quality of fruits and vegetables, the product, environmental and packaging material factor must be considered in creating favourable conditions for MAP of fresh produce in order to keep the quality. Therefore, in this section a brief description of commodity factors and environmental and packaging material factors for MAP will be presented.

Commodity factors: In order to develop an appropriate modified atmosphere environment in packages several product factors need to be understood. These includes the rate of $O_2$ uptake and $CO_2$ evolution, permeability of packaging films to $O_2$ and $CO_2$, tolerance of plant materials to levels of these gases and diffusivity of fruits and vegetable skin and flesh to $O_2$ and $CO_2$ (Fidler et al., 1973; Isenberg, 1979; Smock, 1979; Kader, 1985; Salveit, 1989). Zagory and Kader (1988) classified the commodity factors affecting the effectiveness of MAP according to resistance to gas diffusion, respiration, ethylene production and sensitivity, optimum temperature, relative humidity, and gas concentrations.

Resistance to gas and water diffusion across the plant material varies with different vegetables or fruits, cultivars, plant organs and stage of maturity (Cameron and Reid, 1982). The resistance to gas diffusion is affected more by anatomical difference than biochemical differences among various vegetables and fruits (Burton, 1974). However, the rate at which $O_2$ passes through skin or epidermal tissue depends on the $O_2$ gradient (Kader et al., 1989; Burg, 1990). In some commodities, the skin and epidermal tissue may possess pores, called stomata, and lenticles, which are the passages for the $O_2$. Cranberry, tomato and green pepper skins contain no pores, and all gases diffuse through holes in the pedicel scar. The resistance of gas diffusion through the boundary gas layer and skin of most fruits and vegetables varies with the type of gases, that is, $O_2$, $CO_2$ and ethylene (Burg, 1990). The rate of gas diffusion from the surface of the product to the interior also depends on the proportion of gas space. In the case of minimally processed fruits and vegetables, the released cellular fluid flows into the gas space and blocks gas transfer. Diffusion of gas would be much slower in cell sap than in the gas-filled intercellular spaces (Burg, 1990). In general, the structures such as the skin, the cell wall, the intercellular space and the cytosol are the barriers of $O_2$ movement to the mitochondria in the cell.

The respiration of fruits and vegetables was discussed above, but without taking into account packaging films and MAP. The effectiveness of packaging films can be evaluated by their ability in keeping the normal respiration rate of produce without decomposition. Based on the rate of respiration, fruits and vegetables are classified as climacteric or non-climacteric. Tomato and carrot are classified as climacteric fruit and root vegetables, respectively, with moderate respiration rates compared to the other fruits and vegetables. The respiration rate increases consistently with an increase in storage temperature. The respiration rate of topped carrots is from 10 to 20 mg $kg^{-1}$ $h^{-1}$ and 46 to 95 mg $kg^{-1}$ $h^{-1}$ at 0°C and 20 to 21°C respectively. For mature green tomatoes the respiration rate varies from 5-8 and 28-41 mg $kg^{-1}$ $h^{-1}$ at 4 to 5°C and 20 to 21°C storage (Salunkhe et al., 1991). Thus, it is apparent that a reduction in storage temperature is an effective means of extending the commercial life of tomatoes and carrots using MAP.

The rate of ethylene production of fresh produce, and the sensitivity to this hormone, determines the type of packaging film appropriate for secured quality maintenance and shelf life extension (Zagory and Kader, 1988). Tomato produces 1 to 10 mg $CO_2$. $kg^{-1}$ $h^{-1}$ ethylene, which is moderate compared to some other fruits (Kader et al., 1985). Very low concentrations of ethylene are required to advance biochemical and physiological changes during storage and accelerate the ripening processes of carrots and tomatoes. The effect of ethylene on fruits and vegetables that can be stored at a temperature range of 0 to 4.4°C is not possible to detect. The recommended storage temperatures for carrots range from 0 to 1°C and hence the effect of ethylene on carrot during storage at this temperature is negligible. The recommended storage temperature for tomatoes is varying from 8 to 13°C, which is sufficiently high for production of ethylene, and should be considered as a postharvest factor affecting the shelf life of tomatoes.

A reduction in ethylene production and sensitivity associated with MAP can delay the onset of climacteric and prolong the storage life of these fruits (Zagory and Kader, 1988). Even non-climactreric fruits and vegetables can benefit from reduced ethylene sensitivity and lower respiration rate attributed to MAP. Ethylene production is reduced by ether low $O_2$, high $CO_2$, or both, and the effects are additive (Zagory and Kader, 1988).

Environmental factors: Air temperature, relative humidity and natural microbial flora of perishable produce are the main environmental factors affecting the effectiveness of modified atmosphere packaging (Zagory and Kader, 1988). Packaged fruits and vegetables have specific ranges of temperature optima for their normal respiration. Below this limit, fruits and vegetables can easily by affected by chilling injury, which advances to high respiration, hastened senescence and short shelf life. The optimum storage temperature for a specific fruit or vegetable is the one that delays senescence, and maintains quality the longest without causing chilling, freezing, or other injury (Zagory and Kader, 1988). The optimum temperature for tropical fruits is above 13°C, because these fruits are sensitive to chilling injury. Non-chilling-sensitive commodities can be stored near 0°C without negative effect. Previous studies indicated that the effect of reduced $O_2$ and elevated $CO_2$ had an effect on chilling injury (Lyons and Breidenbach, 1987). Chilling injury of fruits and vegetables reduced with low $O_2$ and high $CO_2$ concentrations in the storage atmosphere (Lyons and Breidenbach, 1987). The optimum temperature range for carrot and tomatoes are 0-5 and 8-13°C, respectively (Salunkhe et al., 1991). In general, optimum temperature is a key factor in reducing respiration, production of ethylene, chilling injury, enzymatic activities, proliferation of microorganisms during storage of fruits and vegetables, although modified atmosphere packaging expands the limit of optimum temperature.

The danger associated with high relative humidity is the condensation in packages, which creates favourable conditions for microbial growth. Condensation on the package film affects the permeability property and creates unfavourable interior conditions during storage. Proper temperature maintenance throughout the postharvest handling lines is central to prevent the incidence of condensation in films. On the other hand, low relative humidity increases the loss of moisture from fruits and vegetables (Kader, 1987). The optimum range of relative humidity for carrot storage varies from 90 to 100%, whereas for tomatoes, the range can vary from 85 to 90% (Salunkhe et al., 1991)

## Packaging films

Selection of appropriate films for MAP storage of fresh vegetables on their effectiveness in protecting produce during shelf life is critical (Arthey and Dennis, 1991; Perry, 1993; Wiley, 1994; Farber and Dodds, 1995). The principal plastic materials for MAP that can be used with intact vegetables and fruits include polybutylene, low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polyvinylchloride (PVC), polystyrene (PS), ethylene vinyl acetate (VA), ionomer, rubber hydrochloride (pliofilm), and polyvinylidine chloride (PVDC) (Schlimme and Rooney, 1994). Permeability of packaging film to $O_2$ and $CO_2$ varies with type of packaging film material or composition. The characteristics of the main types of plastic films with their potential uses in MAP are summarized in Table 1 (Schlimme and Rooney, 1994). The table shows that the transmission rate for $O_2$ varies from 8 up to as high as 13,000 $cm^3\ m^{-2}\ day^{-1}$ at 1 atm for PVC and LDPE packaging films, respectively. The transmission rate of packaging materials for $CO_2$ also varies from 59 up to 77,000 ($cm^3\ m^{-2}\ day^{-1}$ at 1 atm), which is quite a large variation, the lowest permeability being for PVDC and highest for LDPE. The water vapour transmission rate also varies from 1.5 to 155 g $m^{-2}\ day^{-1}$. The variation in permeability of packaging films to $O_2$, $CO_2$ and $H_2O$ could give a wide range of choices for films appropriate for specific commodities.

Temperatures have effects on the permeability of packaging films. As temperature increases, the film permeability increases, which may affect the passive modified atmosphere that the film is designed for. Permeability of $CO_2$ is affected more than $O_2$ permeability, implying that a film that is a suitable packaging material at one temperature may not be so at another (Zagory and Kader, 1988). Kader et al. (1989) reported that most common films are relatively good barriers to moisture vapour, because they maintain high internal humidity even in dry, ambient conditions. This means that relative humidity affects the permeability of packaging films less than storage temperature. However, condensation inside films decreases the permeability of $CO_2$ and $O_2$ (Rodov et al., 1995).

It is obvious that the quality of fresh commodities can be dependent on the types of packaging film used for MAP. Under poor modified atmosphere storage management, occurrence of anaerobic metabolism is also possible in commodities packaged in films with low permeability to $O_2$, $CO_2$ and water vapour. Losses in physiological weight are higher from fresh commodities packaged in low-density packaging films than in high-density films. However, because near ambient $O_2$ level is maintained in the headspace of packages, the occurrence of anaerobic metabolism of fresh commodities could be avoided with the use of packaging films with higher permeability to $O_2$, $CO_2$ and water vapour during storage. Lower weight loss and firmness of tomatoes were maintained better in polyolefin bags (0.015 mm thick) than in PVC (0.0177 mm thick) during 5 weeks of storage at 10°C and 80% relative humidity (Frezza et al., 1997).

**Table 1.** Permeability characteristics of several plastic films with potential for use as MAP of fresh and lightly processed produce (Schlimme and Rooney, 1994).

| Film type | Transmission rate | | |
|---|---|---|---|
| | $O_2$* | $CO_2$* | $H_2O$ vapour** |
| Low density polyethylene (LDPE) | 3900 to 13000 | 7700 to 77000 | 6 to 23.2 |
| Linear low density polyethylene (LL DPE) | 7000 to 9300 | - | 16 to 31 |
| Medium density polyethylene (MDPE) | 2600 to 8293 | 7700 to 38750 | 8 to 15 |
| High density polyethylene (HDPE) | 52 to 4000 | 3900 to 10000 | 4 to 10 |
| Polypropylene (PP) | 1300 to 6400 | 7700 to 21000 | 4 to 10.8 |
| Polyvinylchloride (PVC) | 620 to 2248 | 4263 to 8.138 | >8 |
| Polyvinylchloride (PVC), plasticized | 77 to 7750 | 770 to 55000 | >8 |
| Polystyrene (PS) | 2000 to 7700 | 10000 to 26000 | 108.5 to 155 |
| Ethylene vinyl acetate copolymer (12% VA) | 8000 to 13000 | 35000 to 53000 | 60 |
| Ionomer | 3500 to 7500 | 9700 to 17800 | 22 to 30 |
| Rubber hydrochloride (Pliofilm) | 130 to 1300 | 520 to 5200 | >8 |
| Polyvinylidine chloride (PVDC) | 8 to 26 | 59 | 1.5 to 5 |

*Expressed in terms of $cm^3\ m^{-2}\ day^{-1}$ at 1 atm. **Expressed in terms of g $m^{-2}\ day^{-1}$ at 37.8°C and 90% RH.

The shelf life of tomatoes was extended better when packaged in polyethylene and PP films as compared with PVC bags (Batu and Thompson, 1998). The lowest weight losses and the highest soluble solids contents after 60 days of storage were found in tomatoes packaged in polyethylene and PP films. Shelf life studies of pink ripe tomatoes packaged in polyethylene films with 100, 200 or 300 gauge showed that freshness was best maintained in perforated films compared with the other (Singh et al., 1996). The reason for this may be due to higher permeability to gases of the two films as compared with polyvinyl chloride.

MAP using LDPE delayed changes in acidity, soluble solids, texture, colour and PG activity, and resulted in substantial reductions of weight loss of tomatoes, while higher density films showed the lowest weight losses, and the highest soluble solids content after 60 days of storage (Nakhasi et al., 1991). However, it could be possible that the higher microbial populations found in these packages were due to relatively a higher storage temperature (13°C) and moisture accumulation in the headspace of packages.

Ben-Yehoshua et al. (1998) has shown that perforating the film affected the concentrations of both $O_2$ and $CO_2$ and water condensation without affecting the relative humidity of the air in the package headspace. The perforated film prevented the decay and maintained the postharvest quality of vegetables and fruits compared to storage in open boxes. Polyethylene bags with 2 to 4 diffusion holes per 4 kg tomatoes gave the best results, as the $CO_2$ permeability was improved (Esquerra and Bautista, 1990). Similarly, LDPE bags were found to be better in maintaining the quality of carrots during storage compared with high-density polypropylene bags (Seyoum and sadik. 2001). This indicated that the microperforated packaging films maintain the best quality of tomatoes during MAP. The strategies for combining films or film and micropore combinations could lead to realistic solutions to meet the required gas transfer properties (Exama et al., 1993).

The common films, such as PVC and LDPE, can satisfy the gas flux requirements of low respiring tissues of carrots (Exama et al., 1993). Emond et al. (1995), on the other hand, showed that perforated films significantly reduced water loss and condensation in packages of carrots during storage at 2°C and 95% relative humidity, compared to unperforated films. Nazar et al. (1996) showed that perforations in polyethylene bags equivalent to 0.5% of the total effective surface area of the package had no effect on the shelf life of carrots. The packaging film permeability also greatly influences disease incidence and sprouting of carrots during storage (Lingaiah and Reddy, 1996), as did non-ventilated polyethylene bags (Lingaiah and Reddy, 1996).

## SUMMARY

The literature survey shows that any preharvest treatment, either to improve yield or quality, has an effect on fresh commodity quality at harvest and during storage. It is clear that not all the reviewed conditions could be optimised simultaneously. The reviewed conditions were also not described for specific cultivars of a vegetable type. This means that many of these conditions will have to be accepted as constant in a study, e.g., agricultural practices and environmental conditions, with focus on a few selected variables, e.g. ComCat® treatment, postharvest disinfection and storage temperature. The postharvest performance of high yield ComCat® treated vegetables, e.g. carrots and tomatoes have not yet been investigated. The reviewed literature on postharvest performance of carrots and tomatoes stretches over several years and the research was carried out in many countries, while using different experimental approaches. Experiments will have to be designed carefully and proper controls will have to be incorporated.

Postharvest treatments of vegetables include disinfecting, and use of MAP and cold storage. According to the literature survey, disinfecting methods can gene--rally be classified as chemical, biological, and physical methods. Although, several chemicals and biological products are available in the market, their success remains limited due to variability experienced in their effectiveness and lack of experience on how to adapt them to the commercial settings. The literature shows that chlorine treatment is currently the most commonly used, easiest to use and the cheapest method, but not necessarily the most effective. It is very effective for control of microorganisms, but almost no knowledge is available on its effect on the physiological aspects of harvested vegetables. Chemical methods have residues that have negative impacts on health and environment or ecology, while physical methods need high initial investment. This encourages further research not only for microbiological safety, but also to develop environmentally and ecologically safe sustainable disinfectants as a partial or complete substitution for chemicals.

Regarding extended shelf life, the literature pointed to MAP and specific storage temperature for best results. New packaging material is constantly reaching the market, so that those aspects should be the final methods to test the postharvest performance of preharvest treated vegetables. MAP, combined with cold storage are the most popular method as a result of its efficiency in increasing the shelf life of fresh commodities without much quality deterioration, less operational and material cost and easy consumer packaging. The observation that preharvest treatment increase harvest yield of vegetables may be effectively used for food security purposes in underdeveloped countries when production is immediately followed with sustainable preservation technology. Despite high market demand after production, 20 to 50% of commodities are lost before reaching consumers in these countries due to a shortage of cooling facilities.

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