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Controlled atmosphere and modified atmosphere storage for horticulture commodities: A review

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Abstract

Horticultural produce is highly perishable, as fruit and vegetables continue their metabolic processes that lead to ripening and senescence after harvest, making them ultimately unmarketable. Advanced postharvest technologies are essential for reducing food waste while maintaining high standards of safety and quality. Together with cold storage, controlled atmosphere (CA) and modified atmosphere packaging (MAP) have been applied to alter the produce's internal and external environment, decreasing its metabolic activity and extending shelf-life. Both CA and MAP have benefitted from technological innovation. Respiratory quotient control has improved the management of conventional and recently developed CA systems; gas scavengers have made MAP more efficient; and the inclusion of natural additives has enhanced food safety across the supply chain. The present review represents the application of new postharvest techniques to manipulate gaseous environments and highlights areas that require further study.

Keywords: Controlled atmosphere, modified atmosphere, fruits, shelf life

Introduction

Fruits as living biological entity which respire and transpire. Before harvest, when they are attached to the parent plant, losses due to respiration and transpiration are replaced by water, photosynthates and minerals from plant. After harvest, losses of reparable substrates and moisture are not replaced; therefore deterioration occurs soon followed by senescence or total death (Gonzalez *et al.*, 2019) [13]. The physiological and biochemical changes during respiration and transpiration are influenced by environmental factors like temperature, ethylene, oxygen and carbon dioxide concentration (Kader, 1994) [16] and in general these biological activities cause decline in quality of the produce and limit its self-life. Besides, physiological changes there are other factors that influence the limited shelf life of fruits, which include mechanical damage, pathological causes like anthracnose, stem end rot etc. several practices and technologies are available to extend its shelf life and maintain quality. Shelf-life extension of fresh fruits can be achieved by post-harvest operations like proper grading and packaging and processes to retard the deterioration of the fruits like low temperature storage, CA/MA storage, hypobaric storage, using chemicals and irradiation.

Storage is general term used to prevent the loss of produce to a great extent. In case of high perishable horticultural produce, storage is meant to extent shelf life by controlling the post-harvest environmental condition of temperature, relative humidity, atmospheric concentration of certain gases and also by chemical treatment and irradiation. There are various gases and methods of increasing the storage life. The management of temperature and relative humidity are the most important factors determining storage life of horticultural produce. The natural means like ice, cold water, and night temperature have been used for long time for protecting food materials from spoilage and these are still common. However, with the development of innovative technologies, it is possible to achieve optimal environments in the insulated stores.

Principle of storage

1. Slow biological activity of the produce at low temperature with controlled atmospheric composition to prolong their availability and retain their quality for longer time.
2. Reduce product drying by reducing the difference between product and air temperature and maintaining high humidity in the storage room.
3. Slow growth of microorganisms.

Objective of storage

Fresh fruits being perishable are extremely susceptible to irreversible damage in terms of overall quality in response to the change in its environment. The primary objective of an optimal storage protocol is to arrest this damage and extend the shelf life. Some of the common objectives of storage of fresh produce are

1. To increase the period of consumption
2. To extend their period of availability.
3. To arrest the metabolic breakdown and microbial deterioration of the produce.
4. To control the rate of transpiration and respiration.
5. To lessen the undesirable biochemical changes and disease infection.
6. Regulate the market in an orderly manner.
7. Avoid glut and distress sale in the market, thus prolonging the market period.
8. In long term storage, making the food available in off-season, however, long-term storage is costly and requires technical knowledge.
9. In short-term storage, helping earning profits during low market price.

Storage of fresh fruits is one of the important aspects of post-harvest management system. Fruits after harvest respire and have life. It is difficult to stop the process but it can be minimized. Fruits can be classified on the basis of their perishability and storage life (Table 1).

Table 1: Relative perishability and storage life of fruits (Kader, 1994) [16]

Relative Perishability	Fruits	Potential Storage Life (Weeks)
Very low	Dry fruits	More than 16
Low	Lemon, and some varieties	8-16
Moderate	Orange, lime, pomegranate, Kiwi fruit and some varieties of apple and pear	4-8
High	Mango, Banana, guava, grape, mandarin, papaya, Indian goose berry, litchi, peach, plum, melons	2-4
Very high	Strawberry, fig, apricot, cherry, phalsa, Indian black berry	Less than 2

Storage of Fruits

For proper storage of fruits at low temperature, it is necessary to ensure regulated distribution and extending the duration of their availability. In general, proper storage practices include control temperature, relative humidity control, air circulation and maintenance of space between containers for adequate ventilation and avoiding incompatible product mixes. During storage deterioration of fruits is mostly caused due to:

1. Loss of moisture
2. Loss of carbohydrates and vitamins
3. Physiological disorders
4. Seed germination
5. Attack of pests and diseases.

Controlled or modified atmospheric storage (CAS)

The normal composition of air is 78% Nitrogen, 21% Oxygen, 0.03% Carbon dioxide and traces of other noble gases. Modified atmosphere is the method for extending the shelf-life of perishable and semi-perishable food products by altering the relative proportions of atmospheric gases that surround the produce. Although the terms Controlled Atmosphere (CA) and Modified Atmosphere (MA) are often used interchangeably but a precise difference exists between these two terms.

Table 2: Temperature, humidity and modified atmospheric requirement of different fruits

Commodity	Temperature (°C)	Humidity (%)	Modified Atmosphere %	
			O_2	CO_2
Apricot	0-5	90	2-3	2-3
Orange	3-9	90-95	5-10	0-5
Banana	13-15	90-95	2-5	2-5
Persimmon	0-5	90-95	3-10	5-8
Sweet Cherry	0-5	90-95	4-10	10-15
Apple	0-5	90	1-3	1-3
Blue berry	0-5	90-95	5-10	15-20
Peach	0-5	90-95	1-2	3-5
Pear	0-5	90-95	2-3	0-1

Controlled Atmosphere (CA)

This refers to a storage atmosphere that is different from the normal atmosphere in its composition, wherein the component gases are precisely adjusted to specific concentrations and maintained throughout the storage and distribution of the perishable foods. Controlled atmosphere relies on the continuous measurement of the composition of the storage atmosphere and injection of the appropriate gases or gas mixtures into it, if and when needed. Hence, the system requires sophisticated instruments to monitor the gas levels and is therefore practical only for refrigerated bulk storage or shipment of commodities in large containers. If the composition of atmosphere in CA system is not closely controlled or if the storage atmosphere is accidentally modified, potential benefit can turn into actual disaster. The degree of susceptibility to injury and the specific symptoms vary, not only between cultivars, but even between growing areas for the same cultivars and between years for a given location. With tomatoes, excessively low O_2 or high CO_2 prevents proper ripening even after removal of the fruit to air, and CA enhances the danger of chilling injury.

Modified Atmospheric (MA)

Unlike CA, there is no means to control precisely the atmospheric components at a specific concentration in MAP once a package has been hermetically sealed. Modified atmosphere conditions are created inside the packages by the commodity itself and / or by active modification. Commodity generated or passive MA (Modified Atmosphere) is evolved as a consequence of the commodity's respiration. Active modification involves creating a slight vacuum inside the package and replacing it with a desired mixture of gases, so as to establish desired EMA (Equilibrated Modified Atmosphere) quickly composed to a passively generated EMA. In general, MA containing between 2-5% oxygen and 3.8% carbon dioxide have shown to extend the shelf life of a wide variety of fruits. Few types of films are routinely used for MAP. The important ones are polyvinyl chloride, (PVC), polystyrene, (PS), polyethylene (PE) and polypropylene (PP). The recent developments in co-extrusion technology have made it possible to manufacture films with designed transmission rates of oxygen. MA storage conditions may strongly affect product quality, such as color, flavor, and taste. Thus, proper selection of storage conditions suitable for each F&V is essential. There are limitations to the ability of conventional generally milder methods to extend shelf life and to scaling up. (Yujie Fang and Minato Wakisaka, 2021) [48].

This method must be considered to supplement the maintenance of optimal condition of temperature and RH for the fruit. The underlying principle of these methods lies in reducing the respiration rate and ethylene synthesis of the fruit during storage. Respiration is a metabolic process by which organic material in living cells are continuously broken down evolving CO_2, H_2o and energy. The reparation rate, expressed as either rate of oxygen consumption or CO_2 evolution is dependent on, factors like temperature and state of maturity of the fruit and on the gas composition of the environment in which it is stored controlled.

In CA and MA storage, the fruit is stored in a depleted oxygen and elevated CO_2 environment. In CA the gas composition is controlled in the sense that it is closely monitored and controlled while MA refers to the gas exchange between the fruit and its microenvironment within a suitable enclosure. In this system, produce is held under atmospheric condition modified by package, over wrap, box or pallet cover. The first requirement of CAS is as sufficiently as tight envelope around the produce and the second requirement is some means of maintaining the concentration of CO_2 and O_2 at the desired level. This method in combination with refrigeration markedly enhanced the storage life of fruit. Modified atmospheric storage (MAS) implies a lower degree of control of gas concentration in atmosphere surrounding the commodity. Therefore, the MAS and CAS differ only in degree of control. CAS is more exact. Controlled atmosphere (CA) and modified atmosphere (MA) storage involves altering and maintain an atmospheric composition from normal air composition. Together with cold storage, controlled atmosphere (CA) and modified atmosphere packaging (MAP) have been applied to alter the produce's internal and external environment, decreasing its metabolic activity and extending shelf-life (Natalia Falagan and Leon A Terry, 2021) [27].

The positive influence of CA/MA on shelf life of fruit also have influence on various enzymatic changes taking place in the fruit during ripening (Kader 1994) [13] elevated atmosphere inhibits activity of aminocyclopropane-1-carboxylic acid (ACC) synthase (key regulatory site for ethylene synthesis), while ACC oxidase activity is stimulated at low CO_2 and inhibited at elevated CO_2 and low O_2 levels. Elevated CO_2 atmosphere thus inhibits ethylene action. Optimum atmospheric composition retard biosynthesis of carotenoids and anthocyanins and biosynthesis and oxidation of phenolic compounds.

Table 3: Recommended transit/storage CA/MA requirements

Name of the commodity	Temperature (0 °C)	O_2 (%)	CO_2 (%)	Remarks
Avocado	10 to 13	2 to 5	3 to 10	
Banana	12 to 16	2 to 5	2 to 5	Transit
Orange	5 to 10	5 to 10	0 to 5	No commercial use
Mango	10 to 15	3 to 5	5 to 10	Transit
Pineapple	8 to 13	2 to 5	5 to 10	Transit
Kiwifruit	0 to 5	5 to 10	15 to 20	Commercial

Table 4: Recommendations for CA storage of apple and pear

Cultivar	Temperature (°C)	O_2 (%)	CO_2 (%)	Storage (M)
Fuji	0.3	1.4	1.0	7 to 11
Gala	1.3	1.7	1.6	2 to 9
Red Delicious	0.0	1.6	1.8	6 to 11
Mclntosh	2.5	2.1	2.9	5 to 10
Bartlett	-1 to 0	1-2	0.5	3 to 5
P. Crassane	-1 to 0	3	4-5	5 to 8
YaLi	5.0	4-5	0.4	3 to 4

MA and CA have been successfully adopted for commercial storage of pomegranate, avocado, persimmon, kiwifruit and loquat. Marginal increases in storage life and quality by MA and CA storage have been observed for many other subtropical fruits (Mustafa E and Chien YW, 2006) [26].

Gases used in CA/MA atmosphere

The three main gases used in modified atmosphere packaging are CO_2, O_2 and N_2. The choice of gas is very dependent upon the food product being packed (Table 5). Used singly or in combination, these gases are commonly used to balance safe shelf-life extension with optimal organoleptic properties of the food. Noble or 'inert' gases such as argon are in commercial use for products such as coffee and snack products; however, the literature on their application and benefits is limited. Experimental use of carbon monoxide (CO) and sulphur dioxide (SO_2) has also been reported. Generally, crop stored in controlled atmosphere have a longer storage life because the rate of the metabolic processes is slower. Particularly with climacteric fruit this would slow ripening and deterioration, so that when they have been stored for protracted periods they may well be less ripe than fruits stored in air. The actual effects that varying the levels of different gases in atmosphere vary with such factors as under:

1. Species of crop
2. Cultivar of crop
3. Concentration of gases in store
4. Crop temperature
5. Stage of maturity at harvest
6. Degree of ripeness of climacteric fruit
7. Growing conditions before harvest
8. Presence of ethylene in store
9. Pre-storage treatments.

Table 5: Recommended gas mixture for MAP

Product	O_2 (%)	CO_2 (%)	N_2 (%)
Apple	1-2	1-3	95-98
Apricot	2-3	2-3	94-96
Avacado	2-5	3-10	85-95
Banana	2-5	2-5	92-97
Grape	2-5	1-3	93-96
Grape fruit	3-10	5-10	80-85
Kiwi fruit	1-2	3-5	93-96
Lemon	5-10	0-10	80-95
Mango	3-7	5-8	85-92
Orange	5-10	0-5	85-95
Papaya	2-5	5-8	87-93
Peach	1-2	3-5	93-96
Pear	2-3	0-1	96-98
Pineapple	2-5	5-10	85-93
Straw Berry	5-10	15-20	70-80

Carbon dioxide

Carbon dioxide is a colorless gas with a slight pungent Odour at very high concentrations. It is an asphyxiate and slightly corrosive in the presence of moisture. CO_2 dissolves readily in water (1.57 g/ kg at 100 kPa, 20 °C) to produce carbonic acid (H_2CO_3) that increases the acidity of the solution and reduces the pH. This has significant implications for MAP of foods. The high solubility of CO_2 can result in pack collapse due to the reduction of headspace volume. The effect of carbon dioxide in extending the storage life of crops appears to be by reducing respiration. Knee (1973) [20] showed that carbon dioxide could inhibit an enzyme (succinate dehydrogenase) in the tricarboxylic acid which is part of the crop's respiratory pathway. The atmosphere inside the tissue of the crop will equalize with the atmosphere in the store if it is at the same temperature and pressure. Where the level of carbon dioxide in the store is increased this will therefore increase its levels within the crop tissue. Some of following effect of increase carbon dioxide level on stored fruits:

- Decreased synthetic reactions in climacteric fruit.
- Delaying the initiation of ripening.
- Inhibition of some enzymic reactions.
- Decreased production of some organic volatiles.
- Modified metabolism of some organic acids.
- Reducing the rate of breakdown of pectic substances.
- Inhibition of chlorophyll breakdown.
- Production of off-flavour.
- Induction of physiological disorders.
- Retarded fungal growth on the crop.
- Inhibition of the effect of ethylene.
- Inhibition of postharvest development.

Oxygen

Oxygen is a colorless, odorless gas that is highly reactive and supports combustion. It has a low solubility in water (0.040 g/kg at 100 kPa, 20 °C). Oxygen promotes several types of deteriorative reactions in foods including fat oxidation, browning reactions and pigment oxidation. Most of the common spoilage bacteria and fungi require oxygen for growth. Therefore, to increase shelf life of foods the pack atmosphere should contain a low concentration of residual oxygen. If oxygen levels in plant cells fall, the rate of chemical reactions decreases and metabolism is reduced. This effect tends to be accelerated at very low levels of oxygen. If the oxygen level in the cells is too low there may be undesirable change in the chemicals which contribute to the flavor and aroma of the crop. At very low levels of oxygen the tricarboxylic acid cycle is inhibited but the glycolytic pathway may continue. This results in less efficient energy production during respiration, since there is insufficient oxygen to metabolize stored carbohydrates to water and carbon dioxide. Instead, the blocking of the glycolytic pathway results in a build-up of acetaldehyde and ethanol, which are toxic to the cells if allowed to accumulate. The effect of oxygen on post-harvest response of fruit were reviewed and summarized as under:

- Reduce respiration rate.
- Reduce substrate oxidation.
- Delay ripening of climacteric fruit.
- Prolong storage life.
- Delayed breakdown of chlorophyll.
- Reduce rate of production of ethylene.
- Change fatty acid synthesis.
- Altered texture.
- The temperature of the crop.
- The innate metabolic rate of the crop.

Carbon dioxide and oxygen damage

The exposure time to different gases affect susceptibility with fruits ripeness, harvest maturity and storage temperature. Threshold level of oxygen and carbon dioxide required to cause injury to fruits are described in table 6.

Table 6: Threshold level of oxygen and carbon dioxide required to cause injury to fruits (Kader 1994) [16]

Fruit	CO_2 Injury Level	Symptoms	O_2 Injury Level	Symptoms
Banana	>15	Green fruit softening, undesirable texture and flavor	<1	Dull yellow or brown skin discoloration, failure to ripen, off flavor
Fig	>25	Loss of flovour	<2	Off-flovour
Grape	>5	Browning of berries	<1	Off-flavour
Grape fruit	> 10	Scald rind and off-flavour	<3	Off-flavour due to increased ethanol
Kiwi	>7	Internal breakdown of flesh	< 1	Off-flavour
Lemon	>10	Increased susceptibility to decay, decrease acidity	<5	Off-flavour
Mango	>10	Softening, off-flavour	<2	Skin discoloration, greyish flesh colour
Nectarine	>10	Flesh brown and loss of flavor	<1	Failure to ripen, skin browning, off flavour
Orange	>5	Off-flavour	< 5	Off-flovour
Papaya	>8	Off-flavour	< 2	Failure to ripen, off-flavour.

Nitrogen

Nitrogen is a relatively un-reactive gas with no odour, taste, or color. It has a lower density than air, non-flammable and has a low solubility in water (0.018 g/kg at 100 kPa, 20 °C) and other food constituents. Nitrogen does not support the growth of aerobic microbes and therefore inhibits the growth aerobic spoilage but does not prevent the growth of anaerobic bacteria. The low solubility of nitrogen in foods can be used to prevent pack collapse by including sufficient N_2 in the gas mix to balance the volume decrease due to CO_2 going into solution. Treatment of fruits in atmospheres of total nitrogen prior to storage was shown to retard the ripening of tomatoes (Kelly and Saltveit 1988) [17] and avocados (Pesis *et al.* 1993) [32]. Burden *et al.* (1994) [4] showed that pretreatment of mango fruits in 97% nitrogen and 3% oxygen resulted in their remaining firmer and generally ripening more slowly than untreated fruits during subsequent storage in air. This effect lessened with increased storage duration.

Carbon monoxide

Carbon monoxide is a colorless, tasteless and odorless gas that is highly reactive and very flammable. It has a low solubility in water but is relatively soluble in some organic solvents. CO has been studied in the MAP and has been licensed for use in the USA to prevent browning in packed lettuce. Commercial application has been limited because of its toxicity and the formation of potentially explosive mixtures with air. Carbon monoxide has fungi static properties, especially when combined with low oxygen levels (Kader 1994) [16]. *Botrytis cinerea* on strawberries was reduced where the carbon monoxide level was maintained at 5% or higher in the presence of 5% oxygen or less. Decay in mature green tomatoes stored at 12.8 °C was reduced when 5% carbon monoxide was included in the storage atmosphere (Morris *et al.* 1981) [25]. Carbon monoxide is an analogue of ethylene, and it was shown in initiate ripening of bananas when the fruit were exposed to concentrations of 0.1% for 24 hours at 20 °C.

Noble gases

The noble gases are a family of elements characterized by their lack of reactivity and include helium (He), argon (Ar), xenon (Xe) and neon (Ne). These gases are being used in a number of food applications now e.g. potato-based snack products. While from a scientific perspective, it is difficult to see how the use of noble gases would offer any preservation advantages compared with N2 they are being used.

Role of other gases in controlled/modified atmosphere

Ethylene

Ethylene was known to have physiological effects on crops, but it was first identified as a volatile chemical produced by ripening apples by. It was assumed that ethylene was produced only in climacteric fruits during the ripening phase, but with the development of chromatographic analytical techniques it has become clear that all crops are able to produce ethylene under certain conditions (Roberts and Tucker 1985) [38]. Microorganisms which attack stored crops can also produce ethy1ene. There are two regulating systems for the production of ethylene in climacteric fruit: System I is responsible for the low-rate synthesis of ethylene before the climacteric, and the basic System II is responsible for the self-catalyzed production of ethylene during the climacteric. Some fruits can synthesize ethylene in a short time; the ethylene level can be raised by several orders of magnitude compared to System I levels. Ethylene synthesis in both systems follows the methionine pathway (Yujie Fang and Minato Wakisaka, 2021) [48].

Ethylene is synthesized in plant tissue from methionine via a pathway that includes S-adenylyl methionine (SAM), which is converted to 1-aminocyclopropane-1-carboxylic acid (ACC) by ACC synthase. ACC is converted to ethylene by ACC oxidase enzyme. Ethylene biosynthesis in fruit is related to oxygen levels. Ethylene in a storage container may come from produce or from outside sources during storage, several commodities are stored together and under these conditions ethylene given off by one commodity can adversely affect another. Coal gas, petroleum gas and exhaust gases from internal combustion engines contain ethylene and contamination of stored produce by these gases may introduce sufficient ethylene to initiate ripening in fruit and promote deterioration in non-climacteric produce. The level of deleterious action will depend on the concentration of ethylene that accumulates. A concentration of 0.1 µl/l is often cited as the threshold level, but some studies indicate that threshold level of ethylene is less than 0.005 µl/l. So, there is no safe level of ethylene and any reduction in ethylene concentration will lead to some extension in post storage life. As fact that all fruit produce minute quantities of ethylene during their growth development and ripening, climacteric fruits produce much larger amounts of ethylene than non-climacteric fruits. The difference between the two droops of fruit is further classified by the internal ethylene concentration found at several stages of development and ripening the internal ethylene concentration of climacteric fruits varies widely but for non-climacteric fruits changes little during development and ripening.

The rate of ethylene production by apples was shown to be about half in an atmosphere of 2.5% oxygen compared to fruit stored in air (Burg and Burg 1962) [5]. Ethylene biosynthesis was shown to be affected by carbon dioxide levels in storage. Increased levels of carbon dioxide reduced ethylene levels in controlled-atmosphere stores containing apples (Tomkins and Meigh 1968). [45]

Table 7: Effects of ethylene on respiration rate of selected crops

Crop	Respiration rate (µlO_2 g^{-1} h^{-1})	
	Control	Ethylene
Apple	6	16
Avocado	35	150
Cherimoya	35	160
Lemon	7	16
Grapefruit	11	30
Potato	3	14
Rutabaga	9	18
Beet	1	22
Carrot	12	20
Sweet potato	18	22

Factors effecting CA/MA atmosphere

There are many factors which effect modified atmosphere packaging of fresh produce. Movement of O_2, CO_2, and C_2H_4 in produce tissues is carried out by the diffusion of the gas molecules under a concentration gradient. Different commodities have different amounts of internal air space (tomatoes 15-20%, apples 25-30%). A limited amount of air space leads to increase in resistance to gas diffusion. The evaluation of these gases (O_2, CO_2 and C_2H_4) by three varieties of apricots stored at 10 °C under four plastic films of different permeability's has been studied (Pretel *et al.*, 2000) [36]. One of the primary effects of MAP is a lower rate of respiration, which reduces the rate of substrate depletion. Ethylene (C_2H_4) is a natural plant hormone and plays a central role in the initiation of ripening, and is physiologically active in trace amounts (0.1 ppm). C_2H_4 production is reduced by about half at O_2 levels of around 2.5%. This low O_2 retards produce ripening by inhibiting both the production and action of C_2H_4.Also metabolic processes such as respiration and ripening rates are sensitive to temperature. Biological reactions generally increase two to three-fold for every 10 °C rise in temperature. Therefore temperature control is vitally important in order for a MAP system to work effectively. Film permeability also increases as temperature increases, with CO_2 permeability responding more than O_2 permeability. Low RH can increase transpiration damage and lead to desiccation, increased respiration, and ultimately an unmarketable product. One serious problem associated with high in-package humidity is condensation on the film that is driven by temperature fluctuations. A mathematical model was developed for estimating the changes in the atmosphere and humidity within perforated packages of fresh produce (Lee *et al.*, 2000) [22]. The model was based on the mass balances of O_2, CO_2, N_2 and H_2O vapors in the package. Also a procedure to maintain desired levels of O_2 and CO_2 inside packages that are exposed to different surrounding temperatures was designed and tested. For most commodities light is not an important influence in their post-harvest handling. However green vegetables, in the presence of sufficient light, could consume substantial amounts of CO_2 and produce O_2 through photosynthesis. Shock and vibration leads to damage to produce cells which causes an increase in respiration and may lead to enzymes being released that will cause browning reactions to begin.

MAP applications

One of the major benefits of modified atmosphere packaging (MAP) is the prevention or retardation of fruit senescence (ripening) and associated biochemical and physiological changes. Temperature is the most effective environmental factor in the prevention of fruit ripening. Both ripening and ethylene production rates increase with an increase in temperature. To delay fruit ripening, fruits should be held as close to 0 °C as possible, without suffering chilling injury. The use of MAP as a supplement to proper temperature maintenance in the effort to delay ripening is consequentially more effective for chilling sensitive fruits, but is generally beneficial for all fruits. Reducing O_2 concentration below 8% and/or elevating CO_2 concentration above 1% retards fruit ripening. It has been established that 2% O_2 level anaerobic respiration may result in the development of off-flavour and off-odours. Fruits exposed to such low O_2 levels may also lose their ability to attain uniform ripeness upon removal from MAP. Successful applications of MAP on fruits include Royal Gala apples, Granny Smith apples, lemons (whole, peeled, and sliced), and oranges (whole, peeled, and sliced). The effectiveness of modified atmospheres and packaging materials on the growth of Penicillium expansum and patulin production in Granny Smith apples was determined (Moodley *et al.*, 2002) [24]. It showed conclusively that PE is an excellent packaging material for the storage of apples since it inhibited the growth of P. Expansum, thereby allowing patulin to be produced, regardless of gaseous environment. A lot of work has also been reported on the effect of MAP on the other fruits. Fresh-cut Conference pears were packaged under different modified atmosphere packaging conditions, stored in refrigeration and the effects of packaging atmospheres on the microbial viability as well as on quality parameter were studied (Soliva-Fortuny *et al.*, 2003) [41]. The use of plastic bags of a permeability of 15 cm^3 O_2/m^2/bar/24 h and initial atmospheres of 0 kPa O_2 extended the microbiological shelf life of pear cubes for at least 3 weeks of storage. The changes in sensory quality and proliferation of spoilage microorganisms on lightly processed and packaged cactus pear fruit were also measured as a function of storage temperature and MAP (Corbo *et al.*, 2004) [8]. It was found that cactus pear fruit had longer shelf life at 4 °C. Also, the three different varieties of pear (Williams, Conference, Passacrassana) that had reached their commercial ripening stage were evaluated for suitability for minimal processing (Arias *et al.*, 2008) [1]. Conference pear was found to be the most suitable variety. An integrated strategy was developed to control postharvest decay of Embul banana by combining essential oils with MAP (Ranasinghe, *et al.*, 2005) [37]. Treatment with emulsions of cinnamon oils combined with MA packaging can be recommended as a safe, cost-effective method for extending the storage life of Embul bananas up to 21 days in a cold room and 14 days at 28±2 °C without affecting the organoleptic and physico-chemical properties. The effect of MAP on chilling induced peel browning in banana was also studied (Nguyen *et al.*, 2004) [29]. The combined influence of mild heat pre-treatments (MHPT) and two types of MAP conditions on metabolic response of fresh-cut peaches was studied during eight day long storage under refrigeration (Steiner *et al.*, 2006) [44]. The quality of 'Royal Glory' peaches was also evaluated using a combination of hot water treatment and MAP (Malakou & Nanos, 2005) [23]. Hot water treatment did not cause any fruit damage but reduced firmness loss. The modified atmosphere package combined with ozone and edible coating films were used for improving the effect of preservation of strawberry (Zhang *et al.*, 2005) [47]. The optimum gas composition of MAP test for strawberry was 2.5% O_2 þ16% CO_2. Also, the integrated model approach was used to study the effect of MA conditions on the keeping quality of 'Elsanta' strawberries as limited by spoilage (Hertog *et al.*, 1999) [15]. Headspace fingerprint mass spectrometry had been used to characterize strawberry aroma at super-atmospheric oxygen conditions (Berna *et al.*, 2007) [4]. Ethyl acetate is one of the most important off-flavours in strawberries. The results showed that after 4 and 7 days of storage under super-atmospheric oxygen concentrations (without carbon dioxide) the production of ethyl acetate was suppressed. Also storage of table grapes in 80% O_2 or 40% O_2 and 30% CO_2 improved berry hardness, springiness, chewiness, flavour and membrane integrity over control stored in air (Deng *et al.*, 2005) [9]. It was observed that the quality of SO_2-free 'Superior seedless' table grapes was preserved in MAP (Artes-Hernandez *et al.*, 2006) [2]. The improvement of the overall quality of table grapes stored under modified atmosphere packaging in combination with natural antimicrobial compounds had also been studied (Guillen *et al.*, 2007) [14]. The effects of modified atmosphere packaging (MAP) on the storage life of loquat fruit were investigated by Ding *et al.*, (2002), Ding *et al.* (2006) [11, 12]. 'Hass' avocado fruit showed potential for long-term storage (up to 9 weeks) under MA in a commercial size package (Meir *et al.*, 1997) [25]. The influence of MAP and post-harvest treatments on quality retention of litchi was studied (Sivakumar & Korsten, 2006) [40]. The emission of the metabolites, acetaldehyde and ethanol from litchi fruit has also been monitored during maturation and storage (Pesis *et al.*, 2002) [31]. The effects of an antioxidant dipping treatment (in an aqueous solution of 1% ascorbic acid and 1% citric acid for 3 min) and of modified atmosphere (90% N_2O, 5% O_2 and 5% CO_2) packaging on functional properties of minimally processed apples have been investigated by Cocci *et al.*, (2006) [6]. Storage of mango fruits at 12 °C caused slight chilling injury symptoms on the fruit peel expressed as red spots around the lenticels (Pesis *et al.*, 2000) [30]. An integrated approach was studied for control of post-harvest brown rot of sweet cherry fruit (Spotts *et al.*, 2002) [43]. The post-harvest quality of papaya was enhanced significantly by combining methyl jasmonate (MJ)-treatments and MAP (Gonzalez-Aguilar *et al.*, 2003) [12]. Use of MJ at 10_5 M with MAP is beneficial to maintaining post-harvest quality of papaya during low-temperature storage and shelf-life period. Post-harvest water dipping of Ber (*Ziziphus mauritiana* Lamk) at 50 °C for 5 min significantly increased the shelf life and maintained the quality of ber fruits, particularly late in the storage period (Lal *et al.*, 2002) [21]. Fruits packed in sealed polythene bags significantly lowered the loss in fruit weight, spoilage and ripening with consequent increase in acidity and organoleptic score. Citrus fruit are relatively non-perishable, and can normally be stored for long periods of 6-8 weeks. However, the development of various types of rind disorders limits the postharvest storage capability, and causes massive commercial losses. Porat *et al.* (2004) [34] found that modified atmosphere packaging (MAP) in "bag-in-box" Xtend® films (XF) effectively reduced the development of chilling injury (CI) as well as other types of rind disorders that are not related to chilling, such as rind breakdown, stem-end rind breakdown (SERB) and shriveling and collapse of the button tissue (aging). In all cases, micro perforated films (0.002% perforated area) that maintained CO_2 and O_2 concentrations of 2-3 and 17-18%, respectively, inside the package were much more effective in reducing the development of rind disorders than macro perforated films (0.06% perforated area), which maintained CO_2 and O_2 concentrations of 0.2-0.4 and 19-20%, respectively. In both types of package, the relative humidity (RH) was 95%. No major differences were found between the effectiveness of polyethylene (PE) and XF packages, despite the fact that XF prevents water condensation inside the bags. Overall, micro perforated and macro perforated XF packages reduced rind disorders not related to chilling (rind breakdown, SERB and aging) after 5 weeks of storage at 6 ºC and 5 days of shelf life conditions by 75 and 50%, respectively, in 'Shamouti' orange, and by 60 and 40%, respectively, in 'Minneola' tangerines. Similarly, micro perforated and macro perforated XF packages reduced the development of CI after 6 weeks of cold storage at 2 ºC and 5 days of shelf life conditions by 70 and 35%, respectively, in 'Shamouti' oranges and by 75 and 45%, respectively, in 'Star Ruby' grapefruit. Furthermore, storage of unwrapped 'Shamouti' oranges in high RH (95%) also reduced rind disorders by 40-50%, similarly to the effects of the macro perforated films. In the light of these data, we suggest that MAP reduces the development of rind disorders in citrus fruits via two modes of action: the first, which is common to both micro perforated and macro perforated films is by maintaining the fruit in a high RH environment; the second, which is specific to the micro perforated film, involves maintaining a modified atmosphere environment with elevated CO_2 and lowered O_2 levels.

Modified atmosphere packaging (MAP) successfully prolongs shelf-life of assorted harvested fruit and vegetables including litchi fruit. The efficacy of MAP is reliant on not only the product, but also importantly on the gas permeability and thickness of the polymeric film used, since this plays a vital role in establishing an appropriate atmosphere within the package. Several types of polymeric film have been recently assessed for their ability to reduce litchi pericarp browning, and extend shelf-life of litchi fruit. Plastic films differentially affected weight loss of litchi during 9 days storage at 13 °C. Increases in weight loss over storage time were also recorded in litchi cv. Mauritius (Sivakumar and Korsten, 2006) [40] and *cv*. Kom (Somboonkaew and Terry, 2008) [42]. Fruit weight loss, pericarp moisture content and dry matter in all treatments changed depending on the gas permeability of plastic film. PF film resulted in less fruit weight loss and thus maintained higher moisture contents in both aril and pericarp, whilst greater weight loss and lower moisture contents were found in NVS-packaged fruit. Nettra Somboonkaew and Leon A. Terry (2010) [27] indicated that packaging films were suitable to retain better quality of imported litchi cv. Mauritius fruit during 9 days storage as compared to unwrapped fruit.

A reduced O_2 concentration of around 3-5% and an elevated CO_2 concentration of 5-10% are the suggested atmosphere compositions for a successful MA/CA system for mango fruit (Kader, 1994 and Yahia, 2009) [16, 46]. However, the CO_2 concentration in MA/CA is critical. Mature green mango fruit (cv. Tommy Atkins and Kent) in modified atmosphere packages (MAP) with CO_2 composition of over 10% results in skin discoloration, uneven ripening and off flavor development, most probably due to the formation of acetaldehyde and ethanol (Postharvest Innovation Programmed Progress Report, 2009) [35]. Although higher concentration of CO_2 (above 10%) can prevent the incidence of postharvest diseases due to its fungi static or toxic activity, CO_2 concentration must not result in any quality defects in terms of off-flavour development, CO_2 injury such as skin discolorations or greyish flesh colour or fruit softening (Singh & Dwiveidi, 2008) [39]. CA (3% O_2 and 10% CO_2) resulted in lower anthracnose incidence in 'Tommy Atkins', and after removal from cold storage to room temperature conditions, the residual effect of CA was clearly demonstrated on the control of anthracnose (Kim *et al.*, 2007) [18]. Storage temperature, the environment such as CA/MA, to light and oxygen exposure, is one of the key factors influencing stability of phenolic antioxidants in fruits during postharvest storage (Piljac-Zegarac J, Samec D, 2010) [33]. However, the CA storage (21% O_2+97% N2; 3% O_2+97% N2; and 3% O_2+10% CO_2+87% N2) had minor effect on the retention of total soluble phenolics and antioxidant capacity in fully ripe *cv*. Tommy Atkin mangoes (Kim *et al.*, 2009) [19]. Temperature management during storage and shipping is a critical factor that affects fruit quality at destinations, and mangoes should be stored and shipped at 8-13 °C (depending on cultivar and duration) and at 85-90% RH (Dharini *et al.*, 2011) [9]. After arrival, proper temperature management has to be practiced at storage or at the retailers' shelf (8-14 °C).

Conclusion

CA storage and MAP serve as important tools to maintain fruit and vegetable quality along the supply chain, reducing food waste and extending fresh produce availability all year round. During the last 50 years, the effects of MA and CA storage have been extensively tested on a wide range of commodities. These offers optimal storage conditions for horticultural commodities to reduce losses and maximize shelf life and the prospect of further maintaining quality with the aid of emerging technologies. This will meet the demands of producers and suppliers to increase income and give consumers access to nutritious food for good health Despite extensive research, interaction between various gas concentrations, both MA and CA, and development of pathogenic micro-organisms are not well documented. More and detailed research are needed to determine the best CA storage conditions for different species and cultivars of horticultural commodities. The advances in CA and MAP will drive the development of more sustainable materials and more efficient gas control, which are essential instruments for postharvest management

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