6

STORAGE ATMOSPHERE

The composition of gases in the storage atmosphere can affect the storage life of horticultural produce. Changes in the concentrations of the respiratory gases — oxygen and carbon dioxide — may extend storage life. This is generally used as an adjunct to low temperature storage, but modification of the storage atmosphere can usefully substitute for refrigeration for some commodities. Many volatile compounds released by produce and from other sources may accumulate in the storage atmosphere. Ethylene is the most important of these compounds and its accumulation above certain critical levels reduces storage life, so methods for its control become important. A role in quality maintenance for other organic volatiles such as acetaldehyde and ethanol released by produce is currently under investigation, particularly in relation to antimicrobial properties for certain compounds.

The terms controlled atmosphere (CA) storage, modified atmosphere (MA) storage and gas storage are frequently used. These terms imply the addition or removal of gases resulting in an atmospheric composition different from that of normal air. Thus the levels of carbon dioxide, oxygen, nitrogen and ethylene in the atmosphere may be manipulated. Controlled atmosphere storage generally refers to decreased oxygen and increased carbon dioxide concentrations, and implies precise control of these gases. The term modified atmosphere storage is used when the composition of the storage atmosphere is not closely controlled, such as in plastic film packages where the change in the composition of the atmosphere occurs intentionally or unintentionally. A more recent term is modified atmosphere packaging (MAP), which relates to packages and film box liners with specific properties that offer a measure of control over the composition of the atmosphere around produce. The original term, gas storage, is now considered inappropriate and should not be used.

CARBON DIOXIDE AND OXYGEN

The general equation for produce respiration is:

glucose + oxygen → carbon dioxide + water + energy

It suggests that respiration could be slowed by limiting the oxygen or by raising the carbon dioxide concentration in the storage atmosphere. The principle appears to have been applied in ancient times, even if unwittingly. The earliest use of modified atmosphere storage may possibly be attributed to the Chinese. Ancient writings report that litchi was transported from southern China to northern China in sealed clay pots to which fresh leaves and grass were added. It may be surmised that during the 2 week journey, respiration of the fruit, leaves and grass generated an atmosphere in the pots that was high in carbon dioxide and low in oxygen, which retarded ripening of litchi. Other examples of primitive modified atmosphere storage include the burying of apples in the ground and the carriage of fruit in the unventilated holds of ships. The first reported scientific observations of the effects of the atmosphere on fruit ripening were made in 1819–20 by Jacques Berard in France, but it was not until the work of Kidd and West at the Low Temperature Research Station at Cambridge, UK, in the 1920s and 1930s that a sound basis for the controlled atmosphere storage of produce was established.

By showing that high carbon dioxide and low oxygen concentrations lowered the respiration rate of seeds and delayed their germination, Kidd and West extended earlier findings that the composition of the atmosphere affected the metabolic rate of plant tissues. It was soon apparent to them that there should be a similar effect in fruit. They subsequently concentrated their work on apples, which culminated in the publication in 1927 of the classic bulletin entitled *Gas Storage of Fruit*. An important stimulus to the work of Kidd and West was the fact that the commercial cultivars grown in the UK were subject to low temperature disorders when stored at less than 3°C and that storage life was too short at temperatures above 3°C.

During the past 50 years, the effects of controlled atmosphere and modified atmosphere have been extensively tested on a wide range of fruit and vegetables, but the responses have varied considerably. Despite extensive research, major commercial application of controlled atmosphere has been confined to some apple and pear cultivars, but modified atmospheres have been applied successfully during transport to a range of produce. For example, high carbon dioxide levels have been used primarily as a fungistat during the transport of strawberries, and improved outturns of lettuce have been achieved by flushing rail trucks or containers with nitrogen and up to 8 per cent carbon monoxide.

As with fruit and vegetables in general, controlled atmosphere storage of ornamentals has not been widely implemented. Nonetheless, controlled atmosphere recommendations have been established for a number of important cut flower crops (Table 6.1). In addition to extended longevity at low temperatures, storage under controlled atmosphere conditions, particularly under high carbon dioxide concentrations, can limit the development of pathogens. However, the lack of commercial usage arises from considerably inconsistent responses between different seasons and different varieties within a given species. In addition, regular production schedules of major species and limited quantities of minor species create little need to store many cut flowers for significant periods.

TABLE 6.1 OPTIMAL CONTROLLED ATMOSPHERE CONDITIONS FOR CERTAIN FLOWERS

SPECIES	%CO_2	%O_2	TEMP (°C)	STORAGE PERIOD
Freesia	10	21	1	3 weeks
Carnation	5	2	0	4 weeks
Lily	10–20	21	1	3 weeks
Mimosa	0	8	7	10 days
Rose	5–10	1–3	0	3–4 weeks

SOURCE Adapted from D.M. Goszczynska and R.M. Rudnicki (1988) Storage of cut flowers, *Hort. Rev.* 10: 35–62.

Factors that have influenced the adoption of controlled or modified atmospheres for different commodities include:

- Inherent storage life in air. If the produce can be stored in a satisfactory condition in air for the total marketing period desired, then there is no need to resort to atmosphere modification to prolong storage life.
- Existence and magnitude of a favourable response to modified atmospheres. There must be a distinct beneficial effect. Not all produce responds favourably to atmosphere regulation and some produce is little affected.
- Substantial atmosphere tolerance. The beneficial effects of atmosphere modification, especially in modified atmosphere storage, need to be sustained over a relatively wide gas concentration range. A small tolerance range will result in variable quality outturns in commercial usage due to insufficient or excessive gas concentrations.
- Seasonal availability. Use of atmospheres can be advantageous where

produce is harvested over a relatively short period in the year. Maximum storage life of such produce is often desirable to extend the marketing period over a greater part of the year.

- Value of the commodity in relation to the cost of atmosphere modification. There needs to be a distinct financial gain from the use of atmosphere control.
- Availability of substitute commodities. While produce may be stored satisfactorily in modified atmospheres, it may be more economical to import produce from another region or country that has a different harvest period.

The use of modified atmospheres on portable packages should have considerable commercial appeal, but the lack of widespread application is largely related to problems in ensuring that the desired atmosphere is maintained throughout the postharvest chain under a diverse range of handling operations and external environmental conditions. A variable modified atmosphere will often result in variable produce quality in the market. The availability of a range of new food-grade polymeric films with different permeabilities to the atmospheric gases in recent years has revived interest in packaging produce in sealed bags. The use of such films for refrigerated produce offers a cheaper alternative to using large containers equipped to provide modified or controlled atmosphere conditions. The development and properties of these plastic films will be covered in greater detail in Chapter 12.

Metabolic effects

Increases in carbon dioxide and decreases in oxygen concentrations exert largely independent effects on respiration and other metabolic reactions. Generally, the oxygen concentration must be reduced to less than 10 per cent (by volume) before any retardation of respiration is achieved. For apples stored at 5°C, the oxygen level must be reduced to about 2.5 per cent to achieve a 50 per cent reduction in the respiration rate. Care must also be taken to ensure that sufficient oxygen is retained in the atmosphere so that anaerobic respiration, with its associated development of off-flavours, is not initiated.

The reduction in the concentration of oxygen necessary to retard respiration depends on the storage temperature. As the temperature is lowered, the required concentration of oxygen is also reduced. The critical level of oxygen at which anaerobic respiration occurs is determined mainly by the rate of respiration, and is therefore greater at higher temperatures. Tolerance to low oxygen levels varies considerably among different commodities. The critical level of oxygen may vary with the time of exposure, with lower levels being tolerated for shorter periods. It may also be affected by the level of carbon dioxide, since lower levels of oxygen often seem to be better tolerated when carbon dioxide is absent or at a low level.

The addition of only a few per cent of carbon dioxide to the storage atmosphere can have a marked effect on respiration. However, if carbon dioxide levels are too high, effects similar to those caused by anaerobiosis (lack of oxygen) can be initiated. Responses to increased carbon dioxide levels vary even more widely than responses to reduced oxygen: cherries and strawberries will withstand, and even benefit from, exposure to 30 per cent carbon dioxide for short periods. In contrast, some apple cultivars are injured by 2 per cent carbon dioxide in storage, and many vegetables appear to respond best to low oxygen when carbon dioxide is kept low or is absent (Figure 6.1).

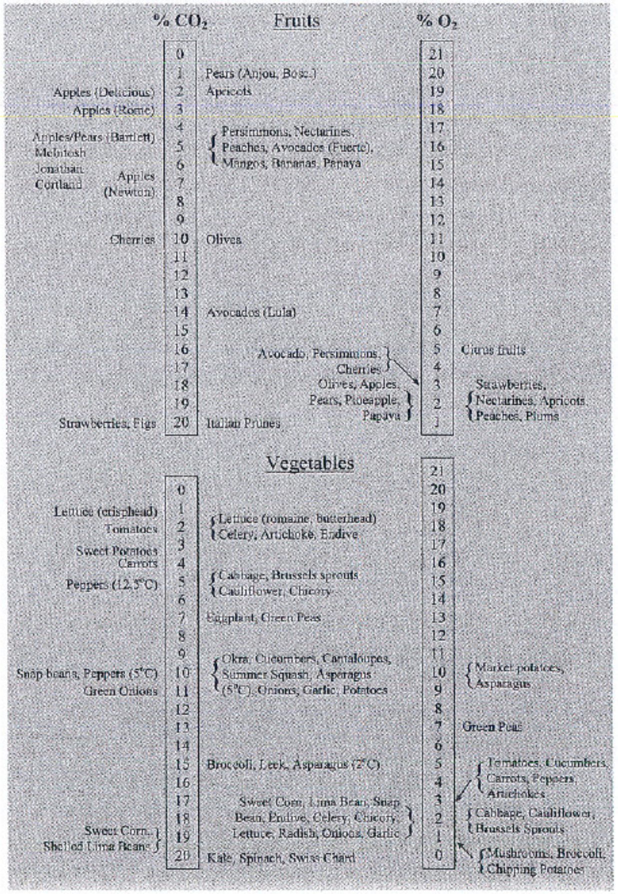

Figure 6.1
Relative tolerance of fruit and vegetables to elevated carbon dioxide and reduced oxygen concentrations at recommended storage temperatures. Normal atmospheric air comprises 0.035 per cent carbon dioxide, 21 per cent oxygen and about 79 per cent nitrogen.
SOURCE A.A. Kader and L.L. Morris (1977) Relative tolerance of fruits and vegetables to elevated CO_2 and reduced O_2 levels, in D.H. Dewey (ed.) *Controlled atmospheres for storage and transport of horticultural crops*, Michigan State University, East Lansing, MI, 260–65.

Many of the beneficial results of modified atmosphere storage cannot simply be attributed to a reduction in respiration. For example, under ideal experimental conditions a 12-fold increase in the storage life of green bananas can be achieved by ventilating the fruits with an atmosphere comprising 5 per cent carbon dioxide, 3 per cent oxygen and 92 per cent nitrogen in the absence of ethylene, but respiration measured in terms of oxygen uptake is reduced to only one-quarter of the rate in air. The greatly increased storage life is attributed to a reduction in the rate of natural ethylene production by the bananas and also to a reduced sensitivity of the fruits to ethylene.

In green vegetables, improved retention of green colour in low oxygen atmospheres is due mainly to a lowering of the rate of chlorophyll destruction. An interesting and contrasting effect has been noted in potato. Greening due to exposure to light can be prevented for several days by maintaining tubers in an atmosphere containing about 15 per cent carbon dioxide.

Modified atmospheres, particularly those containing high carbon dioxide, inhibit the breakdown of pectic substances so that a firmer texture is retained for a longer period. Retention of flavour may also be improved. The responses of various commodities to modified atmospheres can, however, be conflicting. For example, increased carbon dioxide aids in the retention of organic acids in tomato but accelerates the loss of acids in asparagus. Maturity at harvest is more critical for modified atmosphere storage than for ordinary air storage. Because of the widely varying responses of different commodities, and among cultivars, to alterations in oxygen and carbon dioxide concentrations, ideal combinations need to be determined experimentally for each commodity.

Effect on microbial growth

The activity of several decay organisms can be reduced by atmospheres containing 10 per cent carbon dioxide or more, provided that the commodity is not injured by such high carbon dioxide levels. Since strawberries can tolerate high carbon dioxide levels, transport of strawberries under modified atmosphere conditions has been found to significantly reduce rotting and give a valuable extension in marketing life and quality (Table 6.2).

Many commodities cannot tolerate high carbon dioxide levels so that, in practice, atmosphere control cannot always be relied on to reduce rotting. Nevertheless, atmosphere control (by increased carbon dioxide and reduced oxygen) may reduce rotting of produce by retarding ripening and senescence, since the natural resistance of the produce host to pathogens decreases as it ripens or ages. In contrast, some fruits, such as banana and mango, respond well to atmosphere control but eventually lose their resistance to the latent anthracnose disease, which then becomes the factor limiting storage life. Controlled atmosphere or modified atmosphere storage does not necessarily retard ageing and the loss of resistance to decay organisms at the same rates.

TABLE 6.2 DECAY OF STRAWBERRIES AS INFLUENCED BY CARBON DIOXIDE CONCENTRATION (% OF STRAWBERRIES DECAYED)

STORAGE CONDITION	0% CO_2	10% CO_2	20% CO_2	30% CO_2
3 days at 5°C in storage atmosphere	11.4	4.5	1.7	1.3
Plus 1 day at 15°C in air	35.4	8.5	4.7	4.0
Plus 2 days at 15°C in air	64.4	26.2	10.8	8.3

SOURCE Adapted from C.M. Harris and J.M. Harvey (1973) Quality and decay of California strawberries stored in carbon dioxide-enriched atmospheres, *Plant Dis. Reporter*, 57: 44–6.

Carbon monoxide is an effective fungistat but care must be exercised in its use. As well as being explosive, carbon monoxide is a potent mammalian poison binding to blood haemoglobin. It also has the ability to mimic the effects of ethylene when used in the absence of carbon dioxide.

Methods for modifying carbon dioxide and oxygen concentrations

The first commercial applications of controlled atmosphere storage relied on the produce to generate the atmosphere so that carbon dioxide concentrations approximately equalled the reduction in oxygen. The composition of the storage atmosphere was generally maintained in the range 5–10 per cent carbon dioxide and 16–11 per cent oxygen. The build-up of carbon dioxide was mainly responsible for the increased storage life. The store was ventilated regularly to maintain the required carbon dioxide level. Further research showed that low oxygen levels were of greater benefit and that some important cultivars of apple and pear were sensitive to carbon dioxide levels above 3 per cent. To maintain low oxygen levels in the store atmosphere it was necessary to make existing cool stores more gas-tight and to recirculate part of the store atmosphere through a scrubber to remove excess carbon dioxide. Gas-tight cool stores were then developed for controlled atmosphere storage and, along with external generators, increased the viability of commercial controlled atmosphere storage. These generators burn fuels such as propane or petroleum gas and rapidly reduce the oxygen in the store to a required low level that is then maintained. Excess carbon dioxide is removed by scrubbing equipment. Gas generators also allow controlled atmosphere storage to be accomplished, albeit expensively, in a store that is not completely gas-tight.

As a result of these developments in cool store design and operation, the more effective low oxygen atmospheres containing 2–5 per cent carbon dioxide and 2–3 per cent oxygen can readily be maintained. The oxygen concentration must be carefully controlled to prevent anaerobic respiration or fermentation in this type of atmosphere. Methods of constructing and maintaining controlled atmosphere stores are discussed in Chapter 7.

Atmosphere control by the addition of nitrogen and carbon dioxide

In recent years there has been renewed interest in atmosphere control in the long distance transport of perishable produce in containers. One of the factors responsible for this interest is the availability in some countries, notably the USA, of cheap liquid nitrogen. Atmosphere control in large containers has involved either the continuous introduction of carbon dioxide or nitrogen gas during the journey, or charging the container with the appropriate atmosphere before the journey, with no further introduction of gas. Carbon dioxide or nitrogen from pressurised cylinders are used, depending on whether the requirement is for high carbon dioxide or low oxygen levels, or both.

The advent of hollow fibre systems for separating oxygen and nitrogen in air by differential diffusion across a membrane has provided a new means of producing low oxygen atmospheres for continuous ventilation of produce in large containers or in fixed storage rooms. An advantage of the technique is that the starting raw material, normal air, is freely available and there are no hazardous gaseous by-products generated.

The use of liquid nitrogen as a refrigerant in the transport of perishables had stimulated interest in the response of fruit and vegetables to very high nitrogen levels and consequent concentrations of oxygen of 1 per cent or less, both under refrigeration and at higher temperatures. It is now known that many fruit and vegetables can withstand such atmospheres for a short period without harm and show a long-term reduction in respiration when returned to storage in air. The beneficial effects are noted particularly for non-climacteric fruit and vegetables. It also means that the use of liquid nitrogen refrigeration in road and rail transport vehicles is unlikely to be damaging to most perishables because the likelihood of maintaining oxygen-free atmospheres is remote and even 1 per cent oxygen is enough for most commodities to remain viable for several days.

Storage in plastic films

The use of plastic films to achieve modified atmosphere is increasing, not only in packaging but also in controlled atmosphere store construction (Chapter 7). Polyethylene box liners, either sealed or unsealed, have been used for several years in the storage of pears and apples but only to a limited extent with other produce. Unsealed or perforated bags are commonly used to minimise weight loss and reduce abrasion damage. A major problem with sealed bags is that the atmosphere inside depends on the temperature, because the permeability of the film to gases is virtually independent of temperatures at which produce is normally handled whereas respiration is temperature-dependent. Thus sealed bags are risky when the temperature varies more than a few degrees, unless the produce has a low rate of respiration or is tolerant to atmospheres that vary widely in carbon dioxide and oxygen concentrations (like the banana), or both. The film commonly used is 40 μm (0.0015 inch) low density polyethylene. To avoid brown spot and other carbon dioxide injuries, sachets of fresh hydrated lime can be included in the bag to reduce the carbon dioxide concentration. At the rate of 100–200 grams per 10 kilograms of fruit, this has proved useful with apples and pears, particularly with carbon dioxide-sensitive cultivars in cool storage.

The attainment of modified atmosphere in polyethylene bags filled with produce can be accelerated by evacuating the bags to between 50 and 85 kPa (380–635 mm mercury) and then sealing them. Since the polyethylene film is permeable to nitrogen, oxygen and carbon dioxide, the pressure inside returns to atmospheric pressure, but the initial rapid reduction of oxygen concentration is often useful. Eventually the composition of the atmosphere approaches that in bags not subjected to initial evacuation. Fruit must be removed from the bags to achieve normal ripening. If held for longer periods under modified atmosphere, the fruits may not ripen satisfactorily after removal.

The interest in plastic films to generate modified atmospheres has accelerated in recent years through the availability of films with more flexible gas permeabilities. The newer films remove many of the risks of modified atmosphere storage outlined above. The types of film will be discussed in Chapter 12.

Hypobaric storage

Hypobaric storage is a form of controlled atmosphere storage in which the produce is stored in a partial vacuum. The vacuum chamber is vented continuously with water-saturated air to maintain oxygen levels and to minimise water loss. Ripening of fruit is retarded by hypobaric storage due to the reduction in the partial pressure of oxygen and for some fruits also due to the reduction in ethylene levels. A reduction in pressure of air to 10 kPa (0.1 atmosphere) is equivalent to reducing the oxygen concentration to about 2 per cent at normal atmospheric pressure. Hypobaric stores are expensive to construct because of the low internal pressures required, and this high cost of application appears to limit hypobaric storage to high value produce. The technique has now found some application in the storage of fresh meats.

ETHYLENE

Effects on fruit and vegetables

The commencement of natural ripening in climacteric fruits is accompanied by an increase in ethylene production (Chapter 3). Treatment of pre-climacteric fruits with exogenous ethylene advances the onset of ripening. This response is used widely in commercial practice to achieve controlled ripening of fruit such as banana, which is picked and transported in a mature but unripe state and ripened just before marketing (Chapter 11). The action of ethylene must, however, be avoided for such fruit during storage and transport to prevent premature ripening. In contrast, the effect of ethylene on non-climacteric fruit and vegetables offers no apparent commercial benefit but will reduce postharvest quality by promoting senescence, as evidenced by loss of green colour, change in texture and flavour, and promotion of low temperature injuries and microbial decay.

While the levels of ethylene that trigger ripening have been well researched for most climacteric fruits, the threshold concentration that enhances senescence in non-climacteric fruit and vegetables is less well documented. A concentration of 0.1 µL/L is often cited as the threshold level, but recent studies in Australia indicate that the threshold level of ethylene is less than 0.005 µL/L. For practical purposes, this means there is no safe level of ethylene, and hence any reduction in ethylene concentration will bring some extension in postharvest life.

Ethylene in a storage or transport container may come from produce or from outside sources. Often during marketing, several commodity types 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 and ornamentals. The level of deleterious action will depend on the concentration of ethylene that accumulates and the duration of exposure.

In addition to delaying ripening or senescence through reducing ethylene concentrations around produce, the sensitivity of produce to ethylene may be lessened by storage at low temperature, and by either raising the level of carbon dioxide or decreasing the level of oxygen. Under these conditions the amount of ethylene required to induce ripening is increased. A similar effect has been demonstrated for some non-climacteric produce. For example the ethylene-induced breakdown of chlorophyll in broccoli is less sensitive to ethylene at low temperatures.

Effects on ornamentals

Many ornamental crops are sensitive to ethylene. Responses of ornamentals to ethylene can be classed into growth, abscission and senescence responses. An example of an ethylene-induced growth response is epinastic curvature of poinsettia leaves and bracts. Abscission is a far more widespread response across the broad range of ornamental species. Many types of organs may abscise, including stem segments, leaves, fruit, whole inflorescences, buds and flowers, and petals. For example, fruit, leaves and stem segments of Christmas mistletoe sprigs (*Phoradendron tomentosum*) all separate upon exposure to ethylene. Ethylene-induced accelerated senescence is characterised by premature discolouration and wilting of flowers, such as carnations and cymbidium orchids.

Individual species vary widely in their relative sensitivity to ethylene and, in general, cut flowers and flowering pot plants tend to be more ethylene-sensitive than foliage lines. Among cut flowers, carnation and delphinium are considered to be very sensitive to ethylene, while gerbera and tulip are considered relatively insensitive. Among flowering pot plants, hibiscus is classed as highly sensitive and chrysanthemum is of low sensitivity. Finally, among foliage plants, schefflera is highly sensitive and nephrolopis is insensitive. However, it must be noted that ethylene sensitivity can vary markedly among genotypes (e.g. species) within a genus.

Similarly, ethylene production can vary widely between genotypes. For example, some carnations produce a marked ethylene climacteric peak during senescence, whereas others do not produce significant amounts of ethylene. As has been observed for genotype, factors that influence phenotype — including preharvest temperature, RH, light and nutrition regimes — can also affect the relative sensitivity of ornamentals to ethylene.

METHODS FOR REDUCING ETHYLENE CONCENTRATIONS

Avoidance of ethylene accumulation

Reduction of ethylene levels in storage rooms can be achieved by good housekeeping; that is, storing ripe and unripe produce in separate rooms, regularly removing all rotted or damaged produce, and by ensuring that natural gas pipes and cylinders, and exhaust gases from internal combustion engines, are kept well away from storage rooms.

A simple physical method to minimise ethylene accumulation is to ensure good ventilation of the storage chamber with air from outside the storage complex. The ethylene concentration in the atmosphere is normally less than 0.005 μL/L unless there is contamination from nearby industrial sources or heavy automobile traffic. Ventilation with external air could be applicable where no large temperature differential exists between the external air and the storage chamber provided it is at an appropriate relative humidity. If there is a large temperature difference it may be necessary to cool the air before admitting it to the chamber.

Oxidation with potassium permanganate

Ethylene in the atmosphere can be oxidised to carbon dioxide and water using a range of chemical agents. Potassium permanganate ($KMnO_4$) is quite effective in reducing ethylene levels. Since it is non-volatile, potassium permanganate can be physically separate from produce, thus eliminating the risk of chemical injury. To ensure efficient destruction of ethylene, a large surface area of potassium permanganate is achieved by coating an inert inorganic porous support, such as alumina or expanded mica, with a saturated solution of potassium permanganate. Potassium permanganate used in this manner has been found to retard the ripening of many fruits. Table 6.3 demonstrates the benefit to be obtained with banana when used in conjunction with modified atmosphere storage in polyethylene bags. The high carbon dioxide and low oxygen atmosphere generated within the sealed bags decreases the response by the fruits to ethylene and hence retards ripening. The addition of potassium permanganate further retards ripening by maintaining ethylene at a low level for a long period. The technique has also been successfully demonstrated to delay the ripening of whole bunches of bananas during growth on the plant. High humidity in storage containers is a limitation to the longevity of potassium permanganate absorbents as it also reacts with water. While the commercial use of potassium permanganate alone or in conjunction with modified atmosphere is difficult to document, it must be widespread in many countries to sustain the various commercial manufacturers of potassium permanganate sachets that remain in business.

TABLE 6.3 SHELF LIFE OF BANANAS HELD AT 20°C IN MODIFIED ATMOSPHERE WITH POTASSIUM PERMANGANATE

TREATMENT	SHELF LIFE (DAYS)
Air	up to 7
Sealed polyethylene bags	14
Sealed bags + potassium permanganate	21

SOURCE Derived from K.J. Scott, W.B. McGlasson and E.A. Roberts (1970) Potassium permanganate as an ethylene absorbent in polyethylene bags to delay ripening of bananas during storage, *Aust. J. Exp. Agric. Anim. Husb.* 10: 237–40.

Oxidation with ozone

Ozone (O_3) is a suitable oxidising agent for destroying ethylene because it is generated readily from atmospheric oxygen by an electric discharge or ultraviolet radiation, and since it is gaseous, it readily mixes with ethylene. The actual oxidant species is probably a combination of ozone and atomic oxygen, a highly reactive free radical formed from ozone. Some precautions must be taken with ozone: it is a reactive substance and will corrode metal pipes and fittings in refrigeration equipment and react with paper products used to package produce. In addition, ozone readily injures produce and can be toxic to humans at relatively low concentrations. The widespread use of ozone has been hampered by difficulties in controlling its concentration. These problems with ozone can be overcome by its use in a recycling system, as depicted in Figure 6.2. Here ozone is generated in a container with ultraviolet radiation. Air contaminated with ethylene is passed through the chamber where the ethylene is oxidised, and excess ozone is removed by reduction on a substrate such as steel wool. Some small scale commercial ultraviolet scrubbers have been produced but are not in widespread use.

Other oxidants

Activated charcoal that has been brominated will effectively oxidise ethylene but carries a potential health hazard as it generates bromine gas when in contact with excess water. Recent laboratory studies have identified a range of chemicals, such as tetrazine, that react more specifically with ethylene. Their greater specificity for ethylene makes them relatively more efficient in ethylene scavenging than general oxidising agents such as potassium permanganate. Commercial applications are focusing on their inclusion into plastic packaging films. A problem to be overcome is the instability of tetrazines in the presence of moisture.

Other chemicals

A range of chemicals that are toxic to humans can be used as anti-ethylene treatments with ornamentals because they are not eaten. Most notably, cut stems of ornamental material can be pulsed with silver ions supplied as STS, or whole plants or plant parts can be dipped or sprayed with STS. Silver ions block the ethylene binding site, thereby preventing its action. A relatively new ethylene binding site blocker, 1-methylcyclopropene (1-MCP), is likely to replace STS as an anti-ethylene treatment, and is particularly exciting as it can be applied as a gas. At this stage 1-MCP is considered safe in that it has low or no mammalian toxicity and low or no adverse environmental impact. Its application to fruit and vegetables is in relatively early stages of evaluation.

Treatment with ethylene synthesis inhibitors is an alternative to treatment with ethylene binding site blockers. Two such compounds are aminoethoxyvinylglycine (AVG) and aminooxyacetic acid (AOA). Both compounds are used to treat ornamentals, such as carnations, against ethylene. However, the relative drawback is that they only confer protection against endogenously produced, and not exogenous, ethylene. Another approach to reducing or eliminating the effects of ethylene on ornamentals is by genetic engineering. Carnation genotypes that formerly produced ethylene during senescence (i.e. climacteric characteristic) have been engineered using antisense gene technology *not* to produce ethylene. The genetically engineered carnations, showing non-climacteric senescence characteristics, have markedly extended vase life. Similarly, carnation genotypes with blocked ethylene binding and signal transduction and translation will be engineered. These genetic modifications emulate the effects of the chemical ethylene synthesis (e.g. AVG) and binding (e.g 1-MCP) inhibitors, respectively.

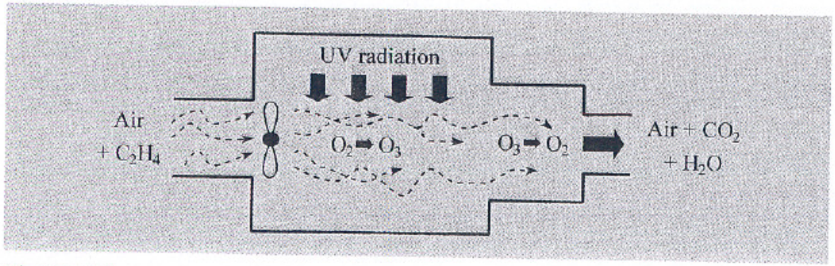

Figure 6.2
System for removal of ethylene with atomic oxygen generated by ultraviolet radiation.
SOURCE Derived from K.J. Scott and R.B.H. Wills (1973) Atmospheric pollutants destroyed in an ultraviolet scrubber, *Lab. Practice*, 22: 103–106.

OTHER GASES

Carbon monoxide (CO) is not released by fresh produce, but it may be introduced to storage atmospheres by equipment powered by internal combustion engines. Carbon monoxide may reach levels that are toxic to persons working in the storage chambers, and with some produce may give effects that mimic those induced by ethylene. However, there are examples of beneficial responses to added carbon monoxide, such as the control of butt discolouration and retardation of the growth of *Botrytis* rots in lettuce. The practice of adding about 5 per cent carbon monoxide to containers or pallet loads of various perishable fruits held in controlled atmospheres is now considered advantageous and is in limited use for export shipments or long distance land transport of specific produce.

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