UNIT 7 CONTROLLED AND MODIFIED ATMOSPHERE STORAGE

Structure

7.0 OBJECTIVES

This unit shall analyze the basic and applied aspects of controlled/ modified atmosphere storage of fruits and vegetables. Here the issues of physiological basis and problems and prospects of CA / MA storage of fruits and vegetables will be discussed. After studying this unit, you will be able to:

- describe the basic requirement of CA/ MA storage;
- explain physiological effects of CA/MA storage on fruits and vegetables;
- enumerate the methods of atmospheric modification; and
- evaluate the economic benefits of CA/ MA technology.

7.1 INTRODUCTION

The effect of gases on harvested fruits is known since ancient times. In earlier days fruits were used to be taken to temples for improved ripening. This was due to the volatiles released on burning of incense containing hydrocarbon gases that helped ripening of the fruits. In 1819 J.E. Bernard in France noticed that harvested fruits absorb O_2 and liberate CO_2.Atmosphere devoid of O_2 caused no ripening in peach, prunes and apricot for several days but ripening continued when they were placed back in air. A commercial cold storage was built in 1856 by B. Nice for apples and ice was used to maintain a temperature of 1°C. After a decade he started experimenting with modifying the cold store gases inside. In 1907 J. Foulton observed the increase in fruit damage by large accumulation of CO_2 in the storage atmosphere. In 1915 R.W. Thatcher after experiments with apples in sealed boxes containing various levels of gases concluded that CO_2 greatly inhibited ripening. The first scientific evidence on the effect of CO_2 on respiratory rates was established by Kidd and West in

1917 in seeds. In the early 1940 the term of 'gas storage' was replaced by Controlled Atmosphere (CA) storage. Now let us discuss the modern understanding of CA/ MA storage.

Atmosphere at ambient conditions comprises of 78.08% N_2, 20.98% O_2 and 0.03% CO_2. Any deviation from this normal atmosphere composition, e.g., elevated level of CO_2 and reduced levels of O_2 and N_2 or any other combination is known as '**Modified Atmosphere**'. When this deviated normal atmosphere is precisely kept under control then it is termed as "**Controlled Atmosphere**". This control can be done in package (Controlled Atmosphere Packaging) or in the storage chamber (CA-storage). Generally, O_2 below 8 per cent and CO_2 above 1 per cent are used in CA-storage. Atmospheric modification is a supplementary practice to temperature management in preserving quality and safety of fresh fruits, vegetables, ornamentals and their products throughout post-harvest handling and storage.

Essentiality of CA/MA technology should be justified only if (a) the commodities are having high market value, (b) it need longer storage life, (c) require significantly better quality, and (d) fetch better price compared to conventional cool stored produce. Retardation of ripening, reduction in decay, prevention of specific disorders and maintenance of product texture are some of the potential advantages of CA/MA storage. However, initiation or aggravation of certain physiological disorders, viz. black heart in potato, brown stain in lettuce, brown heart in apples and pears, etc., take place in CA-storage if appropriate gaseous regimes are not maintained. A concentration of less than 2 per cent O_2 or more than 5 per cent CO_2 in the storage/ package atmosphere results in irregular ripening of banana, tomato and pear. Too low O_2 or too high CO_2 can increase the susceptibility to decay causing organisms. Off-flavour development in fruits and stimulation of sprouting and retardation of periderm formation in potatoes are some of the ill effects of improper CA-condition. On the other hand, a very high concentration of CO_2 (up to 30%) is extremely beneficial in checking the *Botrytis* rot in strawberry fruits.

The quality retention in fresh horticultural produce in CA storage is mainly due to reduction in the respiratory and metabolic activities and check in ethylene liberation.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the basic differences between a controlled atmosphere and modified atmosphere storage?

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2. First scientific evidence on the effect of CO_2 on respiratory rate of fruits was established by ______________.

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3. In general the O_2 concentration below ______ % and CO_2 concentration above ________% are used in CA storage.

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4. What are the essentiality factors to be considered while judging the feasibility of a commodity for CA storage?

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7.2 PHYSIOLOGICAL BASIS OF CONTROLLED ATMOSPHERE (CA) STORAGE

Exposure of fresh horticultural crops to low O_2 and/or elevated CO_2 atmosphere within the range tolerated by each commodity reduce their respiration and ethylene production rates. However, outside this range respiration and ethylene production rates can be stimulated indicating a stress response. This stress can contribute to incidence of physiological disorders and increased susceptibility to decay. Elevated CO_2-induced stresses are additive to and sometimes synergistic with, stresses caused by low O_2; physical or chemical injuries; and exposure to temperatures, RH, and/or ethylene concentrations outside the optimum range for the commodity.

The shift from aerobic to anaerobic respiration depends on fruit maturity and ripeness stage (gas diffusion characteristics), temperature, and duration of exposure to stress-inducing concentrations of O_2 and/or CO_2. Up to a point, fruits and vegetables are able to recover from the detrimental effects of low O_2 and/or high CO_2 stresses (fermentative metabolism) and resume normal respiratory metabolism upon transfer to air. Plant tissues have the capacity for recovery from the stresses caused by brief exposure to fungistatic atmospheres (> 10% CO_2) or insecticidal atmospheres (< 1% O_2 and/or 40 to 80% CO_2). **Climacteric fruits are less tolerant and have lower capacity for recovery following exposure to reduced O_2 and/or elevated CO_2 levels than non-climacteric fruits**. The speed and extent of recovery depend upon duration and levels of stresses, stage of maturity and metabolically driven cellular repair mechanism.

Elevated-CO_2 atmospheres inhibit activity of ACC synthase (key regulatory enzyme of ethylene biosynthesis), while ACC oxidase activity is stimulated at low CO_2 and inhibited at high CO_2 concentrations and/or low O_2 levels. Thus, elevated CO_2 atmospheres inhibit ethylene action. Optimum modified atmospheric compositions retard chlorophyll loss (green colour), biosynthesis of carotenoids (yellow and orange colours) and anthocyanins (red and blue colours), and biosynthesis and oxidation of phenolic compounds (brown colour). Controlled atmospheres slow down the activity of cell wall degrading enzymes involved in softening and enzymes involved in lignification leading to toughening of vegetables. Low O_2 and/or high CO_2 atmospheres influence flavour by reducing loss of acidity, starch to sugar conversion, sugar inter-conversions, and biosynthesis of flavour volatiles. When produce is kept in an optimum atmosphere, retention of ascorbic acid and other vitamins result in retention of better nutritional quality.

Specific responses to CA depend upon cultivar, maturity and ripeness stage, storage temperature and duration, and in some cases, ethylene concentrations. Nitrogen is an inert component of CA. Replacing N_2 with argon or helium may increase diffusivity of O_2, CO_2 and C_2H_4, but they have no direct effect on plant tissues and are more expensive than N_2 as a CA component. Super-atmospheric levels of O_2 up to about 80 per cent may accelerate ethylene-induced degreening of non-climacteric commodities and ripening of climacteric fruits, respiration and ethylene production rates, and incidence of some physiological disorders (such as scald on apples and russet spotting on lettuce). At levels above 80 per cent of O_2 some commodities and post-harvest pathogens suffer from O_2 toxicity. Use of super-atmospheric O_2 levels in CA will likely be limited to situations in which they reduce the negative effects of fungistatic or elevated CO_2 atmospheres on commodities that are sensitive to CO_2-injury.

7.3 EFFECTS OF CA STORAGE

The following are some of the beneficial effects of CA storage.

- Retardation of senescence (including ripening) and associated biochemical and physiological changes, i.e., slowing down rates of respiration, ethylene production, softening, and compositional changes.
- Reduction of sensitivity to ethylene action at O_2 levels < 8% and/or CO_2 levels > 1%.
- Alleviation of certain physiological disorders, such as chilling injury of avocado and some storage disorders, including scald of apples.

- Effects directly or indirectly on post-harvest pathogens (bacteria and fungi) and consequently decay incidence and severity. For example, CO_2 at 10 to 15% significantly inhibit development of *Botrytis* rot on strawberries, cherries, and other perishables.
- Low O_2 (< 1%) and/or elevated CO_2 (40 to 60%) can be a useful tool for insect control during storage of dried products from fruits, vegetables, flowers, nuts and grains.

The harmful effects of CA storage of fruits and vegetables are mentioned below:

- Initiation and/or aggravation of certain physiological disorders, such as internal browning in apples and pears, brown stain of lettuce, and chilling injury of some commodities.
- Irregular ripening of fruits, such as banana, mango, pear, and tomato can result from exposure at O_2 levels below 2% and/or CO_2 levels above 5%.
- Development of off-flavours and off-odours at very low O_2 concentrations and very high CO_2 (as a result of anaerobic respiration and fermentative metabolism)
- Increased susceptibility to decay when the fruit is physiologically injured by too-low O_2 or too-high CO_2 concentrations.

7.4 METHODS OF CREATING MODIFIED ATMOSPHERE CONDITIONS

MAP may be defined as the enclosure of food products in gas-barrier materials in which gaseous environment has been changed in order to inhibit spoilage agents, either by maintaining a higher quality within a perishable food during its natural life or actually extending the shelf life.

Modified atmosphere can be created ***passively*** by the respiration of commodity, also called ***commodity generated*** modified atmosphere, and ***active*** modified atmosphere generation.

7.4.1 Passive Modified Atmosphere

If commodity characteristics are properly matched to film permeability characteristics, an appropriate atmosphere can passively evolve within a sealed package as a result of the consumption of O_2 and the production of CO_2 through respiration. This atmosphere must be established rapidly and without danger of the creation of anoxic conditions on injuriously high level of CO_2.

7.4.2 Active Modified Atmosphere

Because of the limited ability to regulate a passively established atmosphere, an active modified atmosphere can be created by vacuum packaging or replacing the package atmosphere with the desired gas mixture.

- **Vacuum packaging:** It involves placing a product in a film of low O_2 permeability, the removal of air from the package and application of a hermetic seal. During packaging product compression takes place which makes it unsuitable for many products.

- **Gas packaging:** Gas packaging overcomes the limitations of vacuum packaging. Oxygen, nitrogen and carbon dioxide are gases generally used which have specific role, viz. O_2 is essential for respiration of fresh fruits and vegetables, CO_2 is a bacterial and fungal growth inhibitor and nitrogen is inert, tasteless and less prone to pass either into the product or out through the packaging material.

7.4.3 Available Films for MAP

i) Plastic films: The permeability of plastic films is an important attribute which determines their suitability for packaging of fresh fruits and vegetables. An ideal film allows more CO_2 to exit than O_2 to enter. The CO_2 permeability must be somewhere in the range of 3-5 times greater than the oxygen permeability, depending upon the desired atmosphere. Permeability characters of films commonly used for packaging are presented in Table 7.1.

Table 7.1: Gas and water vapour permeabilities of some selected films available for modified atmosphere packaging of fresh produce

Film	**Permeability, cc/m^2 day. atm for 25 meq film at 25°C**		**Water vapour transmission g/m^2 day atm 38°C and 90% RH**
	Oxygen	**Carbon dioxide**	
LDPE	7800	42000	18
HDPE	2600	7600	7-10
Polypropylene cast	3700	1000	10-12
Polypropylene, oriented, OPP	6000-22000	6000-22000	NA
Rigid PVC	150-350	450-1000	30-40
Plasticized PVC	500-30000	1500-46000	15-40
Ethylene vinyl acetate (EVA)	12500	50000	40-60
Microporous, OPP	50000	50000	Variable
	72000	72000	Variable
	120000	120000	Variable
	200000	200000	Variable

NA: Not available

Low density polyethylene (LDPE) and polyvinyl chloride (PVC) are the main films used in packaging of fruits and vegetables. Gas diffusion across a film is determined by: film structure, film permeability to specific gases, thickness, area, concentration gradient across the film, temperature and differences in preserve across the film.

A list of desirable characteristics of plastic films for MAP of fresh produce is as follows:

- Required permeability for the different gases
- Good transparency and gloss

- Light weight
- Heat tear strength and elongation
- Low temperature heat-sealability
- Non toxic
- Non reactant with produce
- Good thermal and ozone resistance
- Good weatherability
- Commercial suitability
- Ease of handling
- Ease of printing for labeling purposes.

ii) Surface coatings: These are synthetic and natural chemicals which are composed of lipids, resin, polysaccharides, proteins and composite or bilayer substances. These surface coatings help to maintain quality of fresh produce and to reduce the volume of disposable non-biodegradable packaging materials. They also act by altering the gaseous atmosphere within and surrounding the fruit.

Surface coatings have been developed to overcome the limitations of MAP and CA. The risk of condensation on the inner surface and the associated incidence of rots in plastic films is eliminated. Surface coatings are used to modify internal atmosphere composition thereby delay ripening, reduce water loss and improve the finish of skin.

Requirements for edible films and coatings

- Good sensory qualities
- High carrier and mechanical efficiencies
- Enough biochemical, physiochemical and microbial stability
- Free of toxins and safe for health
- Simple technology
- Non polluting
- Low cost of raw materials and process.

Commonly used coatings

Lipids and Resins – Natural waxes-carnuba wax, candelilla wax, rice bran wax, bees wax, Petroleum based - paraffin, polyethylene wax, mineral oil, vegetable oils (corn, soybean), acetoglycerides, oleic acid, resins (shellac, wood resin, coumarone)

Polysaccharide based – They are very effective barriers to O_2 and CO_2 but not water. Cellulose derivatives: methylecellulose (MC), hydroxy propylcellulose (HPC), and hydroxy propylmethyl celluose (HPMC). These are commercially sold under the name of Nature seal, Tal prolong, Semperfresh. Chitosan based is Nutrisave.

Proteins – Their use in restricted due to high permeability to water.

Composite and bilayer coatings: They are mostly used when both the O_2 and moisture barrier properties need to be incorporated in the surface coating materials. That means the coating should have both hydrophobic and hydrophilic substances. For example, coating materials made up of sodium caseinate.

iii) Relative tolerance of fruits and vegetables to O_2 and CO_2 concentrations

The extent of benefits from CA and MA use depend upon the commodity, cultivar, physiological age (maturity stage), initial quality, concentration of O_2 and CO_2, temperature, and duration of exposure to such conditions. Subjecting a cultivar of a given commodity to O_2 levels below and/or CO_2 levels above its tolerance limits at a specific temperature time combination will result in stress to the living plant tissue, which is manifested as various symptoms. Tables 7.2 and 7.3 include classifications of fruits and vegetables according to their relative tolerance to low O_2 or elevated CO_2 concentrations when kept at or near their optimum storage temperature and relative humidity.

Table 7.2: Classification of fruits and vegetables according to their tolerance to low O_2 concentrations

O_2 concentration (%)	Commodities
1.0	Some cultivars of apples and pears, broccoli, mushroom, garlic, onion
2.0	Most cultivars of apples and pears, kiwifruits, apricot, cherry, nectarine, peach, plum, strawberry, papaya, pineapple, olive, cantaloupe, green bean, celery, lettuce, cabbage, cauliflower, brussels sprouts
3.0	Avocado, persimmon, tomato, pepper, cucumber, artichoke
5.0	Citrus fruits, green pea, asparagus, potato, sweet potato

Table 7.3: Classification of fruits and vegetables according to their tolerance to elevated CO_2 concentrations

CO_2 concentration (%)	Commodities
2	Apples (Golden Delicious), Asian and European pear, apricot, grape, olive, tomato, sweet pepper, lettuce, Chinese cabbage, artichoke, sweet potato
5	Most cultivars of apples and peach, nectarine, plum, orange, avocado, banana, mango, papaya, kiwifruit, pea, chilli, egg plant, cauliflower, cabbage, brussels sprouts, radish, carrot

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Which of the following statements are right or wrong? Mark (√) or (X).

   i) The role of CO_2 in CA storage is primarily limited to maintaining the freshness of the produce.

   ii) CO_2 at certain concentration acts as a fungistatic.

   iii) CO_2 at certain concentration acts as a fungicide.

   iv) Excess of CO_2 can cause injury to the produce that is similar to that of mechanical injury.

   v) Reduced level of O_2 results in checking the respiratory rates in CA storage.

2. What are the detrimental effects of CA storage?

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3. Write two different methods of atmospheric modification.

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4. Can we create MA condition by use of surface coating on fruits and vegetables? Mention the different type of surface coatings used in commercial practice abroad.

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7.5 COMMERCIAL APPLICATION OF CA STORAGE

Controlled atmosphere storage systems are used commercially for long-term storage of fresh horticultural crops. Commercial use of CA storage is maximum in apples and pears. Recent researches have shown potential advantages of this method in short-term (a few days) and medium-term (a few weeks) storage of certain types of produce. Optimizing storage conditions requires facilities that allow the temperature and the composition of gases in storage rooms to be controlled precisely. Each product reacts in different way to different concentration of gases.

There are various types of CA systems used in commercial storage. These include generating nitrogen by separation from compressed air using molecular sieve beds or membrane systems. Others are ultra low O_2 (1.0 to 1.5%) storage (ULO), low ethylene ($< 1\ \mu L\ L^{-1}$) CA storage; rapid CA storage (rapid establishment of optimal levels of O_2 and CO_2), programmed or sequential CA storage (e.g., storage in 1% O_2 for 2 to 6 weeks followed by storage in 2 to 3% O_2 for the remainder of the storage period), etc. Recent reports of short-term control atmosphere exposure (CAE) techniques indicate a great promise of simulated effect of continuous CA–storage system with particular reference to delay in disease development, delaying the senescence and quality assurance of CA-insensitive climacteric fruits. Other developments include use of atmospheric modification during transport and distribution, improved technologies of establishing, monitoring, and maintaining CA, using edible coatings or polymeric films with appropriate gas permeability to create a desired atmospheric composition around the commodity.

In commercial CA storage the crop is loaded into an insulated store room whose walls have been made gas tight. The temperature is controlled by mechanical refrigeration and the composition of the atmosphere is constantly analysed for carbon dioxide and oxygen levels. Usually the tolerance limits are set at, say plus or minus 0.1%. In active scrubbing, after a predetermined level of CO_2 is reached of the store the atmosphere, is passed through a chemical (CO_2 scrubber) which removes CO_2, and then it is flushed back into the store. In passive scrubbing, the CO_2 scrubber is placed inside the store.

The following factors are to be taken into account with controlled atmosphere storage:

- It is expensive, therefore, only the best fruit should be stored.
- If there is a choice, small fruit should be stored.
- Fruit should be placed in storage as soon as possible after harvest, and in any case within a day.
- The store should be closed and cooled each evening during loading.
- Only one type of crop should be stored in one room and preferably the same cultivar.

The characteristics for a fruit to be compatible with the use of CA are: a long post harvest life, resistance to chilling injury, a large range of non-injurious atmospheres, resistance to fungal and bacterial attack, adaptation to a humid atmosphere, a climacteric fruit that can be ripened during or after storage, and absence of negative CA residual effect.

7.6 ENVIRONMENTAL FACTORS INFLUENCING MA AND CA STORAGES

7.6.1 Temperature and Relative Humidity

The temperature at which a commodity is stored influences the storage life of product, more importantly in film packed commodities. The commodity will cool and warm more slowly than it would if it is exposed directly to ambient temperatures. Temperature also affects the permeability of film. In general, film permeability increases as temperature increases, with CO_2 permeability responding more than O_2 permeability. A film that is appropriate for MAP at one temperature may not be appropriate at other temperature. Relative humidity appears to have little effect on permeability of most films unless actual condensation occurs on the film.

7.6.2 Light

For many commodities, light is not an important factor which influences 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. Greening of potatoes can be avoided by using opaque packages.

7.6.3 Sanitation Factors

Packaging of fresh fruits and vegetables in plastic films can create a high-humidity low-oxygen environment that is favourable to pathogenic microorganisms. Care must be taken to avoid conditions favourable to the growth and reproduction of such microorganisms.

7.7 CA SYSTEMS FOR TRANSPORTATION

Many CA systems have been developed for use during transportation. They should be used when transport periods are long and /or fruit is very perishable. Some of the systems in use are:

Oxytral system	Occidental Petroleum Corporation, California, USA	Highway and sea shipment of lettuce, celery, papaya, pineapple
Tectrol system	Transfresh Corporation, California, USA	Lettuce, strawberry, mango, avocado.
CONAIR-Plus System	G+H Montage GmbH, Hamburg, Germany	Apple, avocado, melon, mango.
PRISM CA	Per Mea Inc., St. Louis, Missouri, USA	Apple, pears.
Fresh tainer	Maidstone, England	Apple
NITEC	Spokane, Washington, USA	Apple.

A comprehensive list of most suitable storage atmospheres for CA or MA storage of vegetables is provided in Table 7.4.

Table 7.4: Recommended controlled atmosphere conditions during transport/storage of vegetables

Commodity	Storage temp (°C)	Optimum oxygen (%)	Optimum carbon dioxide (%)	Approximate storage life
Artichoke	0-5	2-3	2-3	29 d
Asparagus	1-5	21	5-10	21 d
Beans. Snap	5-10	8-10	5-10	7-10 d
Beets	8-12	None	None	8 m
Brinjal	0-5	-	-	1-2 wk
Broccoli	0-5	1-2	5-10	2-3 m
Brussels sprouts	0-5	1-2	5-7	2-3 m
Cabbage	0-5	3-5	5-7	6-12 m
Carrot	0-5	None	None	4-5 m
Cauliflower	0-5	2-3	3-4	2-3 m
Celery	0-5	1-4	3-5	1-2 m
Chicory	0-5	3-4	-	2 m
Cucumber	8-12	3-5	0	14-21 d
Leeks	0-5	1-2	3-5	2-3 m
Lettuce	0-5	2-5	0	3-4 wk
Mushrooms	05	air	10-15	3-4 d
Okra	8-12	3-5	0	7-10 d
Onions				
Bulb →	0-5	1-2	0	8 m
Bunching →	0-5	1-2	10-20	2 m
Pea (green)	0-1	5-10	5	5-10 d
Pepper, bell	8-12	3-5	0	2-3 wk
Pepper, chilli	8-12	3-5	0-5%	-
Potatoes	4-12	None	None	-
Pumpkin	7-10	-	-	2-4 m
Radish	0-5	None	None	3-4 wk
Spinach	0-5	air	10-20	2-3 wk
Squashes	7-10	-	-	1-3 m
Tomatoes	5-13	3-5	2-3	2 wks

d=days; wks=weeks; m=months

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Which of the following statements are right or wrong? Mark (√) or (X).
   i) Commercially CA storage is meant for long term storage.
   ii) In ultra low oxygen CA storage the O_2 concentration ranges from 1-1.5%.
   iii) The establishment of CA condition is very slow in ULO system of CA storage.
   iv) Mango fruits respond very well to CA storage than apples.
2. Mention three different environmental factors crucial to maintain the efficacy of CA storage.

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3. Mention any three commercial system of MA/CA storage used during transportation.

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7.8 LET US SUM UP

Atmosphere at ambient conditions comprises of 78.08% N_2, 20.98% O_2 and 0.03% CO_2 under normal conditions. Any deviation from this normal atmosphere composition, e.g. elevated level of CO_2, reduced level of O_2, and N_2 or any other combination is known as '**Modified Atmosphere**'. When this deviated normal atmosphere is precisely kept under control then it is termed as "**Controlled Atmosphere**". This control can be done in package (Controlled Atmosphere Packaging) or in the storage chamber (CA-storage). Generally, O_2 below 8% and CO_2 above 1% are used in CA-storage. Atmospheric modification is a supplementary practice to temperature management in preserving quality and safety of fresh fruits, vegetables, ornamentals and their products throughout post-harvest handling. Essentiality of CA/MA technology should be justified only if (a) the commodities are having high market value,

(b) it significantly enhances storage life, (c) it retains significantly better quality, and (d) it fetches better price compared to conventional cool stored produce. Elevated CO_2-induced stresses are additive to and sometimes synergistic with, stresses caused by low O_2; physical or chemical injuries; and exposure to temperatures, RH, and/or ethylene concentrations outside the optimum range for the commodity.

The beneficial effects of controlled atmosphere storage are retardation of senescence, reduction of sensitivity to ethylene action, alleviation of certain physiological disorders and direct or indirect effect on post-harvest pathogens. It can be a useful tool for insect control. The harmful effects of CA storage of fruits and vegetables are initiation and/or aggravation of certain physiological disorders, irregular ripening of fruits, development of off-flavours and off-odours and increased susceptibility to decay.

If commodity characteristics are properly matched to film permeability characteristics, an appropriate atmosphere can passively evolve within a sealed package as a result of the consumption of O_2 and the production of CO_2 through respiration. It is also called passive MA. Because of the limited ability to regulate a passively established atmosphere, an active modified atmosphere can be created by vacuum packaging or replacing the package atmosphere with the desired gas mixture. The permeability of plastic films is an important attribute which determines their suitability for packaging of fresh fruits and vegetables. Surface coatings help to maintain quality of fresh produce and to reduce the volume of disposable non-biodegradable packaging materials. They also act by altering the gaseous atmosphere within and surrounding the fruit and create a MA condition.

There are various types of CA systems used in commercial storage. These include generating nitrogen by separation from compressed air using molecular sieve beds or membrane systems. Others are ultra low O_2 (1.0 to 1.5%) storage (ULO), low ethylene (< 1 $\mu L\ L^{-1}$) CA storage; rapid CA storage (rapid establishment of optimal levels of O_2 and CO_2), and programmed or sequential CA storage (e.g., storage in 1% O_2 for 2 to 6 weeks followed by storage in 2 to 3% O_2 for the remainder of the storage period), etc. Many CA systems have been developed for use during transportation. They should be used when transport periods are long and /or fruit is very perishable.

7.9 KEY WORDS

Modified atmosphere : Atmosphere at ambient conditions comprises of 78.08% N_2, 20.98% O_2 and 0.03% CO_2 under normal conditions. Any deviation from this normal atmosphere composition, e.g. elevated level of CO_2, reduced level of O_2, and N_2 or any other combination is known as **Modified Atmosphere.**

Controlled atmosphere : When this deviated normal atmosphere is precisely kept under control then it is termed as **Controlled Atmosphere**.

Passive modified atmosphere : If commodity characteristics are properly matched to film permeability characteristics an appropriate atmosphere can passively evolve within a sealed package as a result of the consumption of O_2 and the production of CO_2 through respiration

Active modified atmosphere : An active modified atmosphere can be created by vacuum packaging or replacing the package atmosphere with the desired gas mixture.

Vacuum packaging : It involves placing a product in a film of low O_2 permeability, the removal of air from the package and the application of a hermetic seal.

Gas packaging : Gas packaging overcomes the limitations of vacuum packaging. Mixed gases or inert gas is used in the package for specific purposes.

Surface coatings : The synthetic and natural chemicals which are composed of lipids, resin, polysaccharides, proteins and composite or bilayer substances are used as surface coating materials for various purposes. These surface coatings help to maintain quality of fresh produce and to reduce the volume of disposable non-biodegradable packaging materials. Edible films and coatings are also available.

Composite and bilayer coatings : It is mostly used when both the O_2 and moisture barrier properties need to be incorporated in the surface coating materials. This means the coating should have both hydrophobic and hydrophilic substances.

7.10 ANSWERS TO CHECK YOUR PROGRESS EXCERCISES

Check Your Progress Exercise 1

Your answer should include the following points:

1. Composition of normal atmosphere is 78.08% N_2, 20.98% O_2 and 0.03% CO_2. Any deviation from this normal atmosphere composition i.e., elevated level of CO_2, or reduced levels of O_2, and N_2 or any other combination is known as **Modified Atmosphere**. When this deviated normal atmosphere is precisely kept under control then it is termed as **Controlled Atmosphere**.
2. Kidd and West (1917).
3. O_2 below 8% and CO_2 above 1%.

4. Essentiality of CA/MA technology should be justified only if (a) the commodities are having high market value, (b) need longer storage life, (c) require significantly better quality, and (d) fetch better price compared to conventional cool stored produce.

Check Your Progress Exercise 2

Your answer should include the following points:

1. i) X ii) √ iii) X iv) √ v) √
2. Initiation and/or aggravation of certain physiological disorders, irregular ripening, development of off-flavours and off-odours, and increased susceptibility to decay.
3. Active and passive modification.

Check Your Progress Exercise 3

Your answer should include the following points:

1. i) √ ii) √ iii) X iv) X
2. Temperature and relative humidity, light and sanitation factors.
3. Any three of the following: Oxytral system, Tectrol system, CONAIR-Plus System, PRISM CA, Fresh tainer or NITEC.
4. Yes, Different types of surface coatings materials are:
   i) Lipid and resin based, e.g., carnuba wax
   ii) Polysaccharide based, e.g., Tal prolong
   iii) Protein based, and
   iv) Composite and bilayer coatings

7.11 SOME USEFUL BOOKS

1. Ludford, P.M. and Isenberg, F.M.R. (1987) Brassica crops. In: Weichman, J. (Ed.) Post-harvest physiology of vegetables, Marcel Dekker Inc., New York.
2. Salunkhe, D.K. and Desai, B.B. (1984) Post-harvest biotechnology of vegetables. Vol. I, CRC Press Inc., Florida.
3. Pantastico, Er. B. (1975) Post-harvest physiology, handling and utilization of tropical and subtropical fruits and vegetables. A VI Publ. Co; Westport, CT.
4. Wills, R.H.H., Lee, T.H., Graham, De., McGlasson, W.B. and Hall, E.G. (1981) Post-harvest: An introduction to the physiology and handling of fruit and vegetables. A VI Publ. Co., Westport, CT.
5. Burton, W.G. (1982) Post-harvest physiology of food crops. Longman, New York.