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Principles of modified atmosphere packaging for shelf life extension of fruits and vegetables: An overview of storage conditions

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Abstract
Freshly harvested Fruits and vegetables are susceptible to pathogenic organisms owing to increased respiration rate after harvesting. With the help of various preservation techniques, respiration rate of fresh agricultural commodity can be reduced. Modified atmosphere packaging (MAP) is a technology that changes the gas concentration in the package around the produce for shelf life enhancement and preservation of the food quality. Extensive research has been conducted in this field during the last two decades. Modified atmosphere packaging uses three main gases such as oxygen (O_2), carbon dioxide (CO_2), and nitrogen (N_2) to modify the atmosphere within the package. Concentration of gases depends on the type of fresh produce being packed. MAP aids in increasing the shelf-life of commodities from many days to many weeks as compared to conventional storage system. MAP reduces physiological injury, disorder, weight loss, fungal growth and pathological deterioration.

Keywords: Modified atmosphere packaging, fruits and vegetables, packaging, quality, shelf life

Introduction

India is the second largest producer of fruits and vegetables in the world after China & accounts for about 15% of the world's total production. According to the National Horticultural Board of India, it produced 169.1 million metric tonnes of vegetables and 90.2million metric tonnes fruits during 2016-2017. The area under cultivation of vegetables stood at 10.1 million hectares while fruits were cultivated in 6.3 million hectares (APEDA, 2018) [1]. The differing agro-climatic zones and soil type of the nation make it conceivable to grow almost all of the horticultural crops. However, India accounts for only 2.2% of the total food processing in the world. In contrast, India is behind the other countries like USA (65%), China (23%) and Philippines (78%) in enhancing the value addition, shelf life and reducing the wastage of the farm products. Cultivation of fruits and vegetables play a significant role in the agricultural economy (Chandrasekharam 2012).

Fruits and vegetables are main source of carbohydrate, organic acids, dietary fibers, mineral and vitamins for human nutrition and diet consideration (Irtwange, 2006) [6]. Hence their demand in the market is ever-growing. Fruits and vegetables contain large portion of water (75-90%) and are therefore more susceptible to microbial damage. Freshly harvested produce has a short storage life, and they lose their freshness and quality rapidly if optimum conditions of temperature and relative humidity are not maintained.

Fruits and vegetables are biologically active and continue their metabolism even after harvesting. It is imperative to store fresh produce and vegetables at optimum storage conditions so as to prevent them from microbial and physiological damage as their respiration rate spikes after the harvest. The improper pre cooling and storage techniques result in the losses which can be microbiological, biological, biochemical, chemical, mechanical, physical or physiological leading to fall in their market selling price Among them, microbiological, mechanical and physiological factors cause most of the losses in perishable crops (Devgan *et al*., 2019; Kader 1997) [4].

To extend the shelf life of fresh produce, it is critical to minimize reaction rate of biochemical changes, enzymatic and microbial degradation. Generally, shelf life of fruits and vegetables is increased by providing proper sanitation condition during harvesting and processing; minimizing their water activity and enzyme functionality; optimizing their temperature and relative humidity during storage (Kader *et al*., 1989; Kirandeep *et al*., 2018; Kumar *et al*., 2020) [9, 10, 12]. In spite of these precautions, gases around the produce continue to give an appropriate medium for reaction of oxidative rancidity as well as aerobic microorganism's growth. Hence, change in atmosphere around the foods could help to maintain their quality. In MAP, food is enclosed in a package with optimal air concentration specifically designed to enhance the shelf life and is different from the atmosphere gas concentration (Church and Parsons, 1995) [3]. Positive effect of MAP on saving freshness of produce were first reported on 1821, when Jacques Etienne claimed that lower concentration of oxygen retards the ripening of fruits and vegetables during storage period (Robertson, 2012) [17].

The main objectives of post-harvest technology are to control the quality and reduction in post-harvest losses. MAP has two factors: temperature control and modified atmosphere for enhancing the shelf life of produce (Fonseca *et al*. 2002) [5]. These primary factors are responsible for preserving quality and enhancing the life of fresh produce after harvest. However, MAP is very successful when the harvesting is done at optimum maturity, it also helps in reducing mechanical injuries by using proper sanitation and handling methods, and giving the suitable temperature and relative humidity during all marketing activity. Secondary factors subsume changes of gases like oxygen (O_2), carbon dioxide (CO_2), and/or ethylene (C_2H_4) composition in the atmosphere around the produce than the air. This is known as the modified atmosphere (MA) storage. If all these parameters are continuously monitored and controlled then MA storage becomes controlled atmosphere (CA) storage systems (Mahajan *et al*. 2007) [14].

Modified Atmosphere Packaging

MAP was introduced as a novel technology in the 1960s to enhance storage life of perishable agricultural commodity and to reduce its microbial spoilage and natural deterioration (Henig and Gilbert, 1975) [7]. Church and Parsons (1995) [3] defined MAP as the packaged product with an optimal gas composition that is specifically designed to extend the shelf life and it is different from the atmosphere gas composition. It is the food preserving technology that maintains the natural quality of fresh produce in addition to prolonging the shelf life. MAP leads to the reduction of respiration rate, activity of microorganisms or insects, control in ripening of agricultural produce, retard senescence, or browning in cut produce, and ultimately enhances the life span of packaged product (Fonseca *et al*., 2002) [5]. Packaging is a process, which extract out the air from the package and it replaces air with a single gas or mixture of gases. The usage of gas mixture is relying on the product type. The gaseous exchange continues, due to this biochemical change, respiration rate of the packed product and slow permeation of gases through the container during the storage period (Parry, 1993) [16].

Modification of package head space air in MAP technique is achieved by the natural interplay between two processes, products respiration and the gases permeation through the packaging material (Mahajan *et al*., 2007; Torrieri *et al*., 2009) [14, 21]. MAP reduces the metabolic activity of a product and of the microorganisms' present, both spoilage and pathogenic, by optimizing the gas composition (O_2 supply, applying an elevated level of CO_2 and balance of N_2). Two types of MAP are commonly used such as active packaging and passive packaging (Ahvenainen, 1996). In the first MAP systems, a reference was made to active and passive atmospheres depending on whether a volume of gas with a different atmospheric concentration was introduced at the time of sealing the package (active MAP), or simply the bag was sealed with atmospheric air (passive MAP). The active packaging is a packaging material that interacts with the atmosphere or gas composition present inside the package by varying the headspace gas composition such as oxygen, carbon dioxide and ethylene, or it contain additives which are incorporated into the package to modify the package headspace atmosphere. There are different ways to make packages active but, the only two mechanisms used for the active packaging like placing the active element inside the package or, incorporating the active element in the package itself. In Controlled Atmosphere storage the atmosphere around the produce is modified and its concentration is strictly controlled according to the specific requirements of produce throughout the storage period (Torrieri *et al*. 2009; Sandhya 2010; Parry 1993; Torrieri, 2008) [21, 19, 16].

Principles of MAP

MAP of fruits and vegetables depends on modification of the atmosphere inside the package, achieved by the natural interplay between two processes, the transfer of gases through the packaging and the respiration of the product. Modified atmosphere contains higher in CO_2 and lower in O_2; and it also rely on the characteristics of the commodity and the packaging film (Mahajan *et al*. 2007; Kumar *et al* 2017) [14]. The relative humidity for storage of fruits and vegetable is kept high (>90%) to avoid physiological loss in their weight and ultimate shriveling. This composition of these gases surrounds the produce can reduce respiration rate, C_2H_4 sensitivity and production, ripening, compositional changes and softening, deterioration and physiological changes (Kader *et al*. 1989; Parry 1993; Kumar 2018) [9, 16, 13]. MAP involves the exposure of commodity to the atmosphere procreated in a pack by the interaction of fruits and vegetables, the package and the external atmosphere. The initial atmosphere may be either a gas mixture or air. Various additives that may affect the atmosphere may be added inside the package before it is sealed.

Atmosphere of package modified rely on packaging film's permeability, respiration rate, gas diffusion characteristics, weight of commodity, surface area, initial free volume and atmospheric air concentration within the package. The film permeability of package is influenced by temperature, relative humidity and air movement. Temperature and modified atmosphere influence the metabolic activity of the fruits and vegetables (Parry, 1993) [16].

Objective of MAP

The objective of design of MAP is to achieve the conditions that will enhance the shelf-life of agricultural commodity. In addition, MAP is aimed to create the equilibrium concentration of O_2 and CO_2inside the package and these concentration lies according to the recommended level required for maximum possible storage life of the commodity. The equilibrium concentration of O_2 and CO_2attainedinside the package for a packaging system requires to be remained constant throughout the storage period to reduce the respiration rate and rate of all metabolic process for stabilizing freshness and prolonging shelf-life of stored agricultural produce(Mahajan *et al*., 2007; Kader *et al*., 1989) [14, 9]. Collating the permeation rate of film for O_2 and CO_2 with the rate of respiration of packaged produce can do this. As different product differ in their behavior and as modified atmosphere packages exposed to a dynamic environment, each package must adapt to specific demand (Saltveit, 1993; Shivaraj *et al*., 2010; Mahajan *et al*., 2007) [18, 20. 14]. An unsuitably designed MAP system may be inefficacious or even shorten the life span of stored agricultural produce. If the desired atmosphere is not maintained, the package will not provide benefit; if concentration of O_2 and/or CO_2 during MAP design are not within the required range, the produce will get serious changes resulting in shortening the storage life.

Effect of MAP

Modified Atmosphere Package reduces respiration rate of agricultural product,it was reported on the basis of plant respiration in low O_2 environment. Respiration starts to slow down at concentration of 10- 12% O_2inside the package (Saltveit 1993) [18]. Rate of reduction in respiration continues until O_2 reaches about 2-5% for most of the commodity. If O_2 concentration goes below 2-5% (depending on product and temperature), fermentative metabolism exchange normal aerobic metabolism and off flavors, off odours, and undesirable volatiles are produced (Kader *et al*. 1989) [9]. Similarly, as the concentration CO_2rises above the atmospheric level, a suppression of respiration rate, inhibition of C_2H_2 production, sensitivity to C_2H_4 and prevention the microorganisms' activities, fungal/bacterial growth has been reported by several studies. Combination of the reduced O_2 and elevated CO_2 composition play a significant role in slowing the rate of respiration as compared to single gas concentration. MAP also reduces weight losses, chilling injury and maintains the colour of commodity (Bodbodak and Moshfeghifar, 2016; Mahajan and Goswami 2001) [2]. The ethylene production and respiration rate of various vegetables and fruits at different temperature are provided in Table 1 and 2 receptively

Table 1: Ethylene production and respiration rate of various vegetables at different temperature

Horticultural Products	Respiration (mg CO_2/kghr) at temperature						Ethylene production (μl C_2H_4/kg-hr)
	0 °C	5 °C	10 °C	15 °C	20 °C	25 °C	
Coriander	22	30	nr	nr	nr	nr	very low
Garlic Bulb	8	16	24	22	20	nr	very low
Garlic Fresh peeled	24	35	83	nr	nr	nr	very low
Ginger	nr	nr	nr	nr	6[3]	nr	very low
lettuce head	12	17	31	39	56	82	very low
lettuce leaf	23	30	39	63	101	147	very low
Radish topped	16	20	34	74	130	172	very low
Radish bunched with top	6	10	16	32	51	75	very low
Salad green Rocked salad	42	113	nr	nr	nr	nr	very low
Salad green Lamb's lettuce	12	67	81	nr	139	nr	very low
Spinach	21	45	110	179	230	nr	very low
Sweet corn	41	63	105	159	261	359	very low
Turnip	8	10	16	23	25	nr	very low
Bean snap	20	34	58	92	130	nr	<0.05(5 °C)
Bean long	40	46	92	202	220	nr	<0.05(5 °C)
Okra	21	40	91	146	261	345	0.5
olive	nr	15	28	nr	60	nr	<0.5(20 °C)
Cucumber	nr	nr	26	29	31	37	<0.6(20 °C)
Beat	5	11	18	31	60	nr	<0.1(0 °C)
Sprout (mung bean)	23	42	96	nr	nr	nr	<0.1(10 °C)
onion	3	5	7	7	8	nr	<0.1(20 °C)
Pea garden	38	64	86	175	271	313	<0.1(20 °C)
Pea edible pod	39	64	89	176	273	nr	<0.1(20 °C)
Cabbage	5	11	18	28	42	62	<0.1(20 °C)
Broccoli	21	34	81	170	300	nr	<0.1(20 °C)
Carrot	15	20	31	40	25	nr	<0.1(20 °C)
Pepper	nr	7	12	27	34	nr	<0.2(20 °C)
Brussels sprout	40	70	147	200	276	nr	<0.25(7.5 °C)
Radicchio	8	13	23	nr	nr	45	<0.3(6 °C)
Cauliflower	17	21	34	46	79	92	<1.0(20 °C)
Asparagus	60	105	215	235	270	nr	2.6(20 °C)
Southern pea whole pod	24	25	nr	nr	148	nr	nr
Southern pea shelled pea	29	nr	nr	nr	126	nr	nr

nr* = not recommended, very low value is considered to be < 0.5 μl C_2H_4/kg-hr

Table 2: Ethylene production and respiration rate of various fruits at different temperature

Horticultural Products	Respiration (mg CO_2/kghr) at temperature						Ethylene production (μl C_2H_4/kg-hr)
	0 °C	5 °C	10 °C	15 °C	20 °C	25 °C	
Litchi	nr	13	24	nr	60	102	very low
Artichoke	30	43	71	110	193	nr	<0.1
Apricot	2	nr	16	nr	40	nr	<0.1(0°C)
Beets	5	11	18	31	60	nr	<0.1(0°C)
Cherry	8	22	28	46	65	nr	<0.1(10°C)
Grape American	3	5	8	16	33	39	<0.1(20°C)
Grape Muscdine	10	13	nr	nr	51	nr	<0.1(20°C)
Grape Table	3	7	13	nr	27	nr	<0.1(20°C)
Grapefruit	nr	nr	nr	<10	nr	nr	<0.1(20°C)
Mandarin (tangerine)	nr	6	8	16	25	nr	<0.1(10°C)
Orange	4	6	8	18	28	nr	<0.1(10°C)
Pineapple	nr	2	6	13	24	nr	<0.1(10°C)
Pomegranate	nr	6	12	nr	24	39	<0.1(10°C)
Strawberry	8	10	16	23	25	nr	<0.1(10°C)
Mango	nr	16	35	58	113	nr	<1.5(20 °C)
Plum (ripe)	3	nr	10	nr	20	nr	<5.0(0 °C)
Nectarine (ripe)	5	nr	20	nr	87	nr	5.0(0 °C)
Peach (ripe)	5	nr	20	nr	87	nr	5.0(0 °C)
Banana (ripe)	nr	nr	80	140	280	nr	5.0(15 °C)
Papaya (ripe)	nr	5	nr	19	80	nr	8.0
Guava	nr	nr	34	nr	74	nr	10(20 °C)
Tomato	nr	nr	15	22	35	43	10(20 °C)
Raspberry	17	23	35	42	125	nr	<12(20 °C)
Kiwifruit (ripe)	3	6	12	nr	19	nr	75
Sapota	nr	nr	nr	nr	nr	nr	<100(20 °C)
Avocado	nr	35	105	nr	190	nr	>100(ripe; 20 °C)
Passion fruit	nr	44	59	141	262	nr	280.0(20 °C)
Mamey Apple	nr	nr	nr	nr	nr	35	400.0(27 °C)
Apple Fall	3	6	9	15	30	nr	varies greatly
Apple Summer	5	8	17	25	31	nr	varies greatly
Asian Pear	5	nr	nr	nr	25	nr	varies greatly
Blackberry	19	36	62	75	115	nr	varies; 0.1-2.0
Blueberry	6	11	29	48	70	101	varies; 0.5-10.0

Nr* = not recommended, very low value is considered to be < 0.5 μl C_2H_4/kg-hr

MAP Gases

MAP is designed for shelf-life enhancement of the agricultural commodity. During Map design commonly used gases are CO_2, O_2 and N_2 (Mahajan and goswami, 2001). Shelf life of the food products can be prolonged by using recommended gas mixtures showed in table 1 and 2.

Oxygen (O_2)

It is odourless and colourless gas which is highly reactive and supports combustion. Solubility of oxygen in water is low (0.040 g/kg at 100kPa, 20°C). Several deteriorative reactions such as browning reaction, fat oxidation and pigment oxidation are caused due to presence of O_2. It also helps in growth of aerobic bacteria and fungi. Therefore, to extend the shelf life of fresh produce, O_2 concentration must be optimized (Sandhya 2010) [19].

Carbon dioxide (CO_2)

Carbon dioxide is a bacteriostatic and colourless gas. At very high concentrations, it produces a slight pungent odour. In the presence of moisture, CO_2 behaves as a sphyxiant and is slightly corrosive. Solubility of CO_2 in water is 1.57 g/ kg at 100 kPa, 20°C. Carbonic acid (H_2CO_3) is produced due to water solubility which enhances the acidity of solution and reduces the pH. Due to its soluble behavior in water, it reduces the volume of headspace by collapsing the pack. The inhibitory effect of CO_2 increases with a decrease in temperature (Sandhya 2010) [19].

Nitrogen (N_2)

N_2 is used as a filler gas to displace O_2 due to its minimum reactivity. Nitrogen is an odourless, tasteless, colourless and inert gas; it does not show any bacteriostatic effect. It has low density and low solubility in water (0.018 g/kg at 100 kPa, 20°C). It prevents the growth aerobic spoilage but does not inhibit the growth of anaerobic bacteria. Due to its low solubility in water can be used to prevent pack collapse by adding sufficient N_2 amount in gas mixture to maintain the volume (Sandhya 2010) [19].

Carbon monoxide (CO)

Carbon monoxide is a tasteless, colourless and odourless gas that is very flammable and highly reactive. It has also low solubility in water but is relatively soluble in some organic solvents. CO has been analyzed for meat packaging and MAP of meat has been used in USA for prevention of lettuce browning. Because of its toxic nature, it has limited commercial applications (Sandhya 2010) [19].

Noble gases

The noble gases are helium (He), argon (Ar), xenon (Xe) and neon (Ne) having low reactivity. These gases are being used in a number of food applications like potato-based snack products. As the scientific notion, it is difficult to see the preservation advantages of these noble gases compared with N_2 (Sandhya 2010) [19].

Low O_2 atmosphere active-MAP of fresh cut produce

To maintain the quality and to enhance shelf life, some fresh cut fruits and vegetables require low oxygen (1-5 kPa) and increased carbon dioxide (5-10 kPa). Enzymatic browning can be prevented by low oxygen atmosphere-active MAP (Ghidelli and Pérez-Gago, 2016) [6].

High O_2 atmosphere fresh cut produce

Higher concentration of oxygen (>70 kPa) has been observed to be effective at preventing anaerobic fermentation, controlling enzymatic browning and growth of both aerobic and anaerobic microorganisms. Efficacy of high concentration of oxygen relies on type of commodity, physiological

Applications of MAP

The principal application of MAP is to enhance the shelf life of fresh agricultural commodity. After harvesting of fruits and vegetables from their parent plant, they continue to respire continuously. Storage life of commodity is based on the respiration rate. An equilibrium gas composition is established; when the gas ($O_2$and CO_2) and water vapour transmission rate of packaging film equals the rate of respiration of the commodity (Church and Parson, 1995) [3]. The equilibrium value relies on: weight of the product, the respiration rate of the product, and the film surface are which is available for gas exchange. Storage temperature, variety of the commodity, growing area and condition, injury to the product influences the respiration rate of fruits and vegetables (Parry 1993) [16].

By minimizing the concentration of O_2, the respiration rate and the rate of all metabolic process are correspondingly decreased. These results in delayed ripening and senescence, which may be seen as chlorophyll retention, delayed softening and the prevention of discoloration. MAP also reduces the quantity of water vapor lost from the commodity (Church and Parson 1995) [3]. Additionally, MAP pack present an attractive form of produce stage, cultivar, storage condition (Ghidelli and Pérez-Gago, 2016) [6]. The potential benefits of MA/CA storage for various types of fruits and vegetables are provided in Table 3 and 4 receptively.

Table 3: MA/CA Potential benefits for Deciduous, Subtropical and Tropical Tree fruits

Horticultural Products	Temperature (°C)	MA/CA Oxygen (%)	MA/CA Carbon dioxide (%)	Benefits
Deciduous Tree Fruits				
Apple	0-3	1-3	1-5	Excellent
Apricot	0-5	2-3	2-3	Fair
Fig	0-5	5-10	15-20	Good
Grape	0-2	2-5	1-3	Fair
Guava	10-15	2-5	2-5	Good
Kiwifruit	0-5	1-2	3-5	Excellent
Nectarine	0-5	1-2	3-5	Good
Peas	0-5	1-2	3-5	Good
Pear, Asian	0-5	2-4	0-1	Good
Pear, European	0-5	1-3	0-3	Excellent
Persimmon	0-5	3-5	5-8	Good
Plum and prune	0-5	1-2	0-5	Good
Raspberry	0-3	5-10	15-20	Excellent
Strawberry	0-2	5-10	15-20	Excellent
Sweet cherry	0-2	3-10	10-15	Good
nuts and dried fruits	0-25	0-1	0-100	Excellent
Subtropical and Tropical Tree fruits				
Grape fruit	10-15	3-10	5-10	Fair
Lemon	10-15	5-10	0-10	Good
Lime	10-15	5-10	0-10	Good
Litchi	0-2	2-3	2-5	Good
Nectarine	0-5	1-2	3-5	Good
Olive	5-10	2-3	0-1	Fair
Orange	5-10	5-10	0-5	Fair
Mango	10-15	3-5	5-10	Fair
Papaya	10-15	3-5	5-10	Fair
Pineapple	8-13	2-5	5-10	Fair

Source: S. V. Irtwange,2006; Mangraj, 2009 [6, 15].

Table 4: MA/CA Potential benefits for vegetables.

Horticultural Products	Temperature (°C)	MA/CA Oxygen (%)	MA/CA Carbon dioxide (%)	Benefits
Artichokes	0-5	2-3	2-3	Good
Asparagus	0-5	15-20	5-10	Excellent
Beans	5-10	2-3	4-7	Fair
Beets	0-5	2-5	2-5	Fair
Broccoli	0-3	1-2	5-10	Excellent
Brussels sprouts	0-5	1-2	5-7	Good
Cabbage	0-5	2-3	3-7	Excellent
Cantaloupes	3-7	3-5	10-15	Good
Carrots	0-5	3-5	2-5	Fair
Cauliflower	0-2	2-3	2-5	Fair
Celery	0-5	1-1	0-5	Good
Corn, sweet	0-5	2-4	5-10	Good
Cucumbers	8-12	3-5	0-2	Fair
Honeydews	10-12	3-5	0-2	Fair
Leeks	0-5	1-2	3-5	Good
Lettuce	0-5	1-3	0-3	Good
Mushroom	0-3	Air	10-15	Fair
Okra	8-12	3-5	0-2	Fair
Onions, dry	0-5	1-2	0-5	Good
Onions, green	0-5	1-2	10-20	Fair
Peppers, bell	8-12	3-5	0-2	Fair
Peppers, chili	8-12	3-5	0-3	Fair
Potatoes	4-10	2-3	2-5	Fair
Radish	0-5	1-5	2-3	Fair
Spinach	0-5	18-21	10-20	Good
Tomato	15-20	3-5	0-3	Good

Source: S. V. Irtwange,2006, Mangraj, 2009 [6, 15].

Application of MAP include long term storage of apple, kiwi, pears, potato, orange, sapota, cabbage; temporary storage and/or transport of strawberries, bush berries, cherries, bananas, litchi, guava, mushroom, tomato, etc. (Table 5)MAP is also applicable for prolonging the shelf lives of the minimal processed and mixed vegetable salad subsumes cut carrot, cucumber, sliced garlic and green pepper (Sandhya 2010) [19]. MAP endue desired atmosphere during the whole post-harvest handling time from harvest to consumption (Shivaraj *et al*. 2010; Mahajan *et al*. 2007, Mangraj and Goswami, 2009) [20, 14]. The advantages and disadvantages of MAP are listed below:

Advantages

- MAP enhances shelf-life of commodity from many days to many weeks as compared to tradition storage system.
- Delay of ripening takesplace.
- MAP reduces physiological injury, disorder, weight loss, fungal growth and pathological deterioration takesplace.
- Reduction of respiration rate, loss of moisture, production of metabolic heat, yellowing, browning decay and C_2H_4 sensitivity and production occurs.
- MAP maintains the quality in terms of color, flavors, moisture and maturity retention occurs.
- It delays softening and compositional changes.
- Deterrence of chilling injury is common.
- Decrease in production and storage cost due to better utilization of space, labour and equipment.
- Little or no need for chemical preservatives.
- Expanded distribution area and reduced transport costs due to less frequent deliveries is possible.
- It provides clear visibility of commodity in the package.

Disadvantages

- Additional investment in terms of machinery and labour is required which adds as additional investment in the packaging system.
- Improper packaging or temperature can cause spoilage of produce (Table 6 and 7).
- Plastic films used in MAP causes environmental degradation unless effective recycling is established.
- Capital cost of gas packaging machinery.
- Cost of gases and packaging materials.

Table 5: Optimum conditions of MA/CA for some horticultural products and their life span.

Stored Commodity	Temperature (°C)	Optimum MA conditions		Optimum CA conditions		Marketable life indays		MA/CA storage benefits	Commercial benefits
		%O_2	%CO_2	%O_2	%CO_2	MA storage	CA storage		
Apple	0-3	3	3	2	10	200	300	Maintains firmness and acidity	Excellent
Avocado	7	2-5	3-10	1	15	12	56	Delays softening	Good
Banana	12-15	2	5	1	8	21	60	Suppression ofclimacteric pattern	Excellent
Grapes	0-2	3-5	1-3	1	10	40	90-100	Disease control	Fair
Guava	12-15	2-5	2-5	2	12	15-20	45	Delays ripening and chilling injury	Good
Lemon	15	3-5	0-5	1	6	130	220	Green color retention	Good
litchi	0-5	3-5	3-5	2	14	20-30	2230	Delay in ripening	Good
Mango	13	3-5	5-8	2	8	14-28	21-45	Delay ripening	Good
Orange	5-10	10	5	5	5	42	84	Maintenance of firmness	Fair
Papaya	13	3-5	5-8	2	8	14-28	21-35	Less decay	Fair
Pears	0-1	2-3	0-1	1	2	200	300	Delays the flesh and core browning	Excellent
Pineapple	10-15	2-5	10	2	10	12	10-15	Reduces chilling injury	Fair
Strawberry	0	4-10	15-20	1	12	7	7-15	Less decay	Excellent

Table 6: Oxygen limit below which injury can occur for some fruits and vegetables

Minimum O_2 Concentration tolerated (%)	Horticultural Products
0.5orless	Chopped redleaf, greenleaf, Romaine andiceberg lettuce, sliced pear, spinach, broccoli,mushroom
1	Apricot, avocado, banana, cherimoya, atemoya, sweet cherry, cranberry, grape, kiwifruit, litchi, nectarine, peach, plum, rambutan,sweetsop,Broccoli florets, sliced apple, chopped butterhead lettuce, cantaloupe, Brussels sprouts, cucumber,crisphead lettuce, onion bulbs,
1.5	Most apples, mostpears
2	Blackberry, durian, fig, mango, olive, papaya, pineapple, pomegranate, raspberry,strawberry, Shredded and cut carrots, artichoke, cabbage, cauliflower, celery, bell and chili pepper, sweet corn, tomato,
2.5	Blueberry, Shredded cabbage
3	Apples and pears, grapefruit,persimmon,Cubed or sliced cantaloupe, lowpermeability
4	Slicedmushrooms
5	Green snap beans, lemon, lime,orange
10	Asparagus
14	Orange sections

Kader 1997; Saltveit 1997; Mangraj and Goswami, 2009 [9, 15].

Table 7: Carbon dioxide limit above which injury can occur for some fruits and vegetables

Maximum CO_2concentration tolerated (%)	Horticultural Products
2	Lettuce (crisphead),pear
3	Artichoke, tomato
5	Apple (mostcultivars),apricot,cucumber, grape, nashi, olive, orange, peach (clingstone), cauliflower, potato, pepper(bell)
7	Banana, kiwi fruit, bean (green snap),
8	Papaya
10	Asparagus, brussels sprouts, celery, grapefruit, lemon, lime, mango, nectarine, peach (freestone), persimmon, pineapple, sweetcorn, cabbage
15	Avocado, pomegranate, Broccoli, lychee, plum, sweetsop
20	Cantaloupe (muskmelon), durian, mushroom,rambutan
25	Blackberry, blueberry, fig, raspberry,strawberry
30	Cherimoya

Kader 1997; Saltveit 1997; Mangraj and Goswami, 2009 [9, 15].

Conclusions

The paper concludes that MAP and related technology can be used to tackle problems associated with the storage of harvested fruits and vegetables thereby curbing post-harvest losses. Oxygen, CO_2 and N_2 gases are mainly used in modified atmosphere packaging. Gas concentration inside the MAP differs with behavior of produce. MAP can successfully be used to reduce the rate of respiration and inhibit ripening. It helps to enhance storage life and maintain the quality of highly perishable commodity and minimally processed fruits and vegetables. MAP contains higher in CO_2 and lowers in O_2; depending upon the characteristics of the commodity and the packaging film. Storage temperature, variety of the commodity, growing area and condition and field injury to the product influences the respiration rate of fruits and vegetables. MAP increases the life of agricultural commodity from several days to weeks as compared to conventional storage system. This technology is required for commercial application by processors and retailer (fresh produce retailers).

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