Modified Atmosphere Packaging; A Progressive Technology for Shelf-Life Extension of Fruits and Vegetables

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ABSTRACT

Packaging and storage are the final phases in the food industry. Quality preservation, improving safety and reduction of postharvest losses waste are some objectives of the packaging engineering. One of techniques that widely used in packaging of fruits and vegetables are modified atmosphere packaging (MAP). In MAP for fresh fruits and vegetable the air of packaging headspace replaces with a predetermined atmospheric gases different in proportion from that of air. Oxygen, carbon dioxide and nitrogen are the main gases used in MAP for injection to the headspace of pack. The choice and ratio of gases are very dependent upon the material that being packed. respiration rate of crop, O_2 *and* CO_2 *permeability of package material, volume of headspace present inside the package and storage temperature are some factors that affect the quality of MA packaging. Polymeric films are widely used in MAP engineering. The most application of polymeric films for MAP are in flexible package structures. In many cases the plastic packaging films are combined with one another or with other materials such as paper or aluminum through coating, lamination, coextrusion and metallization processes. The equipment used in MAP is divided into two main categories: pillow wrap and chamber. Flexible pillow wrapping machines are composed of Horizontal Form-Fill-Seal (HFFS) machines and Vertical Form-Fill-Seal (VFFS) systems. This paper reviews some recent developments in MAP technology applied for fruits and vegetables.*

Key Words*:*

Modified atmosphere packaging, Fruits, Vegetables, Shelf-life, Headspace, Polymeric films, MAP equipment.

INTRODUCTION

Packaging is an inevitable component of the food processing, for assuring the safe handling and delivery of fresh and processed agricultural products from producer to the consumer (Opara and Mditshwa, 2013). Quality preservation, improving safety and reduction of postharvest losses waste are some objectives of the packaging engineering. Agricultural products packaging is rooted in man's advancement in the production and processing of crops (Sacharow & Griffin, 1970). Along with these developments, humans invented methods to protect food products from dirt and damage. Utilization of natural containers made from tree trunks or rocks, gourds, shells, leaves, papyrus, woven twigs, animal hides, animal parts such as bladders or horns, and pieces of bark are some techniques that were invented for foods storage (Sacharow & Griffin, 1970; Kelsey, 1989, Opara and Mditshwa, 2013). The limitations of these containers led to the development of textile, wood, glass, and ceramic containers. Tinplate was invented in approximately 1200 A.D., leading to the fabrication of soldered metal boxes for storage. The next 7 centuries saw improvements in the manufacture of wood, paper, metal, ceramic, and glass packaging materials that ultimately led to advancements in food preservation. Eventually, packaging progressed to inventions such as the metal can by Durand in 1810 leading to the beginnings of the canning industry. In the 1840s, Pasteur found that microorganisms were the main reason of food spoilage and that heat and sterilization by steam could inactivate these organisms. During the early twentieth century, substantial improvements were made to both rigid and flexible packaging materials. The first commercial aluminum foil was rolled after 1910 and cellophane film was given heat sealability and resistance to moisture during the 1920s. During the 1950s, rubber and adhesive components were made available, heat-shrinkable polyvinyl chloride (PVC) was introduced, nylon was integrated into packaging films, steel cans were modified with coatings, cans were developed with aluminum alloys, and improvements were made to the formation of cans used in food processing. In the 1960s and 1970s, most of the major packaging accomplishments involved the development of plastic jars, bottles, tubs, and films from polyolefins, polyvinyl, polyethylene, vinylidene, vinylchloride, surlyn, and nylon. Based on sealability, tensile strength, rigidity, temperature, water barrier, vapor, and moisture properties, the use of plastic products for food storage is limitless. In addition to plastic, researchers have demonstrated that edible films can be processed from soy proteins, chitin, corn zein, starch, cellulose, and milk proteins (Opara and Mditshwa, 2013).

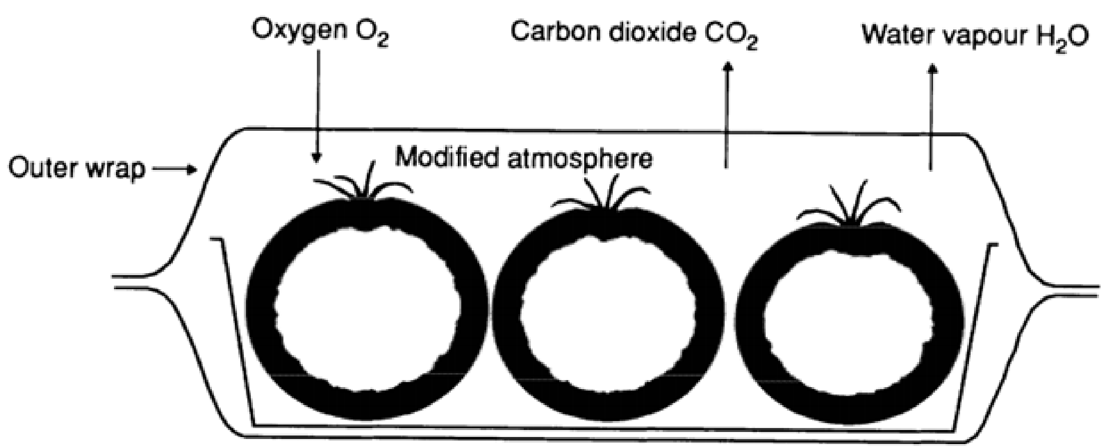
Many foods (specially fruits and vegetables) spoil rapidly in air due to moisture loss or uptake, reaction with oxygen and the growth of aerobic microorganisms. Microbial growth results in changes in texture, color, flavor and nutritional value of these products. Storage of crops in a modified gaseous atmosphere can protect quality and extend product shelf life, by slowing chemical and biochemical deteriorative reactions and by slowing the growth of spoilage organisms (Coles et al., 2003).

MODIFIED ATMOSPHERE PACKAGING

Modified atmosphere packaging known as MAP technology and controlled atmosphere storage (CAS) are novel techniques that are widely applied for preservation of agricultural products especially for fruits and vegetables. These techniques are used to supplement low temperature management to delay ripening, reduce physiological disorders, and suppress decay in many fresh fruit and vegetable (Smith et al., 1987; Kader et al., 1989). MAP is defined as 'the packaging of a perishable product in an atmosphere which has been modified so that its composition is other than that of air' (Hintlian & Hotchkiss, 1986;

Coles et al., 2003), whereas controlled atmosphere storage (CAS) involves maintaining a fixed concentration of gases surrounding the product by careful monitoring and addition of gases, the gaseous composition of fresh MAP foods is constantly changing due to chemical reactions and microbial activity. Gas exchange between the pack headspace and the external environment may also occur as a result of permeation across the package material (Coles et al., 2003). The first use of MAP was in transportation of lamb meat from Australia to England in the early 12th century. Then, the first application of MAP was reported in extending the shelf life of apples in an atmosphere with reduced O_2 and increased CO_2 concentrations in 1927 (Phillips, 1996). MAP is divided into passive and active condition. In passive MAP, respiration rate of crop and permeability of the packaging film are the most parameters. Because of the respiration of food material, the consumption of oxygen is proportional to carbon dioxide production in the atmosphere packaging. After a certain time, gas composition in the package of fresh product reaches a definite balance between respiration rate and permeability of packaging film. In equilibrium state, the total amounts of carbon dioxide produced and oxygen consumed by respiration are the same as that permeated through the membrane exchange. Active modification involves the air evacuation within the pack and then replacing the atmosphere with the desired gas mixture to accelerate gas composition modification and to avoid product exposure to high concentrations of unsuitable gases (Zhang et al., 2014). Figure 1 shows a schematic diagram of a modified atmospheric packaging.

The basic idea of the MAP technique of fresh fruits and vegetable is the replacement of the air of packaging headspace with a predetermined atmospheric gases different in proportion from that of air (Parry, 1993). Oxygen, carbon dioxide and nitrogen are the main gases used in MAP for injection to the headspace of pack. The choice and ratio of gases are very dependent upon the material that being packed. These gases are used to balance safe shelf-life extension with optimal organoleptic properties of the product. Temperature control should be considered extremely in MAP design, as this will influence the gas permeability properties of the film. Also respiration rate of the product is highly



Produce respiration $nO_2 + (CH_2O)n \quad nCO_2 + nH_2O$

Figure 1. Biochemical and physical processes occurring in a modified atmosphere pack (Paine and Paine, 1992).

affected by temperature. Biological reactions generally increase two to three-fold for every 10 °C rise in temperature. Therefore temperature control is vitally important in order for a MAP system to work effectively. Film permeability also increases as temperature increases (Ščetar et al., 2010).

Each packaging design has to be optimized for a specific crop, since the behavior of agricultural products are different and also MA packages are dynamic systems during which respiration and permeation occur simultaneously. Factors affecting both respiration and permeation must be considered for package designing (Cameron et al., 1989; Mannapperuma et al., 1989; Yam and Lee, 1995; Jacxsens et al., 2000). Food mass inside the package, storage temperature, oxygen, carbon dioxide and ethylene partial pressures and stage of maturity are factors influencing respiration in a package (Kader et al., 1989; Ben-Yehoshua et al., 1994; Das, 2005). Type, thickness, and surface area of the packaging film that is exposed to atmosphere and across which permeation of O_2 and CO_2 takes place, volume of headspace present inside the package, temperature, relative humidity, and gradient of oxygen and carbon dioxide partial pressures across the film affect permeation (Ashley, 1985; Renault et al., 1994; Kader, 1997; Das, 2005). In MAP designing it is required to determine intrinsic properties of the produce such as respiration rate, optimum O_2 and CO_2 concentrations, and film permeability characteristics (Cameron et al., 1989; Talasila and Cameron, 1993). Table 1 shows optimum gaseous environment and recommends storage temperature for quality retention and shelf-life extension of some fruits and vegetables.

GASES USED IN MAP

Carbon Dioxide

Carbon dioxide is a colorless gas, an asphyxiant and slightly corrosive in the presence of moisture. CO_2 dissolves readily in water (1.57 g/kg at 100 kPa, 20 °C) to produce carbonic acid (H_2CO_3) that increases the acidity of the solution (Coles et al., 2003). Carbon dioxide has a powerful inhibitory effect on bacterial growth. It is particularly effetive against gram-negative, aerobic spoilage bacteria. However, carbon dioxide does not retard the growth of all types of microorganisms. The inhibitory effect of carbon dioxide is increased at lower temperatures because of its increased solubility (179.7 ml per 100 ml water at 0°C). Carbon dioxide permeates packaging film up to thirty times faster than any other gas used for the packaging of products (Parry, 1993).

Oxygen

Oxygen is probably the most important gas in food deterioration being used metabolically by both aerobic spoilage microorganisms and plant tissues and taking part in some enzymic reactions in agricultural products. Therefore, in MAP, oxygen is either excluded or the levels set as low as possible. The exceptions occur where oxygen is needed for fruit and vegetable respiration (Parry, 1993).

Nitrogen

Nitrogen is a relatively un-reactive gas with no odor and color and with a low solubility in both water and fat. It is commonly used in MAP to displace oxygen. It can also indirectly influence the microorganisms in perishable foods by retarding the growth of aerobic spoilage organisms. The third role of nitrogen is to act as a filler and prevent package collapse in foods that absorb carbon dioxide (Parry, 1993). It has a lower density than air, non-flammable and has a low solubility in water (0.018 g/kg at 100 kPa, 20°C) and other food constituents (Coles et al., 2003).

Other Gases

The potential of various other gases such as ethylene oxide, nitrogen dioxide, ozone and sulphur dioxide for MAP have been investigated experimentally but their commercial use for packaging foods

	Products	Temperature (°C)	Recommended modified atmosphere		Potential
			O_2 (%)	CO_2 (%)	
Fruits					
	Apple	0–5	1–3	1–5	Excellent
	Apricot	0–5	2–3	2–3	Fair
	Avocado	5–13	2–5	3–10	Good
	Banana	12–15	2–5	2–5	Excellent
	Cherry, sweet	0–5	3–10	10–15	Good
	Fig	0–5	5–10	15–20	Good
	Grape	0–5	2–5	1–3	Fair
	Grapefruit	10–15	3–10	5–10	Fair
	Kiwi fruit	0–5	1–2	3–5	Excellent
	Lemon and lime	10–15	5–10	0–10	Good
	Mango	10–15	3–5	5–10	Fair
	Olive	5–10	2–3	0–1	Fair
	Orange	5–10	5–10	0–5	Fair
	Peach and nectarine	0–5	1–2	3–5	Good
	Pear	0–5	1–3	0–3	Excellent
	Persimmon	0–5	3–5	5–8	Good
	Plum	0–5	1–2	0–5	Good
	Raspberry and other cane berries	0–5	5–10	15–20	Excellent
	Red currant	0–2	5–10	15–20	Excellent
	Strawberry	0–5	5–10	15–20	Excellent
Vegetables					
	Asparagus	0–5	Air	5–10	Excellent
	Bean	5–10	2–3	4–7	Fair
	Broccoli	0–5	1–2	5–10	Excellent
	Brussels sprout	0–1	2–4	4–6	Excellent
	Cabbage	0–5	2–3	3–6	Excellent
	Cantaloupe	3–7	3–5	10–15	Good
	Celery	3–5	1–4	0–5	Good
	Chicory	5	2–3	5–10	Excellent
	Corn (sweet)	0–5	2–4	5–10	Good
	Cucumber	8–12	3–5	0	Fair
	Leek	0–5	1–2	3–5	Good
	Lettuce	0–5	1–3	0	Good
	Onion	0–5	1–2	2–5%	Good
	Pepper	8–12	3–5	0	Fair
	Spinach	0–5	Air	0–20	Good
	Tomato	12–20	3–5	0–3	Good

Table 1. Recommended modified-atmosphere conditions for some fruits and vegetables. (Adapted from Kader et al., 1998; Gorris and Peppelenbos, 1999; Rahman and Amad, 2012)

needs approval from the regulatory authorities. For instance, carbon monoxide is a gas that is highly reactive and very flammable. It has a low solubility in water but is relatively soluble in some organic solvents and its commercial application has been limited because of its toxicity and the formation of potentially explosive mixtures with air (Parry, 1993). Also the noble gases are a family of elements characterized by their lack of reactivity. These gases have been applied in some foods. While from a scientific perspective, it is difficult to see how the use of noble gases would offer any preservation advantages compared with N_2 they are being used (Coles et al., 2003).

APPLICATIONS OF POLYMERIC FILMS FOR MAP OF FRUITS AND VEGETABLES

MA packaging of commodity refers to the technique of sealing actively respiring produce in polymeric film packages to modify the O_2 and CO_2 levels within the package headspace (Mangaraj et al.,2009). Polymeric films have been used to package fresh products for over 35 years (Ščetar et al., 2010). The most application of polymeric films for MAP are in flexible package structures (Mangaraj et al., 2009). The most commonly used polymeric films for MAP are Polyolefin, Low-Density Polyethylene (LDPE), Linear Low-Density Polyethylene (LLDPE), High-Density Polyethylene (HDPE), Polypropylene (PP), Polyvinyl Chloride (PVC), Polyesters, Polyethylene Terephthalate (PET), Polyvinylidene Chloride (PVDC), Ethylene-Vinyl Alcohol (EVOH), Polyamide (Nylon), Polychlorotrifluoroethylene (PCTFE), Polyvinyl Alcohol (PVOH), Ethylene-Vinyl Acetate (EVA), Ionomers, Polycarbonate Films, Polystyrene, Cellulose-Based Plastics., Biodegradable Polymers (Couzens and Yearsely, 1956; Karel et l., 1975; Sacharow and Griffin, 1980; Crosby, 1981; Salame, 1986; Burton et al., 1987; Kader et al., 1989; Berins, 1991; Exama et al., 1993; Parry, 1993; Maier, 1995; Prasad, 1995; Kong, 1997; Hernandez et al., 2000; Lange, 2000; Abdel-Bary, 2003; Ahvenainen, 2003; Massey, 2003; Del Nobile et al., 2007; Marsh and Bugusu, 2007; Mangaraj et al.,2009). Although an increasing choice of packaging materials is available to the MAP industry, most packs are still constructed from four basic polymers: polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyproylene (PP) and polyethylene (PE), for packaging of fruits and vegetables (Kader et al., 1989; Calderon and Barkai-Golan, 1990; Exama et al., 1993; Prasad, 1995; Kader and Watkins, 2001; Van Willige, et al., 2002; Ahvenainen, 2003; Marsh and Bugusu B, 2007; Mangaraj et al.,2009). These materials provide a range of permeability to gases and water vapor together with the necessary package integrity needed for MAP (Table 2 and Table 3). Sometimes, the packaging films, do not singly offer all the properties required for a MAP and to achieve the best properties of polymeric films, a combination of materials is used. Therefore, in these cases the plastic packaging films are combined with one another or with other materials such as paper or aluminum through coating, lamination, coextrusion and metallization processes (Mangaraj et al., 2009).

T_g : Glass transition temperature (°C)

T_m : Melting temperature (°C)

T_h : Heat distortion temperature, at 455 kPa (°C)

F_T : Tensile strength (Mpa)

$WVTR$: Water vapor transmission rate at 37.8°C and 90% RH (g µm/m^2 day)

P_{O_2} and P_{CO_2} : permeability at 25°C for O_2 and CO_2 respectively (cm^3 µm/m^2 -h-atm)

$E^P_{O_2}$ and $E^P_{CO_2}$: permeability activation energy of films for O_2 and CO_2, respectively (kJ/mole)

$Q_{10}^{P_{O_2}}$ and $Q_{10}^{P_{CO_2}}$: permeability quotients for 10°C rise in temperature of films for O_2 and CO_2 respectively

Property	POLYETHYLENE FILMS			POLYPROPYLENE		POLYVINYL CHLORIDE	POLYETHYLENE TEREPHTHALATE (PET)		POLYVINYLIDENE CHLORIDE		ETHYLENE-VINYL ALCOHOL (EVOH)		POLYAMIDE	
	LDPE	LLDPE	HDPE	PP	BOPP	PVC	Unoriented	Oriented	General purpose	High barrier	32 mol % ethylene	44 mol % ethylene	Nylon-6	Nylon-11
T_g (°C)	-120	-120	-120	-10	-10	75-105	73-80	73-80	-15 to +2	-15 to +2	69	55	60	-
T_m (°C)	105–115	122–124	128-138	160-175	160-175	212	245-265	245-265	160-172	160-172	181	164	210-220	180-190
T_h	40–44	-	62-91	107-121	-	57-82	38-129	-	-	-	-	-	-	-
Density (g/cm^3)	0.915–0.94	0.915–0.935	0.94-0.97	0.89-0.91	0.89-0.91	1.35-1.41	1.29-1.40	1.4	1.6-1.71	1.73	1.19	1.14	1.13-1.16	1.03-1.05
Tensile modulus (Gpa)	0.2–0.5	-	0.6-1.1	1.1-1.5	1.7-2.4	To 4.1	2.8-4.1	-	0.3-0.7	0.9-1.1	2.6	2.1	0.69-1.7	1.3
FT (Mpa)	8–31	20–45	17-45	31-43	120-240	10-55	48-72	220-270	48-100	83-148	77	59	41-165	55-65
Elongation (%)	100–965	350–850	10-1200	500-650	30-150	14-450	30-3000	70-110	40-100	50-100	230	380	300	300-400
WVTR	375–500	-	125	100-300	100-125	750-15700	390-510	440	79	20	1535	724	3900-4300	1000-2000
P_{O_2}	6666–8750	2916–8333	1666-3041	2083-3916	1541-2416	154-10000	50-100	45	13-18	1.3	0.325	1.25	20-42.5	521
P_{CO_2}	41662–54687	15105-43165	9979-18215	11706-22008	8368-13119	939-61000	255-510	221	62-86	4.95	10.10	37.5	84-179	2084
$\frac{P_{CO_2}}{P_{O_2}}$	6.25	5.18	5.99	5.62	5.43	6.1	5.1	4.91	4.76	3.81	31.0	30.0	4.21	4.0
$E^P_{O_2}$	35.1	37.4	43.1	39.5	38.3	40.5	56.8	60.4	66.5	73.2	-	-	43.5	47.60
$E^P_{CO_2}$	30.3	31.6	34.3	32.7	33.9	30.5	40.4	42.8	51.5	56.7	-	-	40.5	42.40
$Q_{10}^{P_{O_2}}$	1.96	1.84	1.73	1.81	1.77	1.78	1.52	1.5	2.82	2.87	-	-	1.97	-
$Q_{10}^{P_{CO_2}}$	1.71	1.65	1.6	1.62	1.58	1.54	1.5	1.47	2.23	2.26	-	-	1.88	-

Table 2. Major packaging films and their typical properties (Mangaraj et al., 2009).

TYPE OF FILMS	PRODUCT CHARACTERISTICS / FOOD COMPATIBILITY		CONSUMER & MARKETING ISSUES		ENVIRONMENTAL ISSUES		COST
	Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	
LDPE	Soft, flexible and strong material Good moisture barrier Resistance to chemicals Heat sealable and easy to seal Relatively transparent and predominantly used in film application High ratio of CO_2 to O_2 permeability Can be laminated and coextruded		Light weight	Sight haze or translucency	Recyclable	Easily recycled in semi-rigid form but identification and separation more difficult for films	Low cost
LLDPE	Soft, flexible and strong material Better impact strength, tear resistance and higher tensile strength and elongation, better resistance to environmental stress cracking, and better puncture resistance Good moisture barrier Good grease resistance and inert. Good low-temperature performance	Not suitable for applications involving significant exposure to heat.	Light weight	Sight haze or translucency	Recyclable	Easily recycled in semi-rigid form but identification and separation more difficult for films	Low cost
HDPE	Flexible, strong and tough Higher softening point than LDPE and superior barrier properties Resistance to chemicals and moisture Permeable to gases Easy to process and easy to form	Poor clarity	Light weight	Sight haze or translucency	Recyclable	Easily recycled in semi-rigid form but identification and separation more difficult for films	Low cost
Polypropylene (BOPP)	Stronger, denser and more transparent than polyethylene Moderate gas barrier and good water vapour barrier (high gas barrier and moisture vapour barrier than polyethylene) Excellent grease resistance Favorable response to heat sealing		Light weight High clarity, strength and durability as compared to LDPE		Recyclable	Easily recycled in semi-rigid form but identification and separation more difficult for films	Low cost
Polyesters (PET/PEN)	Excellent transparency and mechanical properties Good/adequate barrier to gases and moisture and specially odors' and flavors Good resistance to chemical degradation, heat, mineral oil, solvents and acids.		Light weight High clarity/ glass-like transparency Shatter resistance		Recyclable	Easily recycled in semi-rigid form but identification and separation more difficult for films	Inexpensive but higher cost among plastics
Polyvinyl chloride (PVC)	Strong and transparent Good gas barrier and moderated barrier to moisture vapour Excellent resistance to chemicals, oils/fats and grease etc. Largely used as packaging films		High clarity		Recyclable	Contains chlorine Requires separating from other waste	Inexpensive
Polyvinylidene chloride (PVdC)	High barrier to gases and water vapor Heat sealable Also used in hot filling, retorting, low-temperature storage, etc.	High gas barrier	Maintains product quality		Recyclable	Contains chlorine Requires separating from other waste	Expensive but higher cost among plastics

TYPE OF FILMS	PRODUCT CHARACTERISTICS / FOOD COMPATIBILITY		CONSUMER & MARKETING ISSUES		ENVIRONMENTAL ISSUES		COST
	Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	
Polystyrene	High tensile strength and excellent transparency Used for produce where a 'breathable' film is required	Poor barrier to moisture vapor and gases	Good clarity		Recyclable	Requires separating from other waste	Inexpensive
Polyamide (nylon-6)	Strong Reasonably good oxygen barrier Excellent odor and flavor barrier Good chemical resistance Mechanical and thermal properties similar to PET Excellent high-temp. performance	Poor barrier to moisture vapor			Recyclable	Requires separating from other waste	Relatively costly but inexpensive when used as thin films
Ethylene-vinyl alcohol (EVOH)	Excellent barrier to gases, especially to oxygen, odor and flavor Often used as O_2 barrier material	Low moisture barrier/moisture sensitive	Maintains product quality for oxygen-sensitive products		Recyclable	Requires separating from other waste	Inexpensive when used as thin films
Ethylene-vinyl acetate (EVA)	Excellent transparency Very good heat seal Very good adhesive properties	Poor gas barrier Poor moisture barrier	Excellent clarity Mainly used as component of the sealant layer and adhesive in multilayer films		Recyclable	Requires separating from other waste	Inexpensive
Polylactide (PLA)	Biodegradable Hydrolysable		Suitable for MAP of fresh produce		Recyclable	Requires separating from other waste	Relatively expensive
Laminates/ Coextrusions	Properties can be tailored for product needs		Flexible in design and characteristics		Often allows for source reduction	Layer separation is required	Relatively expensive but cost-effective for purpose.

For selecting the packaging materials, considering the following parameters would be helpful (Mangaraj et al., 2009):

- The type of package (i.e. flexible pouch or rigid or semi-rigid lidded tray)
- The barrier properties needed (i.e. permeability of individual gases and gas ratios when more than one gas is used)
- The physical properties of machinability, strength, clarity and durability
- Integrity of closure (heat sealing), fogging of the film as a result of product respiration.
- Sealing reliability
- Water vapor transmission rate
- Resistance to chemical degradation
- Nontoxic and chemically inert
- Printability
- Commercial suitability with economic feasibility

Three types of polymeric films have been developed for MAP (Mangaraj et al., 2009):

- Microperforated or non-perforations polymeric films
- Macroperforated polymeric films.
- Perforation-mediated packaging systems.

The microperforated films allow the rapid development of proper CO_2 and O_2 concentrations in the package headspace to extend produce shelf-life (Kartal et al., 2012). The gas permeability of a microperforated film is controlled by the number and dimensions of the perforations. By altering the size and density of the micro hole, packaging films with specific flow rates can be adjusted for a specific product. The size of the perforations normally used in MAP is between 50 and 200 μm in diameter (Kartal et al., 2012). These materials are suitable for less CO_2 tolerant commodities such as mango, banana, grapes and apples. The gas permeability in microperforated polymeric films is temperature dependent and this dependence is commonly described by Arrhenius-type equations (Exama , et al., 1993; Mahajan et al., 2007).

Perforated films have higher permeability rate than those of microperforated materials. Such films are used for commodities tolerating simultaneously low O_2 and high CO_2 levels such as fresh-cut products and commodities having high respiration rate (Fonseca et al., 2000; Montero et al., 2008; Rediers et al., 2009) The package headspace dynamics vary with the number of macroperforations. This technique is simple and involves only the punching of desired macroperforations in the ordinary film package to affect higher gaseous diffusion across the film packages. However, the attainment of ideal steady-state headspace partial pressures of O_2 and CO_2 under any type of MAP is still a difficult task in the design of MAP and often requires repetitive experimentation; which increases the cost of experiment (Rai and Singh, 2012).

The perforation mediated MAP does not require very high technical knowhow and holds enough promise for storage of perishable commodities. It has been successfully tried by researchers for enhancing the shelf life of commodities like button mushroom, oyster mushroom, shiitake mushroom (Dhalsamant et al., 2015). In the perforation-mediated packaging system the regulation of the gas exchange is achieved by single or multiple tubes that perforate an otherwise impermeable packaging material. From an engineering point of view, the transport of gases through perforations is a complex phenomenon that involves diffusion gradients together with co-current transport of multiple species, with oxygen entering the package and carbon dioxide leaving it. It is also a good solution for packing high-respiring products, due to the high gas exchange rates and low permeability coefficients achieved (Montanez et al., 2010).

MAP MACHINERY

In the late 1950s and early 1960s, the first efforts were made to develop the commercial use of MAP that resulted in the development of equipment for industrial use. Afterwards, another useful technique called vacuum packaging was presented. In this phase, the production of efficient, safe, and low-cost machinery was very important. Next researches and innovations in this field led to manufacture of different machines and equipment for MAP (Arvanitoyannis, 2012; Brody et al., 2011; Parry, 1993). Recent advances in micro-electronics provides an accurate control of all machine functions in packaging industry including temperature settings and movement of the web through the machine so that the optimum results can be achieved. The control of these functions has enabled some very complex material structures to be handled (Parry, 1993).

MAP equipment is divided into two main categories: pillow wrap and chamber. Flexible pillow wrapping machines are composed of Horizontal

Form-Fill-Seal (HFFS) machines and Vertical Form-Fill-Seal (VFFS) systems.

Chamber machines can use two different techniques. The first is the thermoforming technique. In the second technique, ready containers can be used for the packaging of products named preformed container machines (Blakistone , 1999; Arvanitoyannis, 2012).

Thermoforming Machines

The thermoforming technique involves the use of a rigid or semi-rigid base material which is fed from a reel into grippers or clamps held on chains running either side of the web and the length of the machine. In the heating section, the material is heated to the point that can be treated. Then, the treated material is transferred to a forming station. The next step in this procedure is the cooling of the material and its transfer to the product loading area. modification of headspace in the packages can be carried out by air extraction and gas flushing into the trays (Arvanitoyannis, 2012). Figure 2 shows a packing process in a thermoforming machine.

Preformed Container Machines

Performed container machines or tray sealers and thermoforming machines seem to be similar to each other. The preformed trays used for packaging are fed to machine and the product is loaded. The tray and the material of the top lid are then transferred to the atmosphere modification chamber.. It should be added that the top lid is heat-sealed (Arvanitoyannis, 2012). This type of machines are divided in to three groups; Automatic machines, Semi-automatic machines and Gas flushing without evacuation (Blakistone, 1999).

HFFS

HFFS machines have been invented for many years and are used in many applications to pack a wide variety of products in pillow-pack style (Figure 3). These machines have been developed for the specific requirements of MAP whilst retaining the considerable flexibility associated with non-MAP machines (Blakistone, 1999). Typically, to perform MA packages, a roll of polymeric film is used. The roll passes through a forming collar, named the folding box, then it is transformed into a tube and the two edges of which are sealed together by heated rollers under a definite pressure. The food material is then passed through the tube in different ways depending on its nature. Gas flushing is used for atmosphere modification by a lance that is entered in the tube when the HFFS machine is operated (Arvanitoyannis,

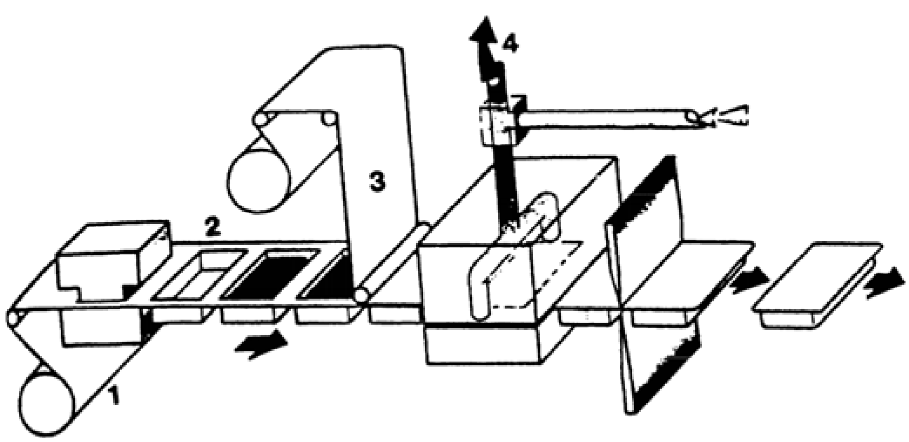


Figure 2. Thermoforming packaging machine fed from two film coils. One inner thermoformable film (1) is formed into a tray (2). The food product is placed in this tray covered by an upper film (3). A vacuum is created in the tray (4), and broken by the gas mixture just before the upper film is sealed (Paine and Paine, 1992).

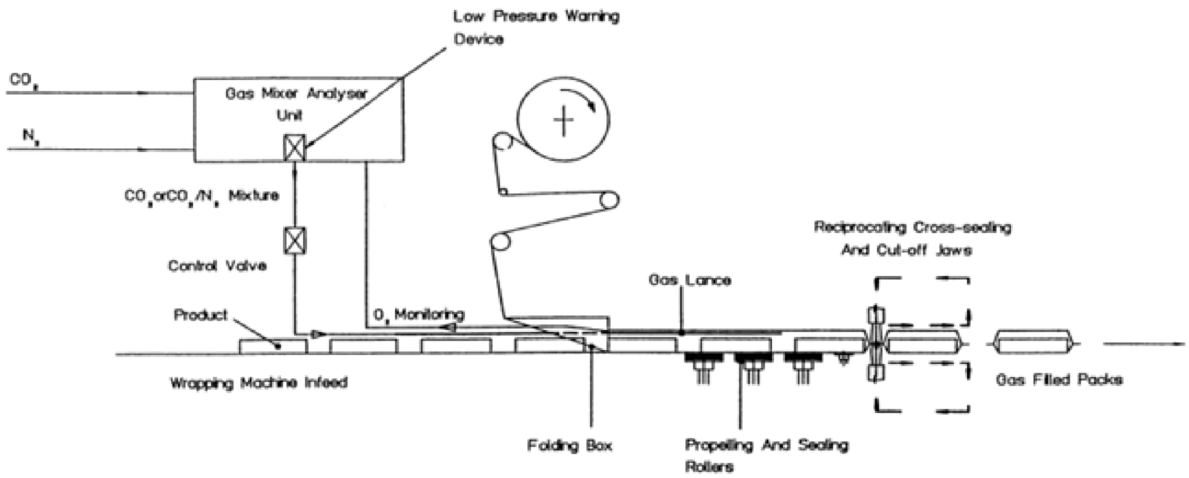


Figure 3. a schematic diagram of horizontal form-fill-seal machine with box-motion sealing head (Blakistone, 1999)

2012; Blakistone, 1999). The box motion cross sealing unit is designed to extend the dwelling time by which the cross sealing jaws that are in contact with the polymeric film, so it can be able to transfer more heat and long-time press into the film as opposed to increasing temperature which can potentially melt the film. To make a box motion unit separate actuators (servo or pneumatic) must be used for the horizontal and vertical motions allowing a variable amount of jaw separation and dwell distance to be achieved. A knife, integral with the sealing jaws, cuts through adjacent packs to produce the separation.

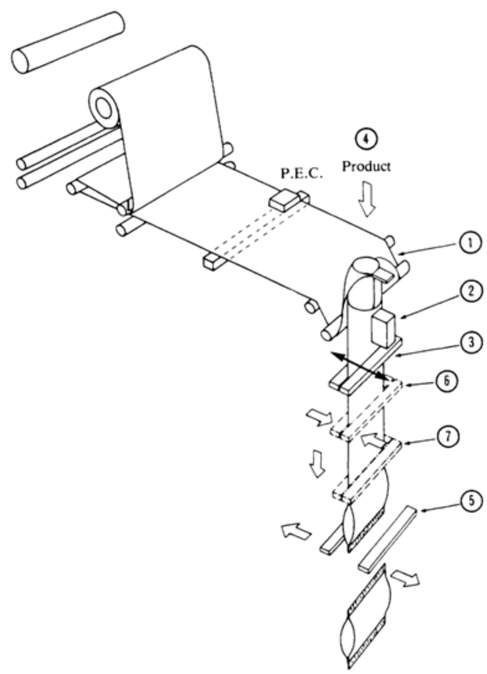


Figure 4. VFFS machine; 1, film from reel made into a tube over forming shoulder; 2, longitudinal seal made; 3, bottom of tube closed by heated crimped jaws which move downwards drawing film from reel; 4, predetermined quantity of product falls through collar into pouch; 5, jaws open and return on top of stroke; 6, jaws partially close and 'scrape' product into pouch out of seal area; 7, jaws close, crimp heat seal top of previous pouch and bottom of new one. Crimp sealed container cut off with knife (Paine and Paine, 1992).

Machinery Selection and Specification

To specify a MAP equipment, many factors should be established to properly facilitate the process based on the nature of the product and the market requirements. Some of these parameters are quality, cleanability, throughput, flexibility, operating cost, processing yield and equipment price. The chamber type of machine gives a better minimum residual oxygen content in the headspace as compared with the continuous flushing systems. However, this is unacceptable when handling fragile products. Pillow wrapping machines and similar which employ continuous gas flushing pose a fire hazard because of the venting of high levels of oxygen into the area surrounding the machine. The packaging machine must be able to give consistent and reliable seals minimizing pack leakers, achieve the desired gas content of the pack and be quickly and efficiently adaptable to meet production requirements. A wide choice is available to the product packer intending to enter MAP (Table 4).

Type of system	Description	Application
Thermoforming/ chamber	Heat forming of rigid, semi-rigid and flexible materials. 'Atmospack'. Vacuum with gas flushing	Meat, poultry, fish, cooked meats, bakery, pet foods, cheese, nuts
Horizontal and vertical form-fill-seal. Pillow pack	Single flexible web. Gas flushing by lance, venting to atmosphere	Bakery, snack foods, cheese, coffee, nuts, meat, fish, salads, fruit, vegetables
Preformed tray or bag	Use of HOPE, PET or HIPS trays. Preformed plastic bags. Vacuum with gas flushing	Meat, fish, nuts, prepared meals
Thermoforming composite boardl plastic tray or preformed board/ plastic tray	Carton blank and plastic tray form composite tray structture with in-line lidding and MAP. Vacuum with gas flushing	Meat, poultry, fish, cooked meats, fruit, vegetables, cheese, ready meals, bakery, salads
Bag-in-box	Barrier or non- barrier bag into corrugated or solid board case. Vacuum with gas flushing	Meat in bulk, poultry, fruit, cheese, nuts, vegetables, dried powders.
Vacuum skin packaging	Multilayer film top web shrunk over product in easipeel forming bottom web. Gas in head space before lidding	Meat, fish
Cryovac shrink vacuum bags	Pre-made bags from PVdC coextruded materials with shrinking. Vacuum with gas flushing	Primal cuts of meat
Bivac vacuum shrink system	Two webs of ionomer film. Upper heated and shrunk over product on base web	Meat
Isopak vacuum skin system	Nylon/Surlyn top web and polyesterI Surlyn/board base. Product held by shrinking of top web	Meat, fish
Trayvac	Product placed on flexible web and rigid tray brought into contact followed by heat shrinking	Meat, fish, poultry
Bag-in-carton	Lined carton gas-flushed	Powders, granular products

Table 4. Some packaging systems for MAP (Parry, 1993)

RECENT ADVANCES AND RESEARCHES IN MAP

Mushroom is a highly perishable agricultural crop and its shelf-life is 1– 3 days at ambient temperature, due to high moisture content and high transpiration rate (Mahajan et al., 2008). Therefore, mushrooms need a special care to keep its quality and freshness, especially when they are minimal processed such as slicing (Iqbal et al., 2009). So a MAP technique seems to be helpful for preservation of mushroom. Oliveira et al. (2012) evaluated the effect of temperature and number of film perforations on quality and developed a shelf-life kinetic model for a MAP for sliced button mushrooms. They packed the sliced mushrooms in a tray, covered with cellophane film and stored for 7 days at four levels of temperature (0, 5, 10, and 15°C) and three levels of perforations at each temperature ranging the number of perforations from 1 (58 perforations per m^2) to 6 (349 perforations per m2). They measured headspace gas composition, weight loss, pH, firmness and colour of mushrooms throughout the storage period. They found that increasing the storage temperature required increasing of the number of perforations for having an optimum MAP conditions. Temperature had a significant effect on quality of sliced mushrooms, firmness was identified as a critical quality parameter and a kinetic model was developed to describe the influence of temperature on firmness and for prediction of shelf-life of sliced mushrooms. They resulted fresh sliced mushrooms had a shelf-life of 1, 2, 4, and 7.5 days at 15, 10, 5, and 0°C, respectively, under optimum MAP conditions. Also it was concluded that the shelf-life of fresh sliced mushrooms in an optimum package was found to be 7.5 and 4 days when stored at 0 and 5°C, respectively.

Jafri et al. (2013) performed a combination of chemical treatments and MAP for quality retention of oyster mushrooms (Pleurotus florida). Three techniques included chemical treatment, MAP and low temperature storage were developed for improvement of physico-chemical attributes of oyster mushrooms. Mushrooms were treated with a solution of sorbitol (0.05%, w/v), citric acid (3%, w/v) and CaCl2 (1%, w/v). They packed chemically treated mushrooms under two different gas compositions. Physico-chemical, textural and sensory properties of the samples were assessed as quality factors during storage at 4°C and for 25 days. Chemical treatment of mushrooms combined with MAP (5% CO_2, 10% O_2) resulted better retention of quality characteristics and higher sensory ratings compared to other samples. They suggested that a combination of chemical treatment and MAP has good promise in maintaining oyster mushroom quality and extending their postharvest life up to 25 days at 4°C. Another important observation made was that the use of chemical treatment alone was more effective than the use of MAP alone with either of the two gas compositions used in packaging headspace. Also they observed weight loss and senescence in the chemically untreated samples.

Effect of active MAP with different initial gas compositions was also investigated by Li et al. (2014) on fresh shiitake mushrooms. They packaged mushrooms at different conditions of high oxygen packaging (HOP) with 100% oxygen; medium oxygen packaging (MOP) with 50% O_2 and balanced with N_2; low oxygen packaging (LOP) with 3% O_2 and 5% CO_2 balanced with N_2 initially. They used passive MAP with air inside (AIR) as the control treatment and all packaged samples were stored at 10 °C with 90% RH for 7 days. During storage, changes in gas compositions, electrolyte leakage, crude water-soluble polysaccharides, total phenolic content and free amino acid content were determined. They resulted that ethanol release was high in LOP and AIR but retarded in MOP and HOP. Packaging could not prevent the polysaccharide content decreasing. Both the active and passive MAP maintained the color and integrity of the mushrooms. The active MAP effectively increased total phenolic content and total amount of free amino acids. Also, LOP had a harmful impact on mushrooms with high levels of electrolyte leakage. They proposed HOP and MOP for mushroom packaging because they had a better effect on maintaining the nutritional compounds of shiitake mushrooms.

Dhalsamant et al. (2015) applied perforation-mediated MAP for extending the shelf life of paddy straw mushroom. They kept mushroom specimens in packages both as untreated and treated with $CaCl_2$ to see the effect of $CaCl_2$ on mushroom in the MAP. The area of perforations were kept as 0, 3.4×10^{-4}, 6.8×10^{-4} and 1.02×10^{-3} % (0, 20, 40 and 60 perforations) in a package size of 175 mm × 110 mm. They observed that perforation mediated MAP effectively increased the shelf life of paddy straw mushroom to 6 days at 12°C (±1°C) as compared to 1–2 days for control. The firmness of both the cap and stem was better maintained with the pre-treated as well as untreated samples in 20 and 40 perforation packs. They recommended that the paddy straw mushroom should be treated with $CaCl_2$ (0.5%) and stored in 40 perforation packages in the specific package size at 12(±1) °C for extending the shelf life up to 6 days.

Gomes et al. (2012) applied MAP method to control quality changes of 'Rocha' pear. "Respiratory behavior of fresh-cut 'Rocha' pear suggests that optimization of O_2 concentration inside MAP is of limited benefit". To test this hypothesis, they carried out some experiments, packages were designed to achieve three equilibrium O_2 partial pressures. Fresh-cut 'Rocha' pear was treated with 250 mM calcium ascorbate solutions buffered at pH 3.0 and pH 7.0, packaged under the three MAP conditions, and stored at 5 °C for 20 days. Actual O_2 levels (mean ± confidence interval at 95%) during the experiment were 16.7 ± 0.2, 1.8 ± 0.2 and 0.25 ± 0.04 kPa with corresponding CO_2 levels of 1.3 ± 0.1, 4.3 ± 0.2 and 6.5 ± 0.4 kPa. Changes in quality attributes of fruit, firmness, titratable acidity, pH, and soluble solids content were not affected by O_2 levels. Overall changes in water activity, levels of ascorbate, and microbial growth were independent of O_2 levels. Oxygen partial pressure inside the packages affected browning, which was more intense at 16.7 kPa O_2. Browning was more intense at pH 3.0 than at pH 7.0 but the kinetics of other quality attributes were not affected by pH. No significant improvements of quality attributes dependent on the physiology of respiration of fresh-cut 'Rocha' pear can be obtained by reducing O_2 partial pressure inside the packages.

Wang and Sugar (2013) investigated effect of MAP technology on quality of 'Bartlett' pears (Pyrus communis L.). The objectives of their research were to evaluate MAP for preserving 'Bartlett' pear quality during storage and transit, determine the effect of O_2 and CO_2 concentrations on MAP-related internal browning (IB) during cold storage, identify temperatures and gas atmospheres that result in MAP-related IB during transit, and determine the possible relationship of both the development of ripening and IB with ascorbic acid retention and membrane lipid peroxidation. 'Bartlett' pears were packed in a commercial MAP (MAPc), an experimental MAP (MAPe) and commercial perforated plastic bags (control). The storage temperature was fixed on −1.1 °C. After 1 and 3 months of storage, and in order to simulate transit temperatures, samples of commercial and perforated bags were transferred to rooms at temperatures of 2, 4.5, 7.5, and 10°C for 3 weeks. They reported MAPc maintained an average internal atmosphere of 12.3% O2 + 5.6% CO_2 and extended significantly the storage life of pears with high eating quality and without IB and other disorders for up to 4 months. The internal gas atmosphere of MAPe equilibrated at 2.2% O_2 + 5.7% CO_2 and resulted 25.5% and 62.3% IB of fruit after 3 and 4 months of storage, respectively. During simulated transit conditions of 2, 4.5, 7.5, and 10°C, the CO_2 concentration in MAPc was maintained at 5.6–7.9% and O_2 was reduced to 10.5, 5.0, 2.5, and 1.0%, respectively. The longer the storage duration and the higher transit temperature, the higher the incidence and severity of IB. The MAPc maintained firmness, color and higher eating quality of fruit after ripening, eliminated senescent scald and core breakdown, suppressed the loss of ascorbic acid (AsA) and titratable acidity during storage at −1.1 ◦C for up to 4 months. In contrast, fruit held in MAP with low O_2 levels (1.0–2.5%) developed IB that appeared to be associated with a reduction in AsA, and exhibited an increase in membrane leakage. MAP inhibited ripening at high CO_2 + high O_2 but lead to IB when the packaging material or elevated temperatures resulted in high CO_2 + low O_2 conditions. The incidence of IB closely correlated with lipid peroxidation and appeared to be related to fruit AsA concentration.

Also the effects of MAP was studied on core browning of 'Yali' pears during cold storage (Cheng et al., 2015). Core browning and avoidance of this phenomena is a major challenge during postharvest storage of pear. Control atmosphere (CA) storage and MAP are the methods that preserve pear quality and extend its storage life. But, pear fruits are sensitive to CO_2 and high CO_2 concentrations that lead to core browning in pears. Therefore, it is the main problem to understand the mechanism of this process to optimize atmospheric conditions during postharvest storage of pear. Cheng et al. (2015) investigated the browning process, phenolic content, polyphenol oxidase (PPO) activity and expression profiles of phenylalanine ammonia-lyase (PAL) and PPO genes in the core tissue of 'Yali' pears under MAP. The pears were divided into three classes. One was packaged in 10-mm-thick low-density polyethylene film as MAP1, the second class was packaged in 30-mm-thick low-density polyethylene film designated as MAP2, and the third lot without packaging was designated as the control. Table 5 shows properties of films that were used for packaging of pear fruits They obtained that MAP1 reduced core browning, retarded the peak appearance of PPO activity and phenolic content and inhibited the expression of PbPAL and PbPPO genes in core tissue relative to the control, but MAP2 exerted the opposite effects during storage. They concluded O_2 and CO_2 concentrations in MAP1 were appropriate for storing 'Yali' pear, and this treatment effectively inhibited core browning and when the CO_2 concentration was very high, as in the MAP2, CO_2 injury would occur and exacerbate core browning. So they proposed that MAP1 was suitable for cold storage under modified atmosphere storage in 'Yali' pears.

Villalobos et al. (2014) studied effect of equilibrium MAP on the stability of 'San Antonio' and 'Banane' breba fruit during cold storage by the use of three different micro perforated films. Gas composition in the wraps, weight loss, % disorder, and microbial counts were investigated for 21 days. The tested micro perforated films extended time of storage for brebas, minimized weight loss

Film thickness	P_{CO_2} (mL/m^2.d.atm)	P_{O_2} (mL/m^2.d.atm)	Permeability rate ($\frac{P_{CO_2}}{P_{O_2}}$)	Size (cm^2)
10 µm	75200.41	10955.56	6.864132	30 ×40
30 µm	15844.76	4766.8	3.323983	30×40

Note: P_{CO_2} and P_{O_2} indicate the values of CO_2 and O_2 permeability of films respectively.

Table 5. Properties of the films used by Cheng et al. (2015) for packaging 'Yali' pear.

and delayed disorders due to fungal proliferation. Among the tested micro perforated films, biaxially oriented polypropylene (BOPP) film with one hole per 50 mm (a total of three holes, ø = 100 µm) (M50) showed the best performance in terms of delaying physicochemical senescence processes of fruit. For 'San Antonio' and 'Banane' cultivars packaged with micro perforated M50, the optimal time of cold storage was 14 and 21 days, respectively.

Oliveira et al. (2015) studied effect of modified atmosphere on polyphenols during storage of pasteurized strawberry purees. They aimed to evaluate phytochemicals concentration during 90 days-storage of pasteurised strawberry puree under three atmospheres and at two storage temperatures to improve polyphenols preservation of processed fruit. Strawberry purees flushed with gas mixtures of 10 kPa O_2 + 90 kPa N_2, 100 kPa N_2 and air (78 kPa N_2 + 21 kPa O_2 + 0.03 kPa CO_2) and were stored for 90 days at 4°C and 23°C. They reported catechin, epicatechin and quercetin-3-rutinoside were not affected by the atmospheres for both temperatures, while ellagic acid concentration was higher for samples stored in air. 100 kPa N_2 at 4°C and 23°C, preserved total anthocyanin content of puree in better form. Totally, MAP allowed higher stability on total antioxidant activity, total phenolic and total anthocyanin content of strawberry puree, while catechins and quercetin-3-rutinoside were the most stable. They recommended refrigerated temperature conditions (4°C) and an anaerobic atmosphere (100% N_2) for preservation of nutritional properties strawberry puree during storage, since under these conditions the concentration of strawberry colouring polyphenols (anthocyanins) would be higher and compounds like catechin, epicatechin, quercetin-3- rutinoside and ellagic acid would be more stable.

Selcuk and Erkan (2015) studied on effects of modified and palliflex controlled atmosphere storage on postharvest quality and composition of 'Istanbul' medlar fruit. The Palliflex system comprises a pallet of boxes of stored product and a plastic cover encompasses the pallet. Several times a day, the system measures the gas concentrations in the cover and corrects them if necessary with CO_2, O_2, N_2 or air. In this storage system, it is possible to set desired O_2 and CO_2 compositions in individual pallets. O_2 and CO_2 can be automatically injected or removed based on operator set points programmed into the controller. This system is suitable for different fruit and vegetables in the same storage room, because it can provide different atmosphere compositions for individual pallets (Selcuk and Erkan, 2015).

MAP technology has also been developed to control decay of 'Red Globe' table grapes during storage. Grapes were packaged in perforated polyethylene (PPE) or MAP bags (ZOEpac or Antimicrobial) with or without different grades of ethanol vapor-generating sachets (Antimold®30, Antimold®60 or Antimold®80) or a SO2-generating pad, and the grapes were kept at 0 °C and 90–95% relative humidity for 4 months. Packaging of grapes with a SO_2 pad in PPE or ZOEpac bags provided better control of fungal decay and stem browning than PPE or ZOEpac bags alone, PPE or ZOEpac bags with Antimold sachets or Antimicrobial bags alone. The PPE bag containing the Antimold®80 sachet was as effective as the SO_2 treatments in reducing the incidence of fungal decay in naturally infected and artificially inoculated grapes for 1 month. Ethanol vapor released by the Antimold sachets enhanced berry color, but caused stem browning depending on ethanol vapor concentrations in the headspace of the bags. The ZOEpac-210 bags alone resulted in significantly lower weight loss and incidence of stem browning, compared to other treatments; however, they did not reduce fungal decay or develop an appreciable level of modified atmosphere (Candir et al., 2012). The storage life of 'Red Globe' grapes was limited to 3 months using

MAP technique developed by them. After 4 months of storage, they observed marked color changes, more than 90% fungal decay occurred, severity of stem browning increased, taste was unacceptable and appearance was unacceptable with the absence of SO_2 treatment. The SO_2 pad in ZOEpac-110 bags was the most effective treatment throughout storage for controlling incidence of fungal decay, controlling stem browning and maintaining acceptable visual appearance followed by the SO_2 pad in PPE bags. ZOEpac-110 bags containing laminated SO_2 pads may extend storage life of 'Red Globe' grapes to 4 months without SO_2 injury and excessive SO_2 residues.

Waghmare and Annapure (2013) carried out some experiments to explore effect of MAP-chemical treatment on quality of fresh-cut papaya. The efficacy of chemical dips and MAP, alone and in combinations, on the quality of fresh-cut papaya were studied throughout 25 days at 5°C. Fresh-cut papaya were dipped in a solution of calcium chloride (1% w/v) and citric acid (2% w/v) and then packed with headspace of 5% O_2, 10% CO_2, 85% N_2 and stored at 5°C for 25 days. Physico-chemical experiments included package atmosphere, weight loss, pH, total soluble solids, firmness and color, microbial quality along with a sensory analysis were measured during storage period. Significant differences were reported among the chemically treated and non-treated fresh-cut papaya in all the parameters considered. Chemical treatment followed by MAP, showed the best results among the treatment in terms of retaining sensory and quality characteristics and extending the shelf-life of 25 days for fresh-cut papaya. Also MAP alone was not effective in preserving quality. Hence, use of chemical dips in combination with MAP has been shown to be effective in extending shelf-life of fresh-cut papaya.

Finnegan et al. (2013) investigated the effects of origin, physiological age and seasonality (intrinsic factors), cut-size, blade-sharpness and dipping treatments (extrinsic factors) on respiration rate (RCO_2) of fresh-cut pineapple chunks. They developed a mathematical model for respiration rate and reported a gradual decrease in rate with time. The initial respiration rate (Ri) and equilibrium respiration rate (Req), were found useful to compare respiration rates for the factors studied. Ri was affected to a greater extent by physiological age and origin than by season. Cut size had a considerable effect on Ri and Req, with larger cut pieces having the lowest Ri and Req of 5.9 and 2.7 ml/kgh, respectively. While, smallest cut pieces had highest Ri of 7 ml/kgh and Req of 3.2 ml/kgh. Cutting the fruit with a razor sharp blade versus a blunt blade decreased the Ri, while only caused a slight reduction in Req. The target O_2 and CO_2 transmission rate required for optimal MAP were reported 7300–12,500 and 13,900–23,500 ml/m^2 day atm covering variability in respiration rate due to intrinsic and extrinsic factors studied.

Caleb et al. (2013) searched effect of MAP on volatile composition and postharvest life of minimally-processed pomegranate arils ('Acco' and 'Herskawitz' varieties). Storage temperature (5, 10 and 15°C) and time of storage were also studied as the effective parameters on the postharvest quality attributes of arils. They extracted volatile compounds, analyzed by a gas chromatography–mass spectrometry and detected 17 and 18 volatiles and identified in the headspace of pomegranate juices of 'Acco' and 'Herskawitz', respectively. They resulted the postharvest life of MA-packaged 'Acco' and 'Herskawitz' was limited to 10 days due to fungal growth ≥2 logCFUg−1 at 5°C. Temperature had a significant effect on changes on volatile profile concentration and composition. Changes in quality parameters and aroma compounds were dependent on cultivar differences, storage temperature and duration. Under 5°C storage conditions, MA-packaged pomegranate arils were best kept than at 10 and 15°C. Flavour life was shorter than the postharvest life and was significantly influenced by storage temperature.

Selcuk and Erkan (2014) studied changes in antioxidant activity and postharvest quality of sweet pomegranate under MAP and during long term storage. The pomegranate were packed in two different types of MAP and were stored at 6 °C and 90–95% RH. After 120 days, different quality analyses were performed on stored fruits. Fruit weight loss, decay index, skin color, total titratable acidity, total soluble solids content, total phenolic, total anthocyanins and antioxidant activity were determined. During cold storage, the CO_2 and O_2 concentrations were periodically measured inside the MAP. They reported that MAP reduced weight loss significantly after 120 days. During storage, a decrease were observed in L*, C* an h° values in all treatments. A decrease was occurred in titratable acidity and total soluble solids after cold storage and shelf-life. Total phenolics, total anthocyanin contents and antioxidant activity showed an increase during the storage period in control fruit. They concluded storage of pomegranates in different MAP treatments significantly reduced weight loss and decay and maintained visual appearance, but had no significant effect on internal quality of fruit (TTA, SSC, total phenol content, anthocyanin contents and antioxidant activity) at the end of both cold storage and shelf-life periods. Also they proposed 'Hicrannar' pomegranates can be stored up to 100 days by using MAP without decay or serious loss in weight.

Silveira et al. (2014) applied non-conventional MAP for quality preservation of watercress. They aimed to investigate the effect of different non-conventional MAPs, nitrogen (89.7% N_2, 10.3% O_2), argon (89.9% Ar, 10.1% O_2), helium (90.1% He, 9.9% O_2), nitric dioxide (89.3% N2O, 10.7% O_2) and air (0.03% CO_2, 21% O_2), on fresh-cut watercress leaves preserved for 13 days at 5 °C. They reported the respiratory rate was reduced by the non-conventional atmosphere up to 3 days of storage, and no significant effects were observed on C_2H_4 production. They observed Helium and N_2O atmospheres increased the antioxidant activity of watercress at the end of the storage period, while no significant effects were observed on polyphenol contents and sensorial parameters, there was no clear effect of non-conventional gases on the color parameters and polyphenol contents of fresh-cut watercress. Moreover, there was no clear effect of non-conventional atmospheres on microbial growth. They suggested that non-conventional atmospheres, combined with other technologies that ensure low microbial counts at the beginning of the storage, could be used for watercress leaves.

Elwan et al. (2014) performed an investigation of storability, shelf-life and quality assurance of sugar snap peas affected by MAP. This investigation was aimed to select the most suitable package to maintain quality of sugar snap peas pods. They selected five types of polypropylene bags included highly perforated (HPPP), nonperforated (NPPP) and micro-perforated with 6, 12 and 24 holes (MPPP6, MPPP12 and MPPP24) for packaging of pods during cold storage at 0 °C and 90–95% RH for 7, 14, 21 days. Also they simulated shelf-life conditions at 10 °C and 80–85% RH for 2 or 4 days after cold storage. Changes in O_2 and CO_2 concentrations, weight loss, visual quality, off odors, decay, color, firmness, crispness, taste, total chlorophyll, vitamin C, SSC, and total sugar contents were considered. They reported that O_2 decreased and CO_2 increased slowly inside MPPP6, MPPP12 and MPPP24 bags, while, the reduction in O_2 and the increments in CO_2 in NPPP bags were very sharp and accompanied with high levels of off odors. MPPP12 bags preserved quality during storage and simulated shelf-life, in terms of higher scores for visual quality, firmness, crispness and taste as well as highest contents of chlorophyll, vitamin C and sugars.

Ghidelli et al. (2014) explored effect of a soy protein-based edible coating with antioxidant activity, and conventional and super atmospheric MAP on the quality of fresh-cut 'Telma' eggplants, during storage. In a first experiment, eggplant pieces were dipped in either a coating composed of soy protein isolate (SPI) and 0.5% cysteine (Cys), or water as an uncoated control. They packed samples in trays under atmospheric conditions to reach a passive MA (MA-P) or two gas mixtures (MA-A: 15 kPa CO_2 + 5 kPa O_2; MA-B: 80 kPa O_2) and stored at 5°C. Atmospheric conditions were used as control. They resulted coated samples packed under MA-B and control conditions yielded the highest whiteness index (WI) values during storage, whereas MA-A did not enhance the shelf-life of minimally processed eggplants and had the lowest WI values. The MA-B and atmospheric control conditions maintained firmness, whereas the coating maintained the weight loss under MA-A and MA-B. In a second experiment, the commercial shelf-life of fresh-cut eggplants was extended to 8 and 9 storage days by increasing the Cys content in the edible coating from 0.5 to 1% under MA-B and control storage conditions, respectively. They concluded that applying a SPI-based edible coating amended with 1% Cys can help control enzymatic browning and maintains the visual quality of 'Telma' fresh-cut eggplants for up to 8–9 days at 5 °C. Also they did not recommend conventional MAP conditions (low O_2 and high CO_2) for storage of fresh-cut eggplants under the studied conditions, since it induces damage of the tissue. Overall, the SPI–Cys coating under air atmospheric conditions provided the best and cheapest approach for extending the shelf-life of fresh-cut eggplant.

Also effect of a soy protein-based coating and MAP was studied to control browning of fresh-cut artichoke (Ghidelli et al., 2015). SPI-beeswax (BW) edible coating was optimized based on BW and Cys content to reduce the enzymatic browning of fresh-cut artichoke. Effect of this optimized coating, combined with different MAs was studied on shelf-life of cut artichokes during storage at 5°C. MAs were made by fluxing two gas mixtures (MA-A: 5 kPa O_2 + 15 kPa CO_2; MA-B: 80 kPa O_2) or by conventional passive MA (MA-P). Atmospheric conditions were also used as the control. They obtained the use of 0.3 g/100 mL Cys combined with a SPI-BW edible coating helped control enzymatic browning and extended the commercial shelf-life of fresh-cut artichokes to 4 days without providing off-odors. The combination of the coating with MAs did not affect the shelf-life of artichoke slices, but enhanced the

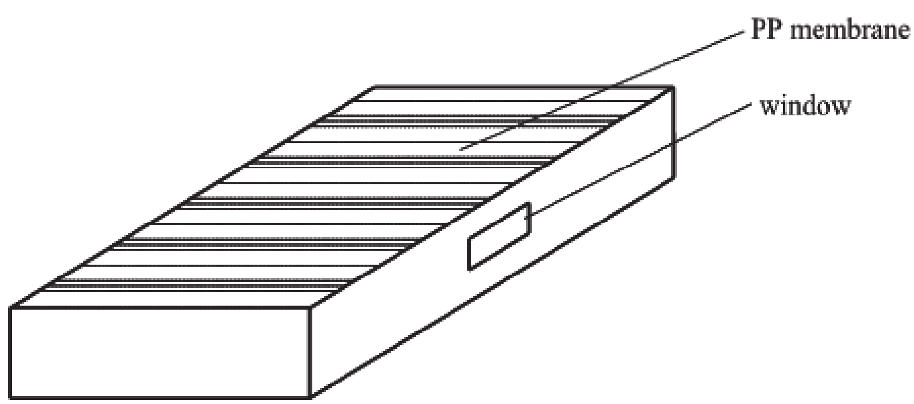


Figure 5. The sketch of packaging tray with silicon gum film window and PP membrane. 18 cm length 12 cm width 4 cm depth, with a wall thickness of 0.3 mm and a total surface area of 456 cm2, which achieves an O_2 permeability of 14.62×10 -16 mol S-1 m-2 Pa-1 and CO_2 permeability of 53.51×10 -16 mol S-1 m-2 Pa-1 at 20 C and 90% RH were used by Li and Zhang (2015).

product's antioxidant capacity as compared to the control packaging conditions.

Li and Zhang (2015) investigated effects of MAP with a silicon gum film window on the quality of stored green asparagus (Asparagus officinalis L) spears. Packages of green asparagus with or without silicon gum film windows were flushed in two different modified systems (50 mLL-1 O_2 with 100 mLL-1 CO_2 and 100 mLL-1 O_2 with 100 mLL-1 CO_2, with N_2 as a balance gas) and stored at 2 ± 1°C for 30 days. Figure 5 shows the package that was used in this research.

The changes in gas headspace, sensory, respiration rate, ascorbic acid content, soluble solid content and chlorophyll content were investigated. They found that, the gas exchange between packages and surrounding atmosphere through the silicon gum film windows induced an in-package optimum atmosphere for green asparagus spears stored at O_2 above 21 mLL-1, CO_2 below 157 mLL-1 and ethylene below 15.84 mLL-1. These packages prevented anaerobic respiration to get good odor score, and were able to keep a relatively low respiration rate and reduce loss of ascorbic acid. The initial atmosphere in packs also affected the quality attributes, where 50 mLL-1 O_2 and 100 mLL-1 CO_2 initial atmosphere was preferred.

CONCLUSION

MAP as a progressive technology, has been developed for preservation and storage of many fresh fruits and vegetables. The advantages of MAP are extending the shelf-life, preserving or stabilizing the desired properties of fruits and vegetables, convenience in use and distribution for retail sale. Recent development achieved in packaging material such as bio-based polymers provides feasibility of MAP development for new applications. Also developments in MAP claim new equipment and machinery and accurate control of process. Recent advances in mechatronics and automation provides reliable control of all machine functions in MAP process such as temperature and gas injection. Many factors should be considered to facilitate MAP process based on the nature of the product and the market requirements. Some of these parameters are quality, cleanability, throughput, flexibility, operating cost, processing yield and equipment price.

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