Project Title	Desk study to review the use of modified atmosphere packaging systems in maintaining quality and improving the storage and shelf-life of field vegetables.
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The results and conclusions in this report are based on a series of experiments conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

For many field vegetables, modified atmosphere packaging (MAP) could offer significant economic benefits over other storage and transport options (including controlled atmosphere storage). Potential benefits include being able to reduce losses, expand the market and manage supply to customers – through extended storage life and/or shelf-life whilst maintaining the quality and nutritional status of the product (and providing the cool chain is properly managed).

The financial case for the use of MAP is clearer for high-value produce.

Background and expected deliverables

The supply of consistent quality product and the continuity of supply to achieve customer satisfaction continue to be key objectives for the fresh produce industry. This has resulted in the development of a wide range of technologies aimed at maintaining food quality and extending post-harvest life. One of the techniques which has shown promise and is being used commercially in some sectors of the fresh produce industry is that of Modified Atmosphere Packaging (MAP). However, despite the fact that MAP has been proven technically to address a range of needs and constraints facing producers and packers of field vegetables, the technology has been adopted by a relatively small number of growers in the UK in comparison to the USA for instance. It is believed that up-take of MAP by the UK field vegetable industry has been limited by the fact that growers/packers are either unaware of the benefits of MAP in relation to their operations; concerned about the additional cost; and/or faced with the problem of being able to select the right type of product for their needs from a plethora of MAP products currently available on the market. This desk study provides up to date information which is hoped will assist growers in making a considered judgement on whether the uptake of MAP is of benefit to their operations.

The Desk Study reviews the current status of MAP in relation to post-harvest life and quality of fresh vegetables and includes information on where and how MAP is currently being used commercially in the field vegetable sector; together with an evaluation of the pro's and con's for the use of the MAP by UK growers and packers *versus* other commercial storage technologies. The impact of MAP on the nutritional status and safety of fresh produce is also discussed.

Summary of the project and main conclusions

MAP covers any packaging that is designed to ensure that when filled and sealed, the internal atmosphere is modified from the normal outside air. The trick in designing a MA package is to achieve a modified atmosphere that is beneficial to the produce and not injurious.

There is a huge body of work demonstrating that atmosphere modification, typically raised CO_2 and reduced O_2 levels can be beneficial in terms of extending post-harvest life of a number of field vegetables. For example, atmospheric modification has been found to have the following benefits for broccoli:

- Minimizes dehydration and weight loss.
- Maintains firmness and tight head.
- Retains green colour. (No yellow buds.)
- Maintains stem condition at butt end (reduced discolouration and dehydration).
- Retards decay.

It should be noted that different produce items and even cultivars differ in their sensitivities and response to CO_2 and O_2.

In the early days of MAP, its use was largely restricted because of the unavailability of appropriate films that provided safe and beneficial atmospheres. However, today we have a much better understanding of the interactions of temperature, O_2 and CO_2 concentrations, water vapour transmission rates, film permeabilities, use of microperforations etc. This has led to the improved selection of appropriate films for each product (produce item and supply chain) and the development of a broad range of packaging formats: bags (retail, food service), pouches, rigid plastic containers with gas diffusion window(s), flow-wrap trays and punnets, carton liners and pallet covers. Further advances in the field of MAP are continually being made e.g. the development of films with high oxygen transmission rates and/or improved water vapour transmission rates, antimicrobial MA films and other 'smart' technologies such as temperature responsive MA films.

Food service pack: Broccoli florets.

A summary of the main technical benefits and disadvantages of MAP is presented in the table at the end of the grower summary.

Financial benefits

For the majority of field vegetables, MAP can provide significant benefits in terms of extending storage life and shelf-life whilst maintaining the quality and nutritional status of the product – so long as the cool chain is properly managed. The benefits to growers/packers in the uptake of MAP can be broadly summarised as follows:

- Reduced losses:
  - Water loss is a reduction of saleable weight and thus a direct loss to the grower/packer. With little or no weight loss there is no need to over-pack thereby leading to savings in raw material and transportation costs
  - Reduced decay leads to reduced economic losses

- Ability to hold produce longer, thus offering the following benefits:
  - Aid stock management
  - Extend season facilitating off-season sales
  - Picking ahead of poor weather forecasts
  - Takes advantage of market price fluctuations i.e. hold low sell high.

- Facilitate market expansion through:
  - Ability to offer new/novel products e.g. baby sprouts picked early in the season to supply the tail end of the season when baby sprouts are not available; microwaveable or steamer packs for asparagus, green beans, peas etc.
  - Extend season facilitating off-season sales.

Action points for growers

Whilst MAP is likely to be a better option than CA storage for the UK grower in terms of cost, flexibility of use etc, it is a more expensive technology than conventional cold storage and therefore may only be viable for medium to high value crops and/or where there are real commercial advantages in storing the product in an MA package e.g. with a view to selling when market prices are higher. It is, therefore, recommended that prior to the adoption of this technology a full cost-benefit analysis is undertaken for each product (produce item/supply chain) to ensure that it is economically viable.

Technical benefits and disadvantages of modified atmospheres.

<table>
<tr><th>Potential benefits</th><th>Disadvantages</th></tr>
<tr><td>

MAP and CA can extend the storage and market-life of fresh produce over that held under refrigerated conditions alone. The extra storage and/or shelf-life conferred by MAP are dependent on the factors outlined in section 2.2.6 of the report.
MAP can reduce losses in the supply chain, for example by:

Slowing down the ageing and senescence processes of the produce e.g. yellowing of leafy vegetables;
Minimising re-growth of leeks and the need to trim;
Reducing discolouration of cut ends e.g. cut butts of broccoli;
Maintaining high relative humidity in the package reduces water loss and subsequent weight loss for a wide range of produce e.g. asparagus
Reduced development of micro-organisms which cause decay and the spread of decay within a store or container.

MAP can maintain the atmosphere throughout the supply chain from the grower/packer to the consumer e.g. using MAP retail packs packed at source. In comparison, the use of CA is restricted to storage and transportation.
MAP is an inherently safer product with physical protection from contaminants, foreign matter and pathogens.
MAP films can be used as a carrier of fungicides, scald inhibitors, ethylene absorbers, or other chemicals to optimise storage and marketing life.
With produce like broccoli, MAP can eliminate the need for ice and all its problems and costs i.e. no ice or waxed cartons required; eliminates the potential contamination from ice, as well as eliminates the messy slush resulting from melted ice.
Some MA films can be used for microwavable or steamer retail packs.
Fresh flavour and nutritional value is preserved during prolonged storage.

</td><td>

MA systems generally use product respiration and passive technology to generate the required atmosphere. However, there can be a delay of up to 48 hours or so before the optimum gas levels are reached. This may have implications in terms of disease control and storage life, although if the product is properly maintained in the cool chain this is unlikely to be much of an issue. CA systems have an advantage over passive MAP in that it can actively manage the composition of the storage atmosphere.
Breaches in the cool chain can for some MAP products lead to:

Increased potential for water condensation within the package which may encourage fungal growth.
High temperatures that may result in the development of anaerobic conditions, which can encourage the growth of anaerobic bacteria and reduce product quality and market life.

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1. Introduction

The supply of consistent quality product and the continuity of supply to achieve customer satisfaction continue to be key objectives for the fresh produce industry. This has resulted in the development of a wide range of technologies aimed at maintaining food quality and extending post-harvest life. One of the techniques which has shown promise and is being used commercially in some sectors of the fresh produce industry is that of Modified Atmosphere Packaging (MAP).

Atmosphere modification, typically raised CO_2 and reduced O_2 levels, has been found to be beneficial in maintaining quality and extending post-harvest life of a number of fruit and vegetables, including: apples, asparagus, avocados, bananas, broccoli, Brussels sprouts, cherries, green beans, kiwi fruit, mangoes, melons, peaches, pears, potatoes, strawberries and sweet corn etc. A modified atmosphere can be achieved by using controlled atmosphere storage (CA) and/or passive or active MAP. Whilst CA is being used routinely on a commercial level for storage and shipment of many fruit and some vegetables, the utilisation of MAP systems has until recently lagged behind. However, in recent year there have been some notable successes, namely: MAP of fresh cut produce e.g. vegetable and fruit salads and extension of storage and shelf-life for some whole produce e.g. asparagus, bananas, broccoli, cherries, melons and potatoes.

Despite the fact that MAP has been proven technically to address a range of needs and constraints facing producers and packers of field vegetables, the technology has been adopted by a relatively small number of growers in the UK in comparison to the USA for instance. It is believed that up-take of MAP by the UK field vegetable industry has been limited by the fact that growers/packers are either unaware of the benefits of MAP in relation to their operations; concerned about the additional cost; and/or faced with the problem of being able to select the right type of product for their needs from a plethora of MAP products currently available on the market. This desk study seeks to provide up to date information which will assist growers in making a considered judgement on whether the uptake of MAP is of benefit to them. The review covers the following subject areas:

Section 2: An introduction to MAP. This will cover the history of MAP; a definition of the different types of MAP; a description of how it works; details of the different films used in MAP, identification of the factors influencing the performance of MAP, a description of the different MAP formats available; a discussion of the impact of MAP on the nutritional status of fresh produce; and the microbial safety of MAP.

Section 3: A review of current MAP applications in the field vegetable sector. Information on current commercial applications of MAP for field vegetables will be presented on a product basis. Details of the benefits of MAP and potential for injury will be presented together with information on available MAP formats and country of use.

Section 4. Benefits and disadvantages of MAP *versus* other technologies for storing field vegetables. This will include an assessment of the technical, economic and environmental implications of using MAP from the perspective of the grower. In addition a summary of the pro's and con's of MAP *versus* conventional cold storage and controlled atmosphere storage will be presented together with comparative costs for these technologies.

2. Modified Atmosphere Packaging

2.1 History of MAP

Atmospheric modification has for a long time been recognised to be beneficial in maintaining quality and extending post-harvest life of crops. Bishop (1996) reports that as far back as the 2nd century BC, Egyptians were storing produce in sealed limestone crypts to prolong storage life. However, the earliest documented scientific study did not appear until 1819 when J.E. Bernard, a French scientist, reported the benefits of storing harvested stonefruit and top fruit in atmospheres with zero oxygen (O_2). In the mid 19th century, B. Nyce built a commercial cold store for apples in Cleveland, USA. By using an air tight chamber he was able to modify the carbon dioxide (CO_2) and O_2 levels and claimed that 4000 bushels of apples were kept in good condition in the store for 11 months. Further storage trials with apples and berries were conducted in the early 20th Century at other sites in the USA using different combinations of CO_2 and O_2. At the same time, two British Scientists, Kidd and West, who are now regarded as the founders of modern controlled atmosphere (CA) storage were conducting a series of laboratory and semi-commercial trials 'termed gas storage'. They were looking at the effects of modifying the store atmosphere on the storage life of crops such as apples, pears, plums, berries and potatoes. The scientific basis for the application of CA technology to the storage of fresh fruit and vegetables has continues to the present day and has led to widespread uptake of this technology for storing fruit and vegetables e.g. storage of apples and pears in the USA and New Zealand.

The concept of using polymeric films as a means of prolonging the storage life of fresh produce through the development, and/or maintenance of atmospheres other than air, date from the first availability of plastics. The technique was not, however, introduced commercially for retail packs until the early 1970's. Marks and Spencer introduced meat packed in MAP in 1979. The success of this product led two years later to the introduction of bacon, fish (both fresh and cured), sliced cooked meats and cooked shell-fish packed in MAP. Other food manufacturers and supermarket chains followed, resulting in a sharply increased availability of MAP food products reflecting the increase in consumer demand for longer shelf-life foods.

The uptake of MAP by the horticultural sector for the storage, transportation and extension of shelf-life of horticultural products was limited up until the 1990's primarily as a result of the unavailability of appropriate films that provide safe and beneficial modified atmospheres, particularly under abusive temperature conditions that can occur in the handling chain. However recent advances in the technology of polymeric films and a better understanding of the products response to MA's have led to a rapid expansion in the use of MAP for fruit and vegetables. This has been primarily driven by the fresh-cut (minimally processed) sector of the industry for vegetable and fruit salads, broccoli florets, asparagus tips, mixes of sliced green beans and peas etc. However, there has also been growth in the whole produce sector e.g. bananas, melons, cherries, broccoli heads and sweetcorn.

Today, a plethora of different MAP formats exist from retail packs, carton liners to pallet covers (shrouds or hoods), made from a range of polymeric products with differing gas permeabilities and physical properties (rigidity, clarity etc.) to suit the wide ranging needs and demands of the industry and consumer.

2.2 Introduction to Modified Atmosphere Packaging

2.2.1. Purpose

To maintain quality and extend the storage and/or shelf-life of produce through modification of the atmosphere surrounding product held in sealed packages.

2.2.2. Definition

Modified atmosphere packaging covers any packaging that is designed so that when the package is filled and sealed, the result is an atmosphere inside that is modified from the normal air (i.e. 78% nitrogen, 21% oxygen, 0.03%

carbon dioxide). The atmosphere within the package can be actively or passively modified (see Box 1).

Box 1. Definition of passive and active MAP.

Passive MAP: Passive modification of the atmosphere, in which the desired atmosphere develops naturally as a consequence of the products' respiration and transpiration and the diffusion of gases through a selected film. It is the most commonly used MAP technique in the whole produce sector. *Active MAP*: Active modification occurs by the displacement of gases in the package which are then replaced by a desired mixture of gases. Often used for retail packaging of salads (fruit and vegetables).

2.2.3. The theory of MA packaging

When produce is harvested, it is cut off from its food supply and is dependent on the limited nutrients stored in its tissues. When these are exhausted, product quality deteriorates very rapidly. As respiration consumes food reserves, the major way to extend the period before rapid quality deterioration occurs is to slow the respiration rate. The best way of achieving this is by reducing the temperature. Having achieved good temperature control, MAP can be used to further reduce respiration rate.

How does MAP reduce respiration? When fresh produce is sealed inside a polymeric (or plastic film) package, the concentration of O_2 inside the package reduces as a result of being consumed during the process of respiration. At the same time the concentration of CO_2 in the pack produced from the oxidation of carbohydrates during respiration increases. The impact of raised CO_2 and lowered O_2 levels within the pack is to slow the produce respiration rate. Reduced O_2 and elevated CO_2 together can reduce respiration more than either alone. Eventually, equilibrium is reached inside the pack, when the rate of O_2 uptake and CO_2 production of the produce equals the O_2 and CO_2 permeability of the bag. (Figure 1.) The trick is to design a MAP whereby the atmosphere equilibrates within a specific range of O_2 and CO_2 concentrations for each individual produce item which is beneficial to the produce and not injurious (see Section 2.2.4). The desired modified atmosphere must be established within a short period of time (typically within 1 to 2 days) without creating anoxic conditions or injuriously high levels of CO_2 that may induce fermentative metabolism.

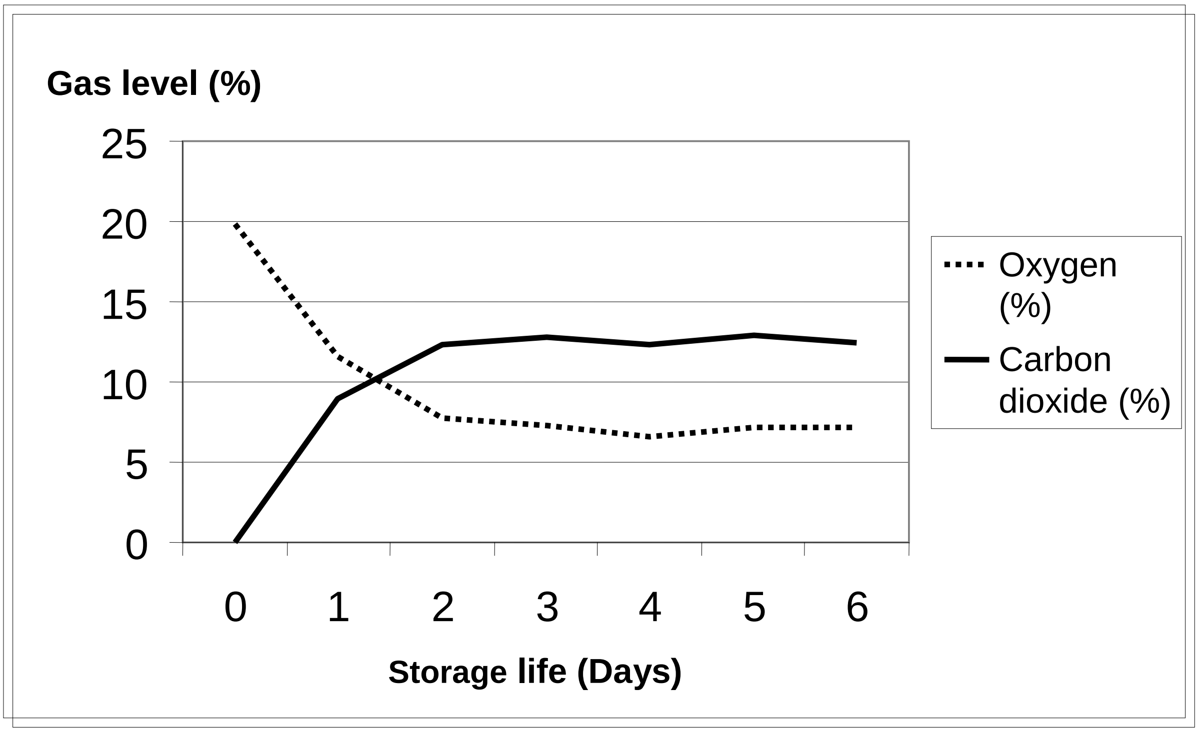

Figure 1. Gas equilibrium within the MAP.

<u>2.2.4. Effects of raised CO_2 and lowered O_2 concentrations on post-harvest responses of fresh produce</u>

The effects of raised CO_2 and lowered O_2 on the post-harvest responses of horticultural produce have been studied for many years and are summarized below (Box 2). Different produce items and even cultivars differ in their sensitivities and response to these gases. For example, CO_2 levels greater than 1.0% are reported to cause core browning of Gloster apples, whereas for Jonathan apples the threshold is 5.0%. It should also be noted that susceptibility to injury will also be affected by exposure time to different gases and there may be interactions with harvest maturity and storage temperature.

Manufacturers of MAP look to achieve a modified atmosphere in the pack that has benefits to the product in terms of maintaining product quality and extending post-harvest life. If injurious effects are observed, manufacturers of flexible films typically resolves this by increasing the pack permeability to CO_2 and O_2. Strategies to increase gas permeability are discussed in section 2.2.8.

Box 2. Summary of the effects of lowered O_2 and raised CO_2 on the post-harvest responses of fresh produce.

Lowered O_2	**Raised CO_2**
Positive effects:	***Positive effects:***
Reduced respiration rate.	Reduced respiration rate.
Reduced ethylene production, thereby slowing down ripening, aging and senescence processes.	Reduced ethylene production and mode of action of ethylene, thereby slowing down ripening, aging and senescence processes.
Delayed breakdown of chlorophyll Reduced yellowing.	Inhibition of chlorophyll breakdown thereby inhibiting or slowing the yellowing of green tissues.
Inhibition of root growth.	Retarded fungal growth.
Reduced curd spotting (cauliflowers).	Reduced sprouting (potatoes).
Reduced substrate oxidation.	Delayed softening.
Decreased discolouration levels. Inhibits discolouration of cut surfaces.	Retention of tenderness/reduced woodiness (asparagus).
	Reduced chilling injury e.g. pitting.
	Reduced regrowth (spring onions/leeks).
	Reduce cap opening (mushrooms).
	Reduced sugar loss (carrots).
	Decreased discolouration levels. Inhibits discolouration of cut surfaces.
Negative effects:	***Negative effects:***
Formation of undesirable flavour and odours.	Production of off-flavours and odours Decreased production of some organic volatiles.
Development of physiological disorders, including internal flesh browning, skin pitting, scald.	Induction of physiological disorders, including: flesh and skin browning, discolouration, stains, scald, internal breakdown, increased pitting.
Inhibit ripening.	Change in sugar content (potatoes).
Altered texture.	Undesirable texture.
Reduced juice content.	Modified metabolism of some organic acids. Decreased acidity.
Lower oil quality.	Increased susceptibility to decay.
Increased sensitivity to freezing.	
Stimulates cap opening (mushrooms).	

2.2.5 Relative humidity

Following harvesting, fresh produce must be held at the correct temperature and relative humidity to reduce water loss. Even in the absence of visible wilting, water loss can cause a loss of crispness and undesirable changes in colour and palatability in some vegetables. A loss in weight of only 5% will cause many vegetables to appear wilted or shrivelled and under, warm, dry conditions without the correct packaging this can happen in only a few hours. Water loss is a reduction of saleable weight and thus a direct loss to the grower or processor.

Fresh produce sealed in a MA package will transpire and as a result this leads to an increase in the relative humidity in the MA package. High humidity can be beneficial in reducing dehydration and weight loss; however it can pose the risk of condensation in the package and may promote the growth of pathogens. The appropriate selection of films with a suitable water vapour transmission rate and/or incorporation of antifog agents (see section 2.2.8) into the film can eliminate these problems.

2.2.6. Factors influencing the level of gases in MAP

There are a number of factors which influence the gas levels (commonly given in terms of percentage levels), including relative humidity, in a MA pack. These are listed below and discussed in the following paragraphs.

- Product respiration rate (see section 2.2.7).
- The type and thickness of plastic film or membrane used i.e. its permeability (see section 2.2.8).
- Mass of fruit or vegetable within the pack. The rate of oxygen consumed is dependent on the weight of product in the pack. Therefore the majority of MAP packs are designed for a specific weight of product.
- The temperature of the fruit or vegetable and the surrounding air. The higher the temperature the higher the respiration rate. A break in the cool chain can raise the respiration rate of the produce item leading to a fall in oxygen to below the recommended level. MAP

manufacturers strongly recommend the use of MAP only in properly maintained cool chains.

- Microbial load. Diseased produce respires at a higher rate, leading to reduced oxygen levels in the pack. In addition there may be an increase in the production of ethylene levels resulting in acceleration of product senescence.
- Whether moisture condenses on the film or membrane surface.
- External airflow around the film or membrane.

2.2.7. Fresh produce respiration

Different fruits and vegetables, and even different varieties will vary in their respiration rates. See Box 3. Those that have high respiration rates tend to be more perishable. Furthermore, when fruit or vegetables are cut, sliced, shredded or otherwise processed, their respiration rates increase. It is paramount to understand the respiration rate of the fresh produce and the factors affecting it when designing a modified atmosphere package.

Box 3. Classification of vegetables according to their respiration rate.

Very Low:	Onion, Potato.
Low:	Cabbage, Lettuces, Salad vegetables, Root crops.
Medium:	Cauliflower.
High:	Beans, Brussels sprouts.
Very high:	Asparagus, Mushrooms, Sweetcorn, Broccoli and Spinach.

The major factors affecting respiration rate of the produce item include:

- Species, cultivar.
- Growing conditions before harvest.
- Microbiology (presence of disease increases respiration rate).
- Stage of maturity of the crop at harvest.
- Crop temperature.
- Post-harvest handling (e.g. mechanical damage can have an impact on the products respiration rate; time taken to remove field heat; storage temperature etc).
- The concentration of gases in store.

- The presence of ethylene. Ethylene, a plant hormone, plays a large role in post-harvest life and can cause a marked increase in respiration rates and enhance senescence.

2.2.8. Film requirements

General

The use of MAP for whole and fresh-cut produce involves careful selection of the film and package type for each specific product, package size and supply chain. Effective MAP requires consideration of the optimal gas concentration, product respiration rate, gas diffusion through the film, as well as the optimal storage temperature in order to achieve the most benefit for the product and the consumer. In addition, when selecting an appropriate film, one has to take into account whether the MAP is for display i.e. retail pack and/or for storage and transportation. Films for retail packs need to provide protection, sealability, clarity, machineability and ability to label and/or print. Clarity is less important for a carton liner or pallet cover.

Film types and permeability

Many types of plastic films are available for packaging, but relatively few have been used to create modified atmospheres for fresh produce. One of the major factors that have limited the choice of polymer films available for MAP is that of low gas permeability (see Box 4). However, recent advances in the technology of manufacturing polymeric films have permitted tailoring films for specific gas diffusion needs of individual produce items and supply chains. Films for low, medium and high respiration rates commodities are now available from many flexible packaging companies and the process of matching the oxygen transmission rate (OTR) to product is being constantly refined. Very high respiration rate commodities such as broccoli, asparagus, sweetcorn, peas and mushrooms once presented a challenge to retail MAP packagers, however, the emergence of films with very high OTRs (>15000 cc/m^2 per day) has meant that even these produce items can be held under

MA. This has also allowed fresh-cut processors to begin to provide a much greater diversity of products which now includes artichoke hearts, baby salad greens, and vegetable mixes such as peas and sliced green beans.

Film permeability to gases is by active diffusion where the gas molecules dissolve in the film matrix and diffuse through in response to the concentration gradient. The permeability of plastic films to gases and water vapour varies with the type and thickness of the plastic used (see Table 1), temperature, and in some cases humidity e.g. the gas transmission of polyamides (nylon) can increase by about 3 times when the relative humidity is increased from 0 to 100% and with ethyl vinyl alcohol copolymer the increase can be as high as 100 times over the same range.

Box 4. Effects of film permeability on produce.

Film permeability too low leads to:

- Over modification of atmosphere. CO_2 rises/O_2 falls.
- Oxygen level too low to support aerobic respiration.
- Off-odours and flavours.
- High CO_2 can injure the crop.

Film permeability matches products respiration rate:

- Equilibrium modified atmosphere adapted to the product.
- Slowing of respiration.
- Slowing of ageing and ripening processes.
- Freshness preserved.
- Extension of shelf-life.

Some film suppliers provide an array of OTR's by varying the thickness of a given film. Thinner films have higher OTR's. However very thin films do not run well on modern automated packaging machinery and so this approach is limited. An alternative approach to increasing film permeability is to microperforate the film. This can be achieved using lasers or hot needles. This is particularly useful where there is a limited package surface area for gas exchange. For example, most cut fruit is packaged in rigid, gas impermeable trays to which a permeable film is heat-sealed. Because the tray is impermeable to gases, there is reduced surface area for gas exchange. All the gas exchange must occur through the lid. Until recently, few films had high enough OTR's to be useful in these applications. Those films that had high OTR's often would not seal to the trays. Microperforated films allow much more rapid gas exchange than would normally be possible through plastic films.

Table 1. Permeability of a selection of plastic films which have been used for MAP of fresh fruit and vegetables. Permeability (cm^3/m^2 /day^{-1}for 25μm film at 22-25^{o}C)

Film	Density range g cm^{-1}	O_2	CO_2	Water vapour transmission cm^3/m^2 /day^{-1} (38^{o}C and 90% relative humidity)
Ethylene-vinyl alcohol (EVOH)		3-5	-	16-18
Polyamide (nylon-6)		40	150-190	84-3100
Low density polyethylene	0.910 - 0.935	3900-13000	7700-77000	18
Medium density polyethylene	0.926-0.940	2600-8293	7700-38750	
High density polyethylene	0.995-0.970	520-4000	3900-10000	7-10
Polypropylene cast		3700	10000	10-12
Polypropylene oriented		10-20	35-50	4-5

Moisture control

Moisture given out by the produce can condense on the inside of the pack. This is especially a problem where there are large fluctuations in the supply chain. Some films, e.g. nylon-based films have high water vapour transmission rates which allow the excess moisture to be removed from the pack whilst maintaining appropriate relative humidity levels within the pack. The result is that no puddles of water form in the pack.

An alternative to using nylon-based films is to include the use of antifog chemicals. This is a technique adopted by a number of manufacturers of MAP films used for retail packing. The antifog agent can be added during the manufacture of plastic films. These do not affect the quantity of moisture inside the packs, but it causes the moisture which has condensed on the inside of the packs to form sheets rather than discrete drops. They can eventually form puddles at the bottom of the pack which is a major disadvantage in terms of the consequences of produce sitting in water. Antifog coatings can also interfere with seal integrity. In order to resolve this issue, manufacturers rely on register coatings that apply the antifog material only on selected areas of the film away from the seal.

2.2.9. Active MAP

For some applications, active MAP or gas flushing is preferred over passive MAP when there is a need to achieve optimum gas levels within a short period e.g. for fresh-cut baby leaf salads. In order to speed up this process the pack can be flushed with nitrogen (N_2) to reduce the O_2 rapidly or the atmosphere can be flushed with an appropriate mixture of CO_2, O_2 and N_2. Although active establishment implies some additional costs, its main advantage is that it ensures the rapid establishment of the desired atmosphere. Active MAP is commonly used for fresh fruit and vegetable salads.

Although O_2, CO_2, and N_2, are the most often used in MAP, other gases such as nitrous and nitric oxides, sulphur dioxide, ethylene, chlorine, ozone and propylene oxide have been evaluated. However, due to safety, regulatory and cost considerations, they have not been applied commercially.

2.3. Smart packaging

The past five years or so have seen the introduction of 'smart' MAP packaging systems (Box 5). Some 'smart' or 'intelligent' systems alter package O_2 and/or CO_2 permeability by sensing and responding to changes in temperature. Other technologies, include the use of sachets of chemicals, placed inside the MA pack, which can remove ethylene from the pack atmosphere - these have been successfully used in combination with MAP to extend storage and shelf-life of a number of ethylene-sensitive produce items e.g. kiwi, broccoli. Further advances are anticipated in terms of incorporating O_2, CO_2 and/or ethylene absorbers and antimicrobial compounds into MA films.

Box 5. Types of 'smart' or 'intelligent' MAP packaging systems for horticultural produce.

Temperature sensitive films:

Landec Corporation (USA) has developed side-chain polymer technology that allows the film OTR to increase rapidly as temperature increases, thereby avoiding anaerobic conditions subsequent to loss of temperature control. In addition these polymers can provide very high OTR's, and adjustable CO_2/O_2 permeability ratio and a range of moisture vapour transmission rates.

Ethylene absorbers:

Removal of ethylene has been shown to improve storage and shelf-life of produce. There are a number of systems available to remove ethylene within MAP, this includes:

- Sachets of ethylene absorbers such as Ethysorb and Purafil. These are made by impregnating an active alumina carrier (Al_2O_3) with a saturated solution of potassium permanganate and then drying it. The carrier is usually formed into small granules. The smaller the granules the larger the surface area and therefore the quicker their absorbing characteristics. Any molecule of ethylene in the package atmosphere which comes into contact with the granule is oxidised.
- MA films which incorporate ethylene absorbers e.g. minerals/clays (see below).

CO_2 generators:

These can be used to rapidly build-up the in-pack concentration of CO_2 to beneficial levels, typically during the first 24-48 hours following sealing. CO_2 generators in the form of pads or sachets are being developed based on the principle of acid/base reactions. Currently these are not available commercially.

Mineral powders incorporated into MAP films:

Mineral powders are incorporated into some MAP films and it is claimed that these films can remove or absorb ethylene, excess CO_2 and water. Some manufacturers have claimed these films have antimicrobial properties, possibly by the physical process of filtering air through the film and thereby removing spores etc and/or by modifying the atmosphere within the pack to reduce or eliminate development of microbes. Some commercial applications for these types of films include: broccoli, cucumber, lotus root, kiwifruit, tomato, sweet corn and cut flowers.

Antimicrobial films:

Manufacturers are looking to produce MAP films with antimicrobial properties for use in the fresh produce industry. However there are no commercial MAP films available at the present. Difficulties facing manufacturers is the need to release the antimicrobial compound from the film in a controlled manner and at a concentration that is inhibitory to the pathogen of interest without a negative impact on the produce.

2.4. MAP formats.

There are a number of MAP formats designed to prolong the storage and shelf- life of fresh produce. Essentially they can be divided into retail, food service and bulk packaging. Each of these will be discussed in turn below. A list of MAP manufacturers are presented in Appendix A. The mention of a manufacturer in this review does not constitute a recommendation and the absence of a manufacturer does not imply a criticism of that product.

2.4.1. Retail packaging

Pack formats range from bags (Plate 1), stand-up pouches (Plate 2) and punnets/ trays with lidded films (Plate 3) or flow-wrapped aimed at maintaining quality and extending shelf-life. Some of these MA packs are microwaveable (Plate 1) or can be used for steaming the produce (Plate 2). The produce e.g. broccoli heads, cauliflower florets, asparagus spears, sliced runner beans, peas etc., is packed into the retail pack at the packhouse and remains under MAP until the pack is opened by the consumer. In some instances the MAP can be resealed by the consumer after removing some of the product.

Plate 1. Microwaveable retail pack: Asparagus

The MA within the retail pack may be created passively or by actively flushing the package with a gas mixture. The former is typically used for whole or minimally processed produce; the latter is used for bags of salad vegetables.

Advantages:

- Reduces dehydration and weight loss on the shelf. For the grower/packer there is no need to over-pack thereby leading to savings in both raw material and transport costs.
- Extends shelf-life for both retailers and the consumer.
- Reduces quality waste.
- More consistent product for customers.
- Increased branding and marketing opportunities.
- Physical protection from contaminants e.g. foreign matter.

Disadvantages:

- More expensive than non-MA packaging.
- Package needs to be designed to cope with a range of in-store (multiples) temperatures.
- Packer may need to modify packing line.

Plate 2. Steamer pouch: Peas and leeks

Plate 3. Tray with heat-sealed MAP film: Mixed vegetables

2.4.2. Food service packs

Typically this involves packing larger quantities of minimally processed produce into MA bags e.g. broccoli florets, asparagus spears, trimmed

Brussels sprouts etc. The product is prepared and packed at the packhouse. Food service packs generally rely on passive MA.

Advantages:

- Reduces dehydration and weight loss during storage.
- Longer storage life – requires fewer deliveries.
- Produce can be minimally processed e.g. preparation of florets and held under MA until required for use.

Disadvantages:

- As for retail packaging.

Plate 4. Food service pack: Broccoli florets.

Plate 5. Food service pack: Parsnips.

2.4.3. Bulk packaging

There are two types of bulk packaging: carton liners and pallet covers (hoods or shrouds). Both types of packaging are used for the storage and transportation of fresh produce. They may use passive or active MA.

Carton liners:

The MA liner is placed in a carton and the produce (a fixed amount) is packed into the liner. Typically, the opening of the liner is gathered together and twisted like a rope. The twisted end is folded over and sealed with a rubber band or held in place with a clip. It is generally recommended the produce is pre-cooled before placing in the liner, otherwise pre-cooling time will be increased. Whole and minimally processed produce can be stored in bulk liners e.g. sweet corn, cauliflower florets.

There are bulk MAP systems that allow product to be packed in the field directly into the carton liner using an integrated bag-in-a box design (see

Appendix A). The product is then pre-cooled and transported or stored. Depending upon the final customer (multiple), the product can be kept in the liner up to the point of sale.

Advantages:

- Easy to use.
- No investment in machinery.
- Reduces dehydration and weight loss.
- Reduces wastage.
- Extends storage and shelf-life.

Disadvantages:

- More expensive that non-MAP liners.
- Precooled product should be packed into liner. Pre-cooling time is doubled if warm product is precooled in the liners and there is the potential problem of free water accumulating in the pack.

Pallet covers:

After pre-cooling the produce, cartons can be covered with an MAP pallet cover (hood/shroud). This is a large bag which surrounds the palletized cartons. The product can be stored and transported under the pallet hood. Pallet hoods are usually removed at the distribution depots. There are active and passive pallet cover systems available (see Appendix A).

Advantages:

- Ease of use.
- Passive systems are relatively inexpensive.
- Reduces dehydration and weight loss.
- Extends storage life.

Disadvantages:

- Film can be ruptured by fork-lift trucks etc with a resulting loss in the MA.

- Active systems are more expensive and require gas flushing equipment.

2.5 Impact of MAP on the nutritional status of fresh produce

MAP is a well-established packaging technique which, when used in conjunction with refrigeration, helps to keep food safe and fresh. One of the benefits of using MAP advocated by the industry is its ability to maintain the nutritional value and flavour of produce by slowing the loss of food reserves, particularly sugars, inhibiting the loss of labile vitamins such as vitamins C and A, and by slowing the accumulation of undesirable secondary metabolites in the plant's tissues, such as free ammonia. In reality, only a moderate number of studies have been conducted to evaluate the impact of MAP on the nutritional status of vegetables. There is, however, a wider body of work looking at the effects of CA on the nutritional status of fresh produce. Table 2 summarises some of the findings published in the literature for MA and CA. In general, the impact of storing vegetables in modified atmospheres on the nutritional status is a positive one i.e. delaying vitamin degradation, particularly vitamin A, and accumulating polyphenolic substances which are purported to have health benefits in terms of reducing coronary heart disease or a neutral one (i.e. no effect). However, there are one or two studies that report vitamin C degradation is greater for some produce items held under modified atmospheres than air e.g. artichokes and leeks. Further studies are required to substantiate the claims of the MAP manufacturers regarding the positive message that storing produce under MAP has a beneficial impact on the nutrient status of the produce.

2.6 Microbial safety

One of the concerns regarding the use of MAP is whether it’s safe from a microbiological perspective. This subject has been discussed in great detail in a number of comprehensive reviews (see Church and Parsons, 1995; Faber *et al*., 2003) and the reader is directed to these publications for a more in depth discussion of the issues relating to microbial safety of MAP and CA. One of the key points raised regarding the use of MAP is that gases in the modified atmosphere could possibly have a stimulatory effect on the growth of pathogenic organisms and the production of toxins. Faber *et al*., (2003) comment: 'the concern when using MAP for fruit and vegetables arises from the potential for food-borne pathogens, which may be resistant to moderate to high levels of CO_2 (characteristic of MAP), outgrow spoilage micro-organisms which may be susceptible to the MA'. However, they go onto say that 'it is generally believed that with the use of permeable films, spoilage will occur before toxin production is an issue; MAP of produce, however, should always incorporate packaging material that will not lead to an anoxic package environment when the product is stored at the intended temperature'.

Table 2. Summary of effects of MAP and CA on the nutritional status of vegetables.

Produce item	**Treatments**	**Effect**	**Authors**
Artichoke	MAP: Six different films were used: perforated polypropylene), polyvinylchloride, low density polyethylene (LDPE) and three microperforated polypropylene films (PP1, PP2 and PP3).	For the MAP treatments, the vitamin C content of the internal bracts (edible part) decreased with storage time in comparison to non-MAP. On the other hand, a large increase in the phenolic content of the internal bracts was observed for the MAP treatments. (Consumption of polyphenols is purported to be inversely related to the incidence of coronary heart disease.)	Gil-Izquierdo *et al*., (2002)
Brassicas	CA: 3-5% O_2 + 4-5% CO_2; balance N_2 at 5°C (95±2% RH), for six days.	Delayed vitamin C degradation.	Moretti *et al*., (2003)
Carrots	MAP: polypropylene (PP) and low density polyethylene (LDPE) films, stored at 0°C and ambient temperature (15-25°C).	The free sugars in carrots were observed to decrease at a slower rate for carrots packed in LDPE than PP and air.	Workneh *et al*., (2001)
Carrots (purple)	MAP treatment: 90% N_2/5%CO_2/5%O_2, stored chilled for 13 days.	Total phenolic content increased with storage time.	Alasalvar *et al*., (2003)
Chinese Cabbage	CA: 10-20% CO_2	No effect on the level of ascorbic acid in comparison to air stored produce.	Wang, (1983)
Leeks	CA: 10% CO_2 + 1% O_2 at O°C + 95% RH.	Greater loss in ascorbic acid in CA in comparison to air storage. Greater retention of vitamin A in CA stored produce in comparison to air storage.	Kurki, (1979)
Sweet potato (fresh-cut)	MAP: Fresh-cut sweetpotato slices held in semi-permeable polyolefin films, with different gas transmission characteristics and kept at 2 or 8 °C for 14 days.	Type of MAP film bags did not significantly affect carbohydrate composition and nutrient content of slices during storage.	Erturk *et al*., (2002)

Fresh-cut produce are typically stored at 1-5% O_2 for both safety and quality reasons. However, it is generally recognised that O_2 levels of <1% may occur and at these low levels a number of food-borne pathogens e.g. *Clostridium botulinum* can survive and grow. Current research indicates that spoilage of the produce will occur before toxins become an issue. However, there is no room for complacency, and scientists are examining the potential for growth of *C. botulinum* and other foodborne pathogens in a wide variety of MAP produce stored under conditions which might favour the growth of these organisms e.g. where the cool chain has not been properly managed..

It is highly unlikely that O_2 levels of <1% will be reached with bulk packaging, as most bulk MAP applications aim for an in-pack O_2 level >3%, unless an entirely inappropriate film in terms of gas permeability has been selected or there has been a high level of temperature abuse.

3. Review of current MAP applications in the field vegetable sector

Table 3 summarises current MAP applications in the field vegetable sector on a product basis. Details of the benefits of MAP and potential for injury are presented, together with information on the types of MAP formats commercially available, their commercial or potential use (e.g. in extending season) and where they are being used. A more detailed list of the commercial benefits offered by MAP to growers is presented in Box 5 using brassicas as an example. These benefits could apply equally to other produce items.

Where it's known, an indication of the potential storage and shelf-life for each produce item under MA are quoted in the final column of Table 3. These figures have been extracted from the literature (scientific and company) and should be treated with some caution, as both the potential storage and shelf-life will be dependent upon many factors, including the conditions of the supply chain, the water vapour and gas transmission properties of the MA package etc.

Box 6. Potential value to growers for storing Brassicas under MAP.

- Field pack directly into bulk liners and/or bag-in-box systems.
- Prolonged storage can aid stock management during periods of over-supply and other fluctuations in crop production.
- Picking ahead of bad weather forecasts.
- Extending season.
- Minimal processing of brassicas during a less busy period e.g. trimming of Brussels sprouts, preparation of broccoli florets etc.
- Picking tender young brassicas e.g. baby sprouts, to supply the tail end of the season when baby sprouts are not available.
- Picking brassicas e.g. Brussels sprouts in advance of the Christmas period (a period of high demand).
- Reduces waste in the supply chain.
- Eliminates need for ice for broccoli (no need for waxed cartons, no mess from ice etc.)

Table 3. MAP applications for field vegetable crops (including herbs).

Product	Benefits of MAP	Potential for injury[1]	MAP formats commercially available	Commercial or potential use	Countries of use	Comments/Remarks
Asparagus (Tips and spears)	• Reduces dehydration and weight loss. • Reduces stem curvature. • Reduces lignification i.e. stem more tender. • Maintains good colour. • Maintains flavour. • Prevents internal breakdown. • Reduces rots due to *Phytophthora*. • Maintains antioxidant levels.	• High CO_2 levels can cause pitting at storage temperatures of 6.1°C but no injury detected at 1.7°C	• Retail formats include: microwaveable pouches/bags; lidded punnets/trays. • Food service packs. • Carton liners.	• Suitable for road, sea and air shipment. • Extend UK season. • Stock management.	• UK • Peru • USA	• MA is highly beneficial to maintaining storage and shelf-life of asparagus. *Storage life: Up to 4 weeks @ 1-2°C.* *Shelf-life: 5 days @ 6-8°C*
Broccoli (Heads, florets and spears). (Includes purple sprouting broccoli)	• Minimizes dehydration and weight loss. • Maintains firmness and tight head. • Retention of green colour. (No yellow buds.) • Good stem condition at butt end (reduced discolouration and dehydration). • Retards decay.	• Off-odours reported when stored at low O_2<0.5% for 24 hours. • Persistent off-odours develop at high CO_2 levels. (>15%).	• Retail formats: bags; lidded punnets and trays. • Food service packs • Carton liners. • Bag-in-box design • Pallet hoods.	• Currently used for land and sea transportation. • Eliminates the need for ice, therefore there is a saving in terms of shipping costs; less mess and no need for waxed cartons. • Potential to pack directly into cartons in the field.	• USA • UK • Spain • Japan	• Used widely on a commercial level. *Storage life: Up to 30 days @ 1-2°C.* *Shelf-life:4/ 5 days at 6-8°C*

[1] Potential for injury will be dependent on a number of factors, including variety. For this reason, threshold levels cannot be stated with any certainty.

Product	Benefits of MAP	Potential for injury	MAP formats commercially available	Commercial or potential use	Countries of use	Comments/Remarks
Brussels Sprouts (Trimmed and untrimmed)	• Reduced dehydration and weight loss. • Retains firmness. • Maintains the green colour. • Reduced yellowing. • Retards butt discolouration.	• Internal discolouration and off-odours at O_2<1%	• Retail formats: bags (microwaveable); lidded punnets and trays. • Food service liners. • Carton liners.	• Suitable for long term storage. • Extend season. • Stock management. **For further details see Box 6.**	• UK • RSA • USA	• Brussels sprouts are being held in CA stores in The Netherlands. *Storage life:* 28 days @ 2-5°C. *Shelf-life: Up to 7 days@ 6-8°C.*
Cabbage (Head/ leaves/ shredded)	• Reduced dehydration and weight loss. • Reduced colour loss. • Inhibits root growth. • Reduced rots.	• Increased sensitivity to freezing and off-flavours at O_2<2%. • Discolouration of inner leaves and apex, off odours at CO_2>10%	• Retail format: bags • Carton liners • Pallet hoods	• Long term storage.	• UK • USA	• This is perhaps the most common vegetable to be stored commercially in CA storage conditions.
Carrot (Baby/ peeled/batons/shredded) (Orange and purple varieties)	• Reduced sprouting and rooting. • Vitamin A and antioxidant activity in purple carrots increased with storage in MAP.		• Retail packs for baby carrots e.g. trays. • Food service industry • Carton liners	• Extend shelf-life of baby carrots. • Inclusion in vegetable medleys/salads.	• UK	Not widely used. *Storage life: Up to 5 months at 0°C*
Cauliflower (Head and florets)	• Reduced dehydration and weight loss. • Maintains crunchiness • Maintains white curd and green leaves. • Reduced curd spotting. • Reduced rots and decay	• Persistent off-flavour and odour develops after cooking when previously stored at O_2 below 2% and/or high CO_2.	• Retail packs: bags, punnets, trays. • Food service packs • Carton liners	• Extend storage • Preparation and short-term storage of florets.	• UK • Spain	*Storage life: Upto:6 weeks@ 0-3°C.* *Shelf-life: Up to 5 days @ 8°C.*

Product	Benefits of MAP	Potential for injury	MAP formats commercially available	Commercial or potential use	Countries of use	Comments/Remarks
Fennel	• Reduced dehydration and weight loss. • Maintains flavour. • Retains crispness • Maintains colour. • Inhibits browning at the cut end.	• Unknown	• Retail packs: bags. • Carton liners.	• Extends shelf-life.	• UK • The Netherlands	
Herbs (Chervil, Chives, Coriander, Dill, Mint, Mizuna Parsley, Rocket, Sorrel, Watercress)	• Reduced dehydration and weight loss. • Reduced wilting. • Reduced leaf abscission. • Maintains green colour. • Reduced decay.	• Not reported.	• Retail packs. • Carton liners.	• Extend shelf-life.	UK Egypt Israel Australia	• Studies report no benefits for storing basil under MA. *Storage life:* *Chive s, dill: 2 weeks@ 2°C+ 3 days @ 10°C* *Mint: 3 weeks @ 2°C+ 3 days @ 10°C.* *Coriander: 3 weeks @ 2°C and 1 week at 10°C* *Parsley: 4 weeks @ 2°C and 1 week at 10°C* *In Australia, one MAP company claims 10 days shelf-life for a range of herbs (conditions unknown).*
Horseradish	No advantages for MA					
Leek (Untrimmed, trimmed and baby)	• Reduced dehydration and weight loss. • Reduced curvature and regrowth (telescoping). • Maintains colour. • Reduced decay.	• None reported.	• Retail packs: bags and trays. • Food service bags. • Carton liners.	• Extend season/storage of harvested and trimmed product.	• UK	*Storage life: Upto7 weeks@ 1°C.* *Shelf-life: 3/4 days @ ambient temperature.*

Product	Benefits of MAP	Potential for injury	MAP formats commercially available	Commercial or potential use	Countries of use	Comments/Remarks
Lettuce (Crispheads and leafy types) (Heads/ leaves/ shredded)	• Reduced dehydration and weight loss. • Reduces senescence. • Inhibits butt discolouration. • Inhibits pink rib • Reduced russet • Inhibits chlorophyll breakdown and yellowing • Retains crispness	• Low O_2 can lead to breakdown at centre and high CO_2 may lead to brown stains. • Cultivar dependent. Leafy lettuce types are more tolerant to high CO_2 than crispheads.	• Retail packs: individual wraps for heads, bags for mixed salads. • Carton liners.	• Extend shelf-life. • Extend transit times. • Food service industry e.g. McDonalds. • Retail retrim unnecessary	• USA • UK	• MAP used primarily for retail salad packs. Typically this involves active MAP, where the pack is flushed with nitrogen. *Storage life: 7-25 days @ 0°C*
Onion (bulb)	No real advantages.	• Below 0% O_2 leads to breakdown and off-odours. • CO_2 above 10% for short terms storage leads to accelerated softening and rots; putrid odour		Not commercially used		
Parsnip (Including baby parsnips)	• Reduced dehydration and weight loss. • Preserves the natural white colour by preventing oxidation. • Maintains firmness and freshness. • Reduced sprouting. • Reduced decay.	None reported.	• Retail packs: bags and trays • Service liners • Carton liners	• Extend storage and shelf-life.	• UK	*Storage life: Up to 3 month 3 months @ 0°C.* Or Storage life: 30 days@ 0°C + 4 days @ 4-7°C.

Product	Benefits of MAP	Potential for injury	MAP formats commercially available	Commercial or potential use	Countries of use	Comments/Remarks
Pea (garden pea) (Shelled or in the pod)	• Reduces dehydration and weight loss. • Retains colour. • Retains sweetness.	None reported.	• Retail packs e.g. pouches (steamers) for shelled peas. • Carton liners for pods.	• Extend shelf-life. • Extend storage life.	• UK • USA	
Potato (New potatoes and salad potatoes)	• Reduced dehydration and weight loss. • Reduced sprouting. • Reduced rotting.		• Retail packs e.g. film sealed punnets or bags of baby and salad potatoes.	• Extend shelf-life	• UK	
Runner beans (Whole and sliced)	• Reduces dehydration and weight loss. • Reduced colour loss. • Reduced yellowing. • Less discolouration at cut ends. • Reduced decay. • Reduced chilling injury symptoms.	• Off-flavours reported at low O_2< 5% for 24 hours. • High CO_2 can result in off-flavours.	• Retail packs include: pouches (steamers), bags. • Food service packs • Carton liners	• Transportation (land and sea). • Extended shelf-life.	• USA • Kenya • Egypt • Morocco • Guatemala	*Storage life: 3 weeks @ 5-7°C* *Shelf-life: 5 days at 8°C*
Spinach	• Reduced dehydration and weight loss. • Reduced yellowing.	• Can produce high levels of ammonia under raised CO_2 levels				• Not stored under MA commercially.
Spring onion	• Reduced dehydration and weight loss. • Minimises regrowth and curvature. • Minimises yellowing.	• Non reported	• Retail packs: bags and trays. • Carton liners.	• Transportation by both air and sea. • Extend shelf-life.	• UK • Egypt • Mexico • USA	• Used extensively commercially. *Storage life: 3 weeks @ 0°C* *Shelf-life:3/4 days at 8°C*

Product	Benefits of MAP	Potential for injury	MAP formats commercially available	Commercial or potential use	Countries of use	Comments/Remarks
Squash (Courgette, marrow, summer and winter squash, pumpkin)	• Reduced dehydration and weight loss. • Maintains firmness. • Inhibits the development of chilling injury symptoms e.g. pitting. • Reduced moulds.	• High CO_2 can lead to off-flavours.	• Retail packs: bags, trays. • Carton liners	• Extend shelf-life. • Extend season.	• USA • UK	*Storage life: 3 weeks @ 5-7°C* *Shelf-life:5 days at10°C*
Swede	No advantages.					
Sweetcorn (Sheath, unsheathed)	• Reduced respiration, sugar conversion and senescence. • Minimises dehydration and weight loss, thereby preventing dimpling of kernels and preserving crispiness. • Reduced moulds on husks and stem. • Prevents trim discolouration.	• Injurious level of O_2<2% leading to off-flavours and odours. • CO_2>10% resulting in off-flavours and odours.	• Retail packs: trays, bags (microwaveable). • Carton liners.	• Long distance transportation. • Long term storage.	• UK • USA • RSA	*Storage life: 3 weeks @ 2°C* *Shelf-life:5 days at8°C or 4 days at ambient*.
Turnip	No advantages					

4. Benefits and disadvantages of MAP versus other technologies for storing field vegetables.

4.1. General

Although there is no technological substitute for good post-harvest management of temperature and relative humidity, the use of post-harvest technologies such as modified atmosphere packing or controlled atmosphere storage may offer benefits to the grower in terms of extending the marketable life of fresh produce and reducing waste. The following section summarises the potential benefits and disadvantages of using MAP from the perspective of the grower. This is followed by a discussion of the pros and cons of MAP *versus* controlled atmosphere storage. The latter section includes comparative costs for MAP, CA and conventional cold storage.

4.2. Benefits and disadvantages of using MAP

Tables 4 to 6 summarise the potential benefits and disadvantages of using MAP (retail and bulk packaging) from a technical, commercial and environmental perspective, respectively.

4.3. MAP *versus* CA.

4.3.1. Pro's and con's

MAP and CA have long been used for storage and transportation of fresh produce. Whilst MA systems generally use product respiration and passive technology to generate the required atmosphere, CA systems actively manage the composition of the storage atmosphere and thereby have the advantage that any combination of O_2 and CO_2 can be used for the product. However, CA storage is relatively expensive (see section 4.3.2) as it requires a dedicated store which is air tight and additional equipment for monitoring and controlling the gas atmosphere. Another disadvantage of using CA is reduced access to monitor the quality of produce in store. In comparison, modified atmosphere packaging offers the advantages of being a lower cost technology (see section 4.3.2) that can be held in a conventional cold store and can be used in the supply chain in a more flexible way i.e.

i) Direct packing in the field into MAP carton liners using an integrated bag-in-a box design (see Appendix A for details of suppliers) or loose liners in cartons. The product is then pre-cooled and transported or stored. The product can be kept in the liner up to the point of sale (varies with the multiples).

ii) Packing into carton liners after trimming/preparation of florets etc. Again the product can be under MAP up to the point of sale (varies with the multiples).

iii) After pre-cooling, the cartons/trays can be covered with a pallet hood/shroud. The product can be stored and transported under the pallet hood.

iv) Retail packaging, where the product (heads, florets etc.) can be packed into MAP at the packhouse and remains under MAP throughout the supply chain to the consumer's home.

Table 4. Technical benefits and disadvantages.

Potential benefits	**Disadvantages**

• MAP and CA can extend the storage and market-life of fresh produce over that held under refrigerated conditions alone. The extra storage and/or shelf-life conferred by MAP are dependent on the factors outlined in section 2.2.6.
 	
• MAP can reduce losses in the supply chain, for example by:
  • Slowing down the ageing and senescence processes of the produce e.g. yellowing of leafy vegetables;
  • Minimising re-growth of leeks and the need to trim;
  • Reducing discolouration of cut ends e.g. cut butts of broccoli;
  • Maintaining high relative humidity in the package reduces water loss and subsequent weight loss for a wide range of produce e.g. asparagus
  • Reduced development of micro-organisms which cause decay and the spread of decay within a store or container.
 	
• MAP can maintain the atmosphere throughout the supply chain from the grower/packer to the consumer e.g. using MAP retail packs packed at source. In comparison, the use of CA is restricted to storage and transportation.
 	
• MAP is an inherently safer product with physical protection from contaminants, foreign matter and pathogens.
 	
• MAP films can be used as a carrier of fungicides, scald inhibitors, ethylene absorbers, or other chemicals to optimise storage and marketing life.
 	
• With produce like broccoli, MAP can eliminate the need for ice and all its problems and costs i.e. no ice or waxed cartons required; eliminates the potential contamination from ice, as well as eliminates the messy slush resulting from melted ice.
 	
• Some MA films can be used for microwavable or steamer retail packs.
 	
• Fresh flavour and nutritional value is preserved during prolonged storage.
	• MA systems generally use product respiration and passive technology to generate the required atmosphere. However, there can be a delay of up to 48 hours or so before the optimum gas levels are reached. This may have implications in terms of disease control and storage life, although if the product is properly maintained in the cool chain this is unlikely to be much of an issue. CA systems have an advantage over passive MAP in that it can actively manage the composition of the storage atmosphere.
	
	• Breaches in the cool chain can for some MAP products lead to:
	  • Increased potential for water condensation within the package which may encourage fungal growth.
	  • High temperatures that may result in the development of anaerobic conditions, which can encourage the growth of anaerobic bacteria and reduce product quality and market life.

Table 5. Commercial benefits and disadvantages.

Potential benefits	Disadvantages

• Reduced losses:
  • Water loss is a reduction of saleable weight and thus a direct loss to the grower/packer. With little or no weight loss there is no need to over-pack there by leading to savings in raw material and transportation costs.
  • Reduced decay leads to reduced economic losses.
 	
• Ability to hold produce longer can offer the following benefits:
  • Aid stock management
  • Extend season facilitating off-season sales.
  • Picking ahead of poor weather forecasts.
  • Takes advantage of market price fluctuations i.e. hold low sell high.
  • Fresh produce can be transported using less expensive methods i.e. sea freight as opposed to air freight.
 	
• Facilitate market expansion through:
  • Ability to offer new/novel products e.g. baby sprouts picked early in the season to supply the tail end of the season when baby sprouts are not available; microwaveable or steamer packs for asparagus, green beans, peas etc.
  • Extend season facilitating off-season sales.
 	
• No dedicated cold stores are required to store MAP products
	• MAP packaging is more expensive than non MAP-packaging. (See Table 7.)
	
	• MAP retail packaging may need modifications to packing line e.g. inclusion of a flow-wrapper etc.
	
	• Increased labour costs if product is hand packed into MAP retail packs.
	
	• Product that is precooled in open MAP bulk liners as opposed to packing pre-cooled product into a MAP liner will slow down the cooling process.

Table 6. Environmental benefits and disadvantages

Potential benefits	Disadvantages
• Reduced product waste.	• Increased packaging waste. Some but not all MAP films are recyclable. Depending on the local infrastructure, recyclable films can end up in landfill where little or no energy recovery can take place. Most MAP materials are neither biodegradable nor compostable.

4.3.2. Comparison of estimated costs of conventional cold storage *versus* MAP and CA

Table 7 includes some estimated costs for conventional cold storage, MAP and CA. The figures are for a complex of 8 stores with a 150t capacity per store. These figures should be treated as a rough guide only as actual costs will be dependent upon a number of factors, including size of the store (economies of scale come into play) and whether the build is on a green site or a modification of an existing facility. Although growers may have individual cold stores of 150t capacity, it is not cost-effective to build and run a CA store of this small size. On the other hand larger CA facilities will only be economic for volume products of medium to high-value or where there is an economic benefit in storing products with a view to selling when market prices are higher.

Table 7. Comparison of estimated costs of conventional cold storage *versus* MAP and CA. *Assumptions: 8 stores of 150 t capacity/per store; refrigeration shared between 8 stores.*

Costs	Conventional cold storage	MAP (+ cold storage)	CA (+ cold storage)
Capital costs. (Building, insulation, refrigeration, gas monitoring and control equipment)	£450 per tonne £67,500 per 150t store.	£450 per tonne	£550 per tonne £82,500 per 150t store.
Operating costs: energy	£110 per day for a block of 8x 150 tonne stores. Approx. £40,000 per year	£110 per day for a block of 8x 150 tonne stores. Approx. £40,000 per year	£110 per day for a block of 8x 150 tonne stores. Approx. £40,000 per year
Operating costs: maintenance	£2500 per year	£2500 per year	£4500 per year
Time taken to pre-cool product.	Cold storage = CA storage	If pre-cooled material is placed in the MAP liner, there is no impact on cooling time. However if pre-cooling is undertaken with warm material packed in the liner, pre-cooling time will be doubled.	Cold storage = CA storage

In terms of building and operating costs, CA storage is typically between 15-30% more expensive than conventional cold storage. In comparison, the use of MAP does not incur additional build costs. However, there is an implication in terms of packaging costs (see Table 8). In all instances, MAP materials are more expensive than their non-MAP counterparts. However the benefits of using MAP in terms of reduced losses, extended shelf-life, increased sales etc., may result in increased profit margins. It is important that a full cost-benefit analysis is undertaken when deciding whether MAP is appropriate for a particular application (produce item and supply chain).

Table 8. Comparative costs for non-MAP and passive MAP packaging.

Packaging	**Non-MAP**	**MAP**
Carton liner	2-10p per liner for a 60x40cm carton. For 1 tonne of produce packed in 10 kg liners: *£6.00 (av. Price)*	12p-20p depending on size of carton and film. For 1 tonne of produce packed in 10 kg liners: *£16 (av price)*
Pallet hood	Not applicable	£85 per 100 pallet hoods. 1 pallet: £0.85 Assuming 70kg product on 1 pallet: *£1.21 per 1 tonne product.*
Retail packaging e.g. 1kg polybag.	Polybag (1 kg): £15 -25 per 1000. (Price depends on whether bag is printed and how many print colours.) For 1 tonne of produce packed in retail bags (1kg pack size*): £15-£25 per tonne.*	MAP retail bag (1kg) 2p-5p per bag. (Price depends on whether bag is printed.) For 1 tonne of produce packed in retail bags (1 kg pack size): *£20- £35 per tonne.*
Giro net e.g. 1 kg net	Giro net (x wt). £15.70 per thousand metres. For 1 tonne of produce packed in giro net (1kg pack size*): £5.23 per tonne.*	Not applicable.

**Actual costs will depend upon number of units purchased and the price of oil.*

5. SUMMARY

The past 10 years or so has seen a rapid expansion in the use of MAP for maintaining quality and extending the storage and/or shelf-life of horticultural produce, particularly for fresh cut or minimally processed products. In the early days of MAP, its use was largely restricted as a result of the unavailability of appropriate films that provide safe and beneficial atmospheres. However, today we have a much better understanding of the interactions of temperature, O_2 and CO_2 concentrations, film permeabilities, use of microperforations etc. This has led to improved selection of appropriate films for each product (produce item and supply chain) and the development of a broad range of packaging formats: bags, pouches, rigid plastic containers with gas diffusion window(s), flow-wrap trays and punnets. Further advances in the field of MAP are continually being made e.g. the development of antimicrobial MA films and other 'smart' technologies such as temperature responsive MA films.

For many field vegetables, MAP can provide significant benefits in terms of extending storage life and shelf-life whilst maintaining the quality and nutritional status of the product – so long as the cool chain is managed properly. This has lead to a rapid growth in the appearance of retail MA packs for vegetable salads and minimally processed vegetables e.g. asparagus tips, green bean slices, pea and green bean mixes, sweetcorn and new potatoes etc. In addition there has been a widespread uptake of bulk MA products (carton liners and pallet covers) in a number of producer countries (particularly the USA) for commercial storage and/or shipment of some field vegetables, namely: asparagus, broccoli, green beans, lettuce and spring onions.

Potential benefits to the UK grower are many e.g. extending season of short-season produce items such as asparagus, however it is imperative that a full cost-benefit analysis is undertaken for each potential application prior to the adoption of this technology. Whilst MAP is likely to be a better option than CA for most UK growers, it is a more expensive technology than conventional cold storage and therefore may only be viable for medium to high value crops and/or where there is a real commercial advantage in storing the product in an MA package e.g. with a view to selling when market prices are higher.

APPENDIX A: Suppliers of MAP

Type	Manufacturer	Product	Description
Retail/food service	Amcor Flexibles Ltd. Lower Road Industrial Estate, Ledbury, HR8 2DJ Tel: 01531 638638 www.amcor.com	P-Plus (passive MA)	• Tailoring gas permeability of flexible films to extend life of fresh produce by naturally creating a modified atmosphere, by using the technology of microperforation. (Varying number and size of perforation). • A wide permeability range to cover all types of fruits and vegetables packed in any format for the retail and foodservice market. **Applications: Asparagus, Beans, Broccoli, Brussels Sprouts, Chicory, Leeks, New Potatoes, Radishes, Spinach, Sweetcorn.**
	Amcor	P-Plus extra (passive and active MA)	• Low and controlled levels of permeability for optimal shelf life. • Maintains positive oxygen in the packs (>2%). • Gas flushing may have a synergistic effect on products sensitive to discolouration. **Applications: Prepared salads. Vegetable and Leaf blends, Chicory, Watercress**
	Amcor	Agrifresh	• A range of speciality films, which utilises Amcor's extensive range of film technology. Each film has been developed to have a specific permeability from the expert choice of its components. Involves laminates and co-extrusions of two or more films which have been combined to convey properties that are not possible with a single film e.g. a laminate of oPP to PE will have the stiffness & clarity of oPP but with the excellent seal performance of PE. **Applications: Iceberg , Romaine, Salad mixes with vegetable inclusions, Leafy Greens**
	Landec Corporation, Inc, 3603 Haven Avenue, Menlo Park, CA, 94025, USA 01-800-277-3075 www.landec.com	Retail and food service	Modified atmosphere packaging systems based on a super-high oxygen permeable membrane that responds to temperature changes in a controllable way. **Applications: Fresh-cut produce**
	Long Life Solutions Ltd., Fenton Barns, North Berwick East Lothian Scotland www.longlifesolutions.co.uk	LLS Smartbag LSS Smartpunnet	One film is used for all produce. The film has higher gas permeability than PE and PP and works on the basis of passive MA, whereby the product regulates the gas atmosphere within the package. **Asparagus, Aubergines, Beetroot, Button Squash, Broccoli, Brussels Sprouts, Carrots, Celery, Cucumbers, Dwarf french beans, Courgettes, Fennel, Herbs, Legumes, Lettuce (romaine, iceberg), Mushrooms, Mange Tout, Parsnips, Sweetcorn, Sweet Potato**

Type	Manufacturers	Product	Description
	Peakfresh Multiflex Packaging Pty Ltd., 103 Bernard Street Cheltenham Victoria 3192 Australia www.peakfresh.com	Peakfresh produce bags	Peakfresh products are made from a mineral impregnated film. The film absorbs and removes ethylene gas which prolongs the life and freshness of the produce. It also maintains high levels of humidity **Applications: Asparagus, Aubergine, Beans, Beetroot, Button Squash, Capsicum, Celery, Chokos, Courgette, Parsnips, Parsley, Peas, Silver Beet, Snow peas, Spinach, Sweetcorn.**
	Stepac LA Ltd. Tefen Industrial Park, Building 12, PBO#73-24959, Tefen Israel www.stepac.com Tel: 00 972 4 9872131	Xtend®	Modified Atmosphere and Modified Humidity (MA/MH) packaging technology. Xtend® manufactured film and bags are engineered to create a produce-specific modified atmosphere (correct balance between O_2 and CO_2) but also, and of equal importance, to maintain the proper humidity level inside the bag, allowing excess moisture to escape into the environment. Produce microwaveable films. **Applications: Asparagus, Bell pepper, Broccoli, Brussels Sprouts, Chillies, Cucumber, Eggplant, Fresh Herbs, Green Beans, Green Onion, Leek, Okra, Parsnips, Snow Peas, Squash, Sweetcorn**
Carton liners	Amcor	Lifespan (passive)	Lifespan is a range of tailored permeability carton liners for modified atmosphere packaging of bulk fresh produce. It naturally sets up beneficial oxygen and carbon dioxide gas levels. Can be used to keep a wide range of vegetables in excellent condition for a longer period of time. **Applications: Asparagus, Beans, Brassicas, Chicory, Sweetcorn, Leeks, Parsnips, Potatoes, Radishes, Brussels sprouts, Spinach**
	Long Life Solutions Ltd., Fenton Barns, North Berwick East Lothian Scotland. www.longlifesolutions.co.uk	LLS Smartbag	One film is used for all produce. The film has higher gas permeability than PE and PP and works on the basis of passive MA, whereby the product regulates the gas atmosphere within the package. **Asparagus, Aubergines, Beetroot, Button Squash, Broccoli, Brussels Sprouts, Carrots, Celery, Cucumbers, Dwarf french beans, Courgettes, Fennel, Herbs, Legumes, Lettuce (romaine, iceberg), Mushrooms, Mange Tout, Parsnips, Sweetcorn, Sweet Potato**

Type	Manufacturers	Product	Description
	Peakfresh	Peakfresh Carton liners	Available in 25 and 35 micron gauge in clear and green tint. The film removes ethylene gas given off by the stored produce, maintains high levels of humidity and extends freshness.
	Stepac L.A. Ltd	Xtend	See under retail packs
Pallet covers	Long Life solutions	See above	Pallet box wrapped in heavy gauge polyethylene, with a silicone membrane window to allow gas exchange regulation and a calibrated hole for pressure regulation.
	Peakfresh	Bulk bin liners and Covers	Bulk bin liners and covers available in 50micron clear film.
	Transfresh P.O Box 1788 Salinas, CA 93902 www.transfresh.com	Tectrol System (TransFRESH Co)	Pallet box bulk unit-wrapped with a barrier plastic film; gases are injected and the bag sealed. **Application: Asparagus, Sweetcorn, Lettuce.**

The mention of a product name in this review does not constitute a recommendation and the absence of a product name does not imply a criticism of that product.

APPENDIX B. References

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