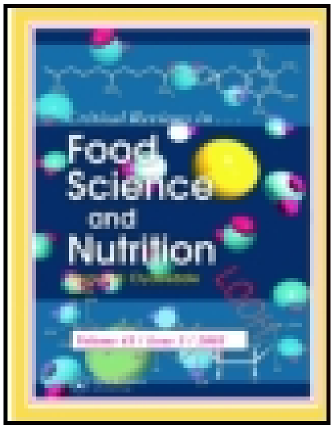

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Recent Developments in Film and Gas Research in Modified Atmosphere Packaging of Fresh Foods

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Recent developments in film and gas research in modified atmosphere packaging of fresh foods

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ABSTRACT

Due to the rise of consumer's awareness of fresh foods to health, in the past few years, the consumption of fresh and fresh-cut produces has increased sturdily. Modified atmosphere packaging (MAP) possesses a potential to become one of the most appropriate technologies for packaging fresh and fresh-cut produces. The MAP has advantages of extending the shelf-life, preserving or stabilizing the desired properties of fresh produces, and convenience in handing *and distribution. The success of MAP-fresh foods depends on many factors including types of fresh foods, storage temperature and humidity, gas composition and the characteristics of package materials. This paper reviews the recent developments highlighting the most critical factors of film and gas on the quality of MAP fresh foods. Although the innovations and development of food packaging technology will continue to promote the development of novel MAP, concentrated research and endeavours from scientists and engineers are still important to the development of MAP that focuses on consumers' requirements, enhancing product quality, environmental friendly design, and cost effective application. .*

Keywords Fresh foods, Modified atmosphere packaging, Nano active films, Micro-perforated films, Noble gases, Gas oxides

INTRODUCTION

The increase in consumersô awareness of fresh foods to health and their willingness to pay higher price for better quality foods have provided strong incentives to food industries to apply advanced technologies to preserve the freshness, prevent nutrient losses, while offering convenience consumption of processed foods. There is also an increasing trend towards consumption of fresh and fresh-cut produces such as leafy vegetables (in consumer-size package), tomatoes, peppers, fresh herbs, sprouted seeds and exotic fruit mixes (Jacxsens et al., 2010). Fresh produces possesse the best possible quality at harvest, which cannot be improved but can be maintained to a reasonable extent during postharvest (Kader, 1986). There are several factors that limit the fresh produce consumption. Firstly, it is recognized that the consumption of fresh produces can be a source of food borne diseases and the outbreaks of food borne diseases from fresh foods appear to be on the rise. Secondly, how to maintain the freshness and good quality of off-season produces and fresh produces, especially fruits and vegetables coming from geographically different locations (or exotic), is a big challenge to postharvest processors. This challenge arises from the fact that fresh fruits and vegetables are biologically active for a considerably long time after harvest due to both metabolic activity (e.g. respiration), and external adverse factors such as physical injury, presence of microbial flora, loss of water and variable storage temperature (Kader et al., 1989; Phillips, 1996).

MAP is a technique used for extending the shelf-life of fresh and minimally processed foods

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(Sandhya, 2010). It involves the removal and/or alteration of the head-space atmosphere surrounding the products before sealing in containers or packages with desired gas-barrier properties (McMillin, 2008). The application of MAP has a history of nearly 90 years (Table 1) (Arvanitoyannis and Stratakos, 2012; Kerry et al., 2006; Phillips, 1996; Siracusa et al., 2008). The first recorded application of MAP goes back to 1927 when the shelf-life of apples was extended by storing them in an atmosphere with reduced O_2 and increased CO_2 concentrations (Phillips, 1996) (Table 1). In 1930s, the application of MAP was gradually applied in the preservation of fresh meats. Later in 1970s and early 1980s, its application was started in bacon, fish (both fresh and cured), sliced cooked meats and cooked shellfish. In 1990s, the MAP was commonly applied in fresh or chilled foods (Phillips, 1996). There were about 10-20 international publications per year on MAP from 1995 to 2000, but this was increased dramatically from about 60 in 2001 to near 190 in 2011 (Fig. 1) . These publications indicate an increasing interest in MAP in the scientific community. Among the 1411 journal articles published between 1995 and 2010, the distribution of the articles was 17.4% for fruits, 23.7% for vegetables, 29.4% for meat, 14.2% for fish products and 8.5% for other foods (e.g. egg, bread, chocolate, cheese, cake and pizza) (Fig. 2). Furthermore, about 6.8% of the published papers deal with the fundamentals and mathematical models of MAP. Among these papers, an overwhelming number (79.0%) of articles are related to the fresh produces including fresh fruits, vegetables, meats, fish products, eggs, ginseng, fennel and almond kernel. This may due to the fact that the

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fresh produces are more susceptible to microbial spoilage. The fresh produces have inherently higher respiration rate and/or higher water activity compared with other foods, which generally result in fast quality deterioration and short shelf life. The MAP is an ideal technology to preserve these fresh produces to improve the microbial safety and also product quality.

There are many factors that affect the efficacy of MAP of fresh produces. These factors include types of food, storage temperature, gas composition and the characteristics of package material used. It is very important to optimise the MAP parameters according to the type of the foods. The storage temperature is a critical factor affecting metabolic processes of fruits and vegetables such as their respiration and ripening rates. Furthermore, the stability of microbial population and growth in the produce is also highly correlated with temperature. Most of the researches have combined MAP with chilling storage at the temperature ranging from 1-8 °C, because higher temperatures inversely correlate to the safety storage time (Lyver et al., 1998).

Most of the packaging materials used in MAP are made from polyamide (PA), polyethylene (PE), polystyrene (PS), polyvinylchloride (PVC), polyester (PES), polyethylene terephthalate (PET), polypropylene (PP), ethylene vinyl alcohol (EVOH), low density polyethylene (LDPE), low linear density polyethylene (LLDPE) and polyvinylidene chloride (PVDC) (Arvanitoyannis and Stratakos, 2012). Other materials such as nylon (Özogul and Özogul, 2006; Siripatrawan et al., 2009), zein (Rakotonirainy et al., 2001), and hermetic stainless steel (Ruiz-Capillas and Moral, 2004) are also used in MAP. In addition, materials such as Cryovac B2650 bags, Riloten

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40/70X bags, biorientated polypropylene (BOPP) bags, microperforated PA-190 film, stomacher bag, macro-perforatedpackages and PD-961EZ bags are commercially available (Singh et al., 2011). The air permeability of the packaging materials is very important to MAP and the materials with low permeability are generally desirable. In practice, to select appropriate packaging films/materials to foods, one has to take into account the protection they can provide, as well as the strength, sealability, clarity, easy to manufacture, ability to label, and the gas gradient across the sealed films (Farber et al., 2003).

The main gases used in most of MAP are CO_2, O_2 and N_2. These gases are combined with air in certain combinations such as CO_2/N_2, CO_2/O_2, CO_2/air, O_2/CO_2/air and $O_2/CO_2/N_2$, and are applied according to the nature of the food and the storage temperatures.. Other gases such as carbon monoxide (CO), nitrous and nitric oxides, sulphur dioxide (SO_2), ethylene, chlorine, ozone, propylene oxide and noble gases (e.g. Argon, Xenon, Krypton and Neon) have been recommended and investigated in MAP (Farber et al., 2003; Phillips, 1996; Sandhya, 2010). However, due to safety, regulatory and cost considerations, most of the above mentioned gases other than N_2, CO_2 and O_2 are not applied commercially (Farber et al., 2003; Sandhya, 2010). In this review, we are tentatively analysing the recent developments in film and gas research in modified atmosphere packaging of fresh foods. The future research trends and directions of MAP will also be proposed.

RECENT DEVELOPMENT IN MAP FILM RESEARCH

MAP involves the use of plastic films for the packaging of products. There is no doubt that MAP films should be selected appropriately according to their gas permeation properties. There are many factors influencing the film permeability, among which polymer type and film thickness are the most important (Mangaraj et al., 2009). Due to differences in the respiration rates of individual fresh foods, the type of plastic film required to achieve any special equilibrium atmosphere must be defined for each commodity. Although most packs are constructed from commonly used four basic polymers, e.g. PVC, PET, PP and LDPE, for packaging of fresh foods, the MAP industry has been increasingly interested in development and application of new packaging films. In recent years, some typical films that have been attracted great attention include antioxidant active films, nano active films, biodegradable films, and micro-perforated films (Table 2). It should be noted that not all these films have been widely used in MAP practice, but their applications in this area is believed to be promising because of their improved positive properties and particular functionalities.

Antioxidant active films

Oxidation is one of the most important degradation reactions in foodstuffs, which seriously limits their preservation and has negative influences on nutritional (such as destruction of vitamins, fatty acids, et al.) and organoleptic qualities (such as colour changes, off-flavours, off-odours etc.) (Nerín et al., 2008). Oxidation not only influences the sensory quality but

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reduces the shelf-life of fresh foods, consequently decreases the product sales. In order to retard or minimize oxidative deterioration of foods, antioxidants may be added. Although synthetic antioxidants have long been used in a variety of foods, their uses have come into dispute due to their suspected carcinogenic potential and consumers preference of natural additives (Camo et al., 2008). In addition to natural antioxidants being added directly to foods, active packages with antioxidant properties have received great attention. Antioxidant active films are one of the most promising alternatives to traditional packaging, in which antioxidants are incorporated into or coated onto food packaging materials to reduce oxidation of the food (López-de-Dicastillo et al., 2011). Compared with direct addition, the active packages technology provides several advantages, such as lower amounts of active substances required, allow slow migration of antioxidants from film to the food matrix, and eliminate additional steps within a standard process intended to introduce the antioxidant at the industrial processing level including mixing, immersion, or spraying (Bolumar et al., 2011).

Nerín et al. (2008) developed an antioxidant active packaging with natural antioxidants from rosemary to extend the shelf life of packaged food, and similar antioxidant active packaging was also applied in minced chicken breast and thigh packaging to delay their oxidation during storage (Bolumar et al., 2011). Camo et al. (2008) compared the active packaging between natural antioxidants from rosemary and oregano on the display life of lamb, and found that active films with oregano extract were significantly more efficient than those with rosemary extract. The

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same research group (Camo et al., 2011) also investigated the active films with oregano extract on the shelf-life of beef steaks, and demonstrated that the oxidative stability of beef steaks was enhanced by 1% oregano extract which significantly increased the display life from 14 to 23 days. López-de-Dicastillo et al. (2011) successfully developed antioxidant active films based on an ethylene-vinyl alcohol copolymer (EVOH) and green tea extract. The results indicated that the films with green tea extract were effective in slowing down the peroxide values of brined sardines, and also reducing the malondialdehyde concentration during the storage. The application of combining modified atmosphere packaging with a new antimicrobial active bag consisting of PP/EVOH film with oregano essential oil or citral has been found effective to inhibit the pathogenic microorganisms *Escherichia coli*, *Salmonella enterica* and *Listeria monocytogenes* and natural microflora of minimally processed salads, and then extend the shelf life (Muriel-Galet et al., 2012a). It was observed that citral-based films were more effective than oregano essential oil in reducing spoilage organisms during the storage. The method of coating the natural antioxidant extracts from barley husks on low density polyethylene film was also proved highly effective in slowing down lipid hydrolysis and increasing oxidative stability of packaged salmon samples (Pereira de Abreu et al., 2010).

Nano active films

Nanotechnology is generally defined as the design, production, and application of structures, devices, and systems through control of the size and shape of the material at a nanometer scale

(Neethirajan and Jayas, 2011). Nanomaterials are a new class of materials that have been proven to be a promising option for packaging materials. The food packaging industry is actively exploring the potential of nanotechnology to obtain new food packaging materials with improved properties (mechanical, barrier) and new functionalities such as antimicrobial activity and monitoring the quality of food (Peter et al., 2012). The most commonly used method to produce nano packaging is incorporating nano metals (e.g. nano-silver, nano-zinc oxide, calcium carbonate nanoparticles, and nano-titanium dioxide) into the films to inhibit the growth of microorganism. The antimicrobial mechanisms of nano metals can be roughly classified into two types: the ability to induce a disruption of the microorganism membrane and change the permeability of microbial cells; through catalysis to affect enzyme systems and the metabolism of bacteria, thus kill the microorganism (Bruna et al., 2012).

Recently, films embedded with nano-silver have been attracted wide interests (Del Nobile et al., 2004; Sontakke et al., 2012; Zhou et al., 2011). The Ag^+-based active film showed a significant effect on inhibiting the growth of *Alicyclobacillus acidoterrestris* and the inhibition efficiency was related to the amount of silver ion released into the medium (Del Nobile et al., 2004). The research results from Zhou et al. (2011) indicated that the nano-structured silver-polyethylene (PE/Ag_2O) packaging could protect the fresh-cut apple against colour degradation and weight loss when they were stored at 5 °C and 15 °C. In addition, the safety test of PE/Ag_2O bag suggested that it could be an alternative for safe food packaging. It was also

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observed that dairy products packed in polyethyleneï TiO_2 nanoparticleï polyethylene packages did not contain TiO_2 after 11 days of storage, suggesting itøs safe in food packaging (Peter et al., 2012). Li et al. (2011) developed a novel nanopackaging by coating PVC film with ano-ZnO powder that showed a significant effect on reducing the decay rate of fresh-cut apple and maintaining a better fruit quality. Also, the nano-ZnO powder-coated PVC film displayed an excellent inhibition effect on the growth of *Escherichia coli* and *Staphylococcus aureus* (Li et al., 2009). Another active nano film was developed by Avella et al. (2007) who incorporated calcium carbonate nanoparticles into the isotactic polypropylene film to reduce the gas permeability of both oxygen and carbon dioxide. The application of the film in the storage of apple slices confirmed that it can retard the oxidation processes and inhibit microbial growth to extend the freshness of the fruits. Some other researchers have used more than 2 nano metal particles to prepare the active packaging film. For example, the LDPE film was blended with a mixed nano-powder of nano-Ag, kaolin, anatase TiO_2, and rutile TiO_2 (Yang et al., 2010), and polyethylene with nano-Ag and nano-TiO_2 (Zhao et al., 2012). Both films showed positive effects on the preservation of the quality of the packaged fruits or green tea.

Biodegradable films

The growing production and application of plastic materials in the world has been a big concern for years as these materials are difficult to degrade and worsen the problem of waste disposal (Avella et al., 2005). These issues have promoted the research in development of

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degradable plastics or other packaging materials. Biodegradable materials are defined as materials that can be degraded by microorganisms into CO_2, H_2O and trace inorganic products under aerobic conditions or to CH_4, CO_2 and inorganic products under anaerobic conditions (Arvanitoyannis et al., 1989). The biodegradable materials which are made from renewable and natural polymers have received considerable interesting in food packaging industry. Most of the biodegradable films are made from organic polymers, such as gelatin (Karnnet et al., 2005), and rice starch-chitosan (Bourtoom and Chinnan, 2008). The starch/clay nanocomposite film was an example of further incorporating of organic polymers with nanomaterials to improve the mechanical properties or functionalities of the film (Avella et al. 2005). The antimicrobial activity of the packaging films was significantly improved by blending biodegradable films (alginate, zein, gelatin-chitosan) with antimicrobial agents (enterocins, essential oils) (Marcos et al. 2007; Gomez-Estaca et al., 2010). It must be noted that an appropriate moisture and gas permeability coefficient is very important to the biodegradable films as it may affect the contamination from both microorganisms and insects, thus the shelf life of packaged foods, for example, plum tomato (Muratore et al. 2005), lettuce (Del Nobile et al., 2008), and fresh green peppers (Koide and Shi, 2007). More information about biodegradable films can be found in a number of critical reviews (Davis and Song, 2006; Gupta and Kumar, 2007; Siracusa et al., 2008).

Micro-perforated films

The key to design a successful MAP of fresh foods is to use a packaging film with appropriate permeability where a satisfying equilibrium modified atmosphere is established when the rate of O_2 and CO_2 transmission through the pack balances the productôs respiration rate (Kartal et al., 2012). In comparison, micro-perforated films have a ratio for O_2/CO_2 transmission approaching 1 and as a consequence the steady-state headspace atmosphere has both a high O_2 and CO_2 composition (Kartal et al., 2012). The mathematical model research of the perforation-mediated modified atmosphere packaging indicated that the rapid development of adequate CO_2 and O_2 levels is the major factor that favours the quality and extends the shelf-life of packaged fresh foods (González-Buesa et al., 2009; Mastromatteo et al., 2012; Mistriotis et al., 2011; Xanthopoulos et al., 2012). For example, Lee et al. (2004) reported that pork loin packed in micro-perforated films had better quality and longer shelf life than that packed in non-perforated films after stored at 1 °C for 14 days. Cliff et al. (2010) also observed that apple slices in micro-perforated packages had lower ethylene concentrations but high CO_2 and high O_2 levels , which resulted in superior fruit quality characteristics. These positive effects of micro-perforated film packaging were also evidenced in storage of broccoli (Nath et al. 2011) and strawberry (Kartal et al., 2012).

RECENT DEVELOPMENT IN MAP GAS RESEARCH

The main gases used in MAP are CO_2, O_2 and N_2. These gases are combined with air in certain ratios and are applied according to the nature of the food and the storage conditions. Recently, some other gases such as gas oxides (carbon monoxide (CO), nitrous and nitric oxides, sulphur dioxide (SO_2), propylene oxide), ethylene, chlorine, ozone, and noble gases (e.g. He, Ar, Xe and Ne) have been investigated in MAP storage (Farber et al., 2003; Sandhya, 2010) (Table 3). This review focuses on the research in gas oxides and noble gases, which show different effects on the quality and shelf life of fresh foods.

Gas oxides

In USA, carbon monoxide is used in the MAP of meat and fish. The maximal CO level of 0.4% is permitted in modified atmospheres packaging of meat while filtered smoke containing 30-40% CO is permitted for pretreatment of fish (Bjørlykke et al., 2011). The existence of CO can inhibit metmyoglobin formation and promote metmyoglobin reduction in meat that reduce lipid oxidation and colour degradation and consequently result in better quality and extended shelf life, as observed in CO pretreated salmon (Bjørlykke et al., 2011), and CO-MAP (0.36% CO/20.34% CO_2) storage of pork chops (De Santos et al. 2007). Interestingly, exposure of brown discoloured ground beef to carbon monoxide is able to turn the meat bright red, suggesting the potential for the industry to misuse carbon monoxide to rejuvenate the colour of spoiled meat, though the odor would remain as a clear inhibitor of such an ill-advised practice. Sulfur dioxide is antimicrobial in its nonionized molecular form and has been widely used in grape storage to protect the fruit decay since 1960s (Nelson, and Ahmedullah, 1976). The release of SO_2 can be

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achieved by using small or large sodium metabisulfite particles and by propriety formulations of the salt and the pad. A new but simple SO_2 release device, e.g. a plastic laminate macro-perforated SO_2 generating pad, was found to have additional barrier to water vapor penetration into the pad but SO_2 diffusion out of the pad decreased in the initial SO_2 release peak and extended the lifetime of the pad, increasing the effectiveness of maintaining the grape quality for a longer time (Zutahy et al., 2008). In addition, combination of slightly CO_2 enriched atmosphere and SO_2 micro-generators had been found an active effect on the storage of table grapes by reducing both weight loss and proliferation of *Botrytis cinerea* (Pretel et al. 2006). Nitrous oxide (N_2O) has been demonstrated to inhibit ethylene production in the controlled atmosphere storage of postharvest climacteric fruits to extend their shelf life (Gouble et al., 1995; Rocculi et al., 2005). The N_2O was used alone or in combination with reduced oxygen levels on the postharvest ripening of mature green banana fruit and the results showed that it slowed down the fruit ripening, and extended the storage life, with no adverse effect on physicochemical qualities (Palomer et al. 2005). This gas was also used in other fresh food packaging and storage, such as fresh-cut pineapple (Rocculi et al., 2009), onion bulbs (Benkeblia and Varoquaux, 2003), strawberry (Zhu and Zhou, 2007), fresh-cut kiwifruit (Rocculi et al., 2005), pears (Liu et al., 2011), and carnations (Bowyer et al., 2003).

Noble Gases

Noble gases are a group of chemical elements that are odorless and colourless and have very

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low chemical reactivity. Noble gases can form clathrate hydrates when dissolved in water and restrict water molecule activity in foods which prolong their shelf life (Zhang et al., 2008). The effects of Ar were reported to interfere with enzymatic oxygen receptor sites and thus reduce metabolic activity of the food product (Spencer, 1995), or reduce microbial growth to improve quality of fresh produces (Jamie and Saltveit, 2002). Some of other noble gases including He, Ne, Kr and xenon Xe have gained interest in recent years (Giménez et al., 2002; Jamie and Saltveit, 2002; Meng et al., 2012; Rocculi et al., 2005; Zhang et al., 2008). For instance, Robles et al. (2010) investigated the effects of high He controlled atmosphere storage on fresh-cut mizuna baby leaves and it was proved to be effective in controlling microbial growth and retaining the bioactive compounds. Wu et al. (2012a) reported that high pressure Ar treatment played an active role in extending the shelf-life of fresh-cut pineapples during cold storage in modified atmospheric packaging. Similar results were also observed in the storage of fresh-cut green peppers (Meng et al. 2012). However, it must be mentioned that different noble gases may have different effects on the MAP storage of foods. In the storage of ready-to-eat arugula leaves, samples in the Ar-enriched atmospheres exhibited respiration rates 13-17% higher than the leaves under He and N_2 enrichment, and the He-enriched atmosphere was the most effective for controlling microbial growth (Char et al., 2012).

Furthermore, noble gases can be mixed together or with other gases (CO_2, N_2) to enhance the effectiveness, such as mixtures of compressed Ar and Xe in storage of asparagus spears (Zhang et al. 2008) and fresh-cut apples and pineapples (Wu et al. 2012b). In comparison with vacuum and over-wrap packaging, MAP with Ar and CO_2 was found to have an advantage on sensorial quality of fresh pork sausages during storage (Claudia and Francisco, 2010).

FUTURE TRENDS OF MAP FOR FRESH FOODS

As discussed earlier, many factors including type of food, storage humidity and temperature, package material (film), gas composition, and the combination of these factors can affect the efficacy of MAP of fresh produces, although only film and gas have been reviewed in the paper. The research on the MAP in food science experienced a fast development in the past decade, as evidenced by the dramatically increased publications from 2001 to 2011 (Fig. 1). It is understandable that different researchers may have different views in this area, the future trends and challenges in application of MAP in fresh foods are tentatively outlined as follows:

1. The MAP technology has a great potential to be one of the most appropriate technologies of packaging fresh, fresh-cut and ready-to-use produces. The increasing demand for fresh foods will promote the development of new MAP technology. The improvement of package technology is normally accompanied by the manufacturersô demand for cost saving and the consumersô demand for more convenient, healthier and nutritionally superior produces. Further study is needed on new gas source, new MAP type, new packing film and new applications to meet the demand of fresh foods.

2. Optimization of MAP parameters is necessary on different commercial fresh foods. As a

technique used for prolonging the shelf-life of fresh or minimally processed foods, MAP involves many important factors and no universal parameters are available for all fresh foods. Thus, it is necessary to optimize the technological parameters based on the nature and the expected shelf-life of different commercial fresh foods.

3. There is a need of research on combination of MAP with other technologies. In order to protect the natural environment and to minimise the pollution due to increased use of packaging materials, development of biodegradable and nano active films in MAP systems is increasingly being emphasized. This is an active research area in the current academic community. In addition, natural additives should be combined with novel MAP films to prevent microbial deterioration or product oxidation. Furthermore, other pretreatments (vacuum cooling/super chilling, coating/dipping, pre-washing etc.) and/or techniques can also be combined with MAP to enhance the MAP efficiency and/or to achieve positive synergic effects.

4. MAP mathematical models regarding the MAP properties should be established and investigated to predict respiration rate, gas exchange, microbial growth, and shelf-life. The predictive models and their implementation tools should incorporate the interactions among the background microflora, food borne pathogens, gas composition and food components in various modified atmospheres used for fresh produces. The predictive system would be useful for studying the effects of different gas environments on the survival and growth of food borne pathogens, protein and lipid degradations, colour and smell variations, as well as their

interactions on the quality of fresh foods. Also, a successful predictive system should be conducive to model changes in MAP during distribution and retail sale using different scenarios of temperature and time.

CONCLUSION

MAP has a great potential to become one of the most appropriate technologies for packaging of fresh and fresh-cut produces. The MAP has advantages in extending the shelf-life, preserving or stabilizing the desired properties of fresh produces, convenience in use and distribution. There are some challenges such as cost associated in designing highly functional packages, requirement of accurate control of storage temperature and requirement of product specific gas compositions. The gas composition and storage temperature for different fruits, vegetables and meat are different. Almost all of the currently designed MAP systems have specific advantages and limitations and balance between microbial safety and product stability should be carefully selected. The use of natural and/or synthetic additives and other preservation technologies in combination with MAP are currently active research areas which offer great opportunities and also big challenges in the future.

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Table 1 History of MAP technology

Year	Application
1927	Apples
1930s	Fresh meats
1970s	Bacon, fish, sliced cooked meats and shellfish
1990s	Fresh and chilled foods
1990s- 2000s	IMAP technology
1990s- 2000s	Use of noble gases

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Table 2 MAP film application in fresh products

Films type	Products	Shelf-life	Reference
Antioxidant active films	Chicken meat	25 days	Bolumar et al., 2011
	Lamb	8-13 days	Camo et al., 2008
	Beef	14-23 days	Camo et al., 2011
	Salad	8 days	Muriel-Galet et al., 2012
	Fresh-cut lotus root	8 days	Xing et al., 2011
Nano active films	Apple slices	10 days	Avella et al., 2007
	Kiwifruit	42 days	Hu et al., 2011
	Chinese jujube	12 days	Li et al., 2009
Biodegradable films	Plum tomato	42 days	Muratore et al., 2005
	Lettuce	9 days	Del Nobile et al., 2008
	Green peppers	7 days	Koide and Shi, 2007
Micro-perforated films	Stawberries	28 days	Kartal et al., 2012
	Sausages	5 days	Mastromatteo et al., 2011
	Pork loin	14 days	Lee et al., 2004
	Apple slices	14 days	Cliff et al., 2010

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Table 3 MAP gas applications in fresh products

Gas type	Products	Shelf-life	Reference
Gas oxides			
CO	Atlantic salmon	12 days	Bjørlykke et al., 2011
CO	Fresh beef	21 days	Jayasingh et al., 2001
SO_2	Grapes	4 months	Zutahy et al., 2008
N_2O	Minimally processed kiwifruit	12 days	Rocculi et al., 2005
N_2O	Banana	10 days	Palomer et al., 2005
Noble gases			
Ar, Xe	Asparagus spears	12 days	Zhang et al., 2008
He	Broccoli	7 days	Jamie and Saltveit, 2008
Ar	Fresh-cut green peppers	10 days	Meng et al., 2012
He	Fresh-cut red chard baby leaves	7 days	Tomás-Callejas et al.,
Ar	Fresh pork sausages	28 days	Claudia and Francisco, 2010

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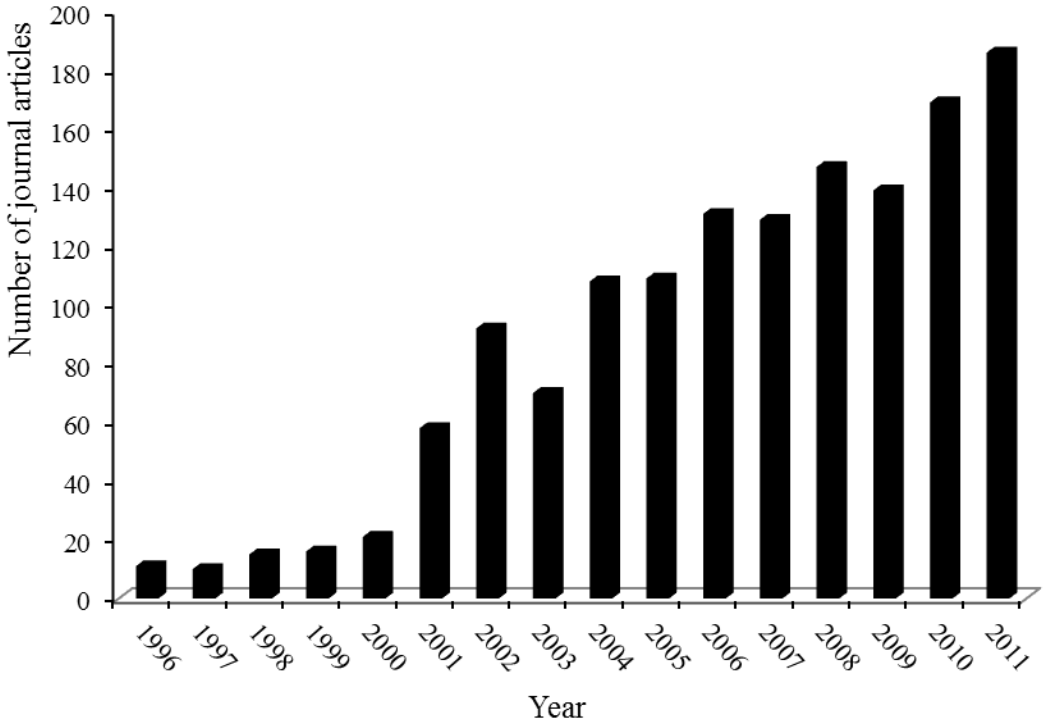

Fig.1 Number of published journal articles on MAP research from 1996 to 2011

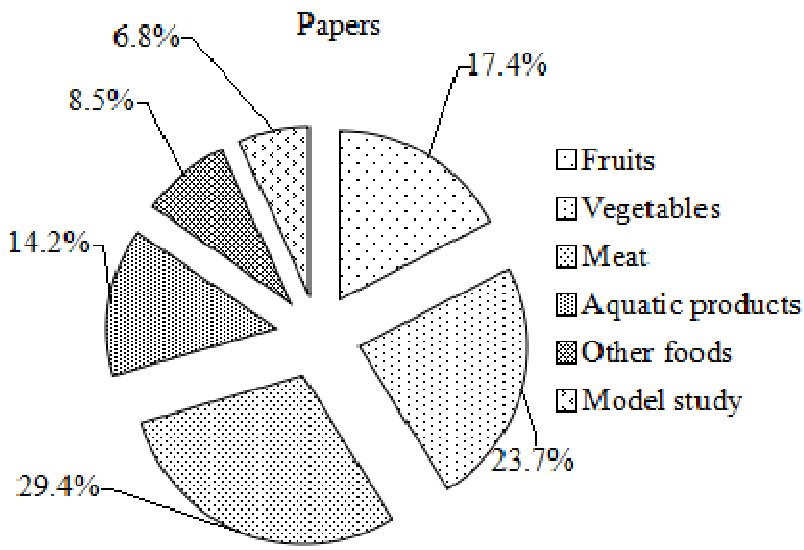

Fig.2 The distribution statistics of publications on MAP in food research