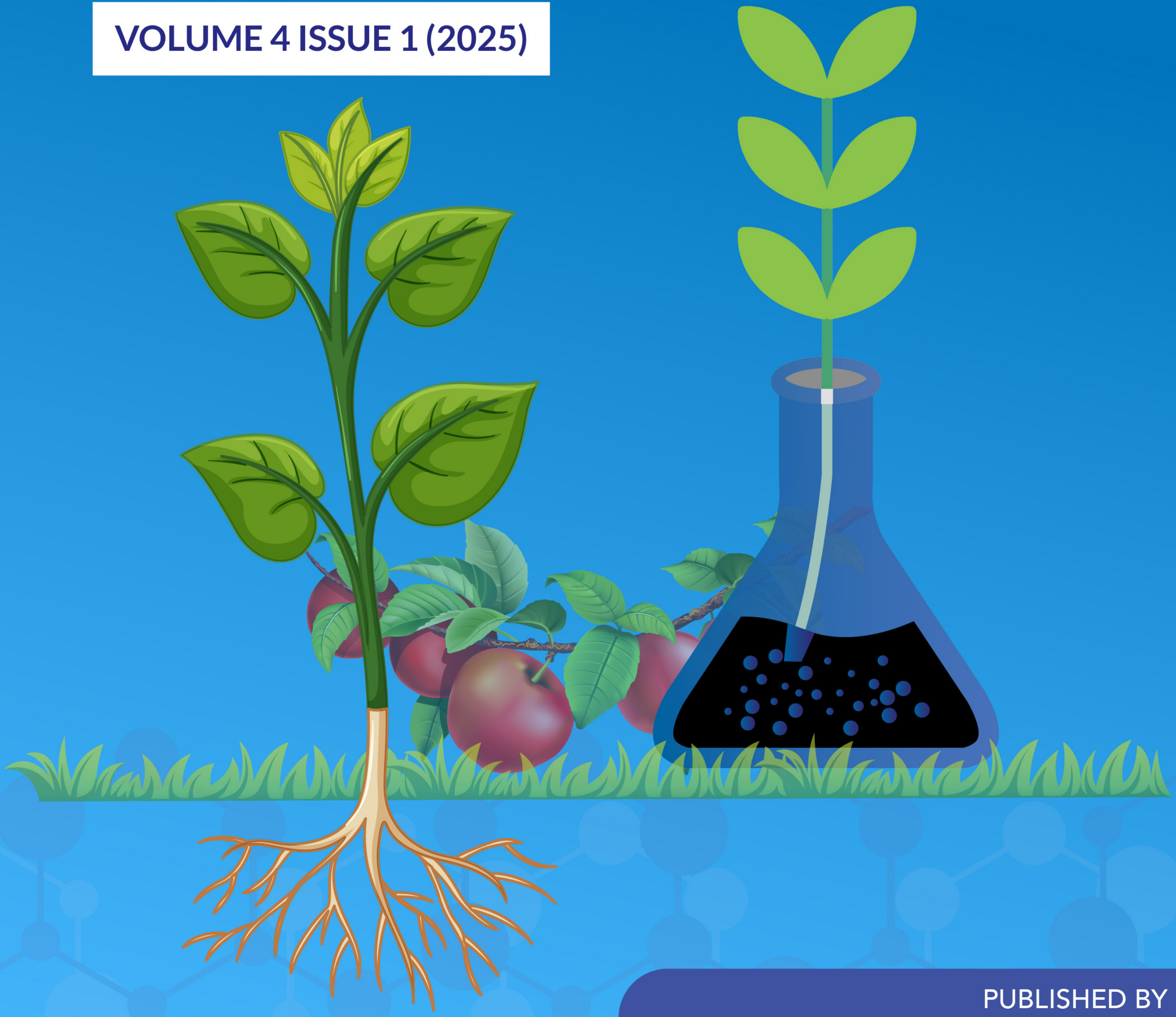
American Journal of Food Science and Technology (AJFST)

ISSN: 2834-0086 (ONLINE)

VOLUME 4 ISSUE 1 (2025)



PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of
Food Science and Technology (AJFST)

Volume 4 Issue 1, Year 2025
ISSN: 2834-0086 (Online)
DOI: https://doi.org/10.54536/ajfst.v4i1.2942
https://journals.e-palli.com/home/index.php/ajfst

Modified Atmospheric Packaging in Various Food Products

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Article Information

Received: April 20, 2024

Accepted: May 27, 2024

Published: January 07, 2025

Keywords

Bio-Based Materials, Food Preservation, Food Processing, Modified Atmospheric Packing, SDG Goals, Food Safety

ABSTRACT

Food spoilage and preservation is a major concern worldwide. This review aimed to provide a comprehensive overview of modified atmospheric packaging usage across various products and underscores food safety and preservation significance. Modified atmospheric packaging emphasizes the potential to maintain quality and extend the shelf life of products. Data was collected from electronic databases from the last fifteen years, 2010 to 2024. MAP technology has successfully extended the shelf-life of numerous food products such as fruit, vegetables, meat, poultry, fish, and dairy goods by adjusting atmospheric gases. As a result, it minimizes microbial growth, delays biochemical changes, and prevents physical degradation in food products. This review highlights the importance of modified atmospheric packaging in achieving sustainable development goals, specifically in reducing food waste. Modified atmospheric packaging is a modern preservation technique which offers insights into sustainability and food safety.

INTRODUCTION

Food is covered by atmosphere which contain many gases that can lead to spoilage. Atmospheric gases include oxygen, carbon dioxide, Nitrogen and Argon. During packing, atmospheric gases can be modified by altering the gases around the food. The presence of oxygen can lead to spoilage of food due to aerobic microorganisms. Conventional methods may create a loss of quality and taste. Chemical changes like rancidity, color, flavor loss, and oxidation are the major problems that occur in most traditional and conventional preservation methods (Rahman & Velez-Ruiz, 2007). The significance of modified atmosphere packaging (MAP) lies in its ability to preserve perishable products by creating an atmosphere that differs from the typical conditions. This technique ensures the food safety (Hintlian & Hotchkiss, 1986). This technology makes the food safe to use.

Food Safety Concern

MAP lacks the ability to ensure food safety directly. It increases the time a product can be stored by slowing down the harmful biochemical and microbiological changes that can affect its safety (Soltani *et al.*, 2015). Numerous organisms exhibit accelerated development in the presence of aerobic organism growth. By providing an appropriate amount of gas mixtures, the proliferation and viability of several bacteria that are accountable for the deterioration of food products can be decreased (Soltani *et al.*, 2015). These organisms themselves or by producing toxins can cause food poisoning and even threaten human life. (Han *et al.*, 2018) However, MAP minimizes the activities of spoilage organisms that normally give warning for potentially unsafe conditions (Sandhya, 2010). Reduced oxygen packaging can lead to botulism caused by Clostridium botulinum by providing anaerobic conditions for its growth. In the fresh-cut industry, the significance of pathogenic bacteria cannot be neglected. A good packaging material is essential for MAP packing to ensure food safety (Larson *et al.*, 1997). A Study conducted by Djordjevic *et al.* (2018) demonstrated the impact of MAP packaging on minced meat. MAP packaging with 50% of carbon dioxide showed a reduction in salmonella count (Djordjević *et al.*, 2018). Several studies showed that MAP significantly reduces the presence of E.coli, Salmonella spp., Listeria, and Campylobacter, but the main concern is Clostridium botulinum, a dangerous bacterium responsible for foodborne illnesses. Food safety in MAP is ensured using correct gas mixtures (Caleb *et al.*, 2013).

Food Preservation

Preservation is extending the shelf life of products by preventing spoilage by microorganisms while maintaining nutritional values and quality. There are many preservation techniques (Kumar, 2019). Massive food waste results in poverty and starvation every year. However, preservation techniques aims at reducing the decomposition of food by microbes and other means (Kumar, 2019).

Traditional Methods

The traditional methods used for preserving food include;

Sun Drying

This is the most ancient type of preservation. Sun drying utilizes solar heat and movement of surrounding air to evaporate water from food items (El Hage *et al.*, 2018).

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Curing

The moisture content in the product is reduced by the osmosis process. The reduction in moisture content results in reduced microbial activity (Hamada *et al.*, 2022).

Canning

Canning is the process of packaging food in sterilized containers and subjecting it to high temperatures to extend its shelf life. This process eliminates spoilage microorganisms and pathogenic bacteria, enhancing food's nutritional and physical quality (Rajput *et al.*, n.d.). However, the anaerobic bacteria Clostridium is a threat to canned foods (André *et al.*, 2017).

Refrigeration

Refrigeration is the preferred method for preserving fresh, high-value commodities due to its minimal impact on food properties at 4°C. However, continuous monitoring and regulation of environmental conditions are required to achieve optimal results (Tuan Pham, 2014).

Freezing

Freezing is a common and effective method for preserving food's taste, appearance, and nutritional value by lowering the temperature to -40°C, as it inhibits chemical reactions, prevents microorganism growth, and reduces cellular metabolic activity (Sutariya & Sunkesula, 2021).

Addition of Sugar and Salt

Preserving food products by adding sugar and salt is a traditional method. However, sugar and salt act as a natural preservative to increase sugar content in the food, leading to hypertonic conditions. This process reduces the water and makes the environment unfavorable for microbial growth. This preservation method is primarily used for preserving fruits (S, 2020).

Boiling or Thermal Treatment

It is a method of preserving food by inhibiting enzymes, toxins, and harmful microorganisms. It is one of the oldest methods, while blanching is a milder method that reduces oxygen content and inactivates enzymes (Dewan, 2020).

Pickling

The foodstuff is immersed in vinegar, oil, or brine. Due to anaerobic fermentation, lactic acid and acetic acid are formed and act as preservatives (Aljahani, 2020).

Fermentation

It is a vital metabolic activity that occurs without oxygen, primarily using sugar. It produces alcohol, gases, and organic acids as byproducts. The microbe's activity during fermentation reduces the product's pH and inhibits the growth of undesirable pathogens (Mani, 2018).

Modern Methods

For preserving and ensuring food quality, following modern methods are used;

Pasteurization

It is a vital preservation technique that ensures food safety. The primary objective of pasteurization is to eliminate microorganisms that cause food spoilage and potential hazards to consumers' health (Ramesh, 2020).

Chemical Food Preservatives

Anti-microbial chemical substances can be added to food to extend the shelf life. The addition of chemical food preservatives in large quantities can be toxic. Benzoates, nitrites, propionate, sulphites, and sorbates are some food preservatives. Certain chemicals may cause allergic reactions and other serious health problems, including cancer (Gupta & Yadav, 2021).

Freeze Drying

It is a process that uses low pressure to convert ice into water vapor and remove it from a substance. Freeze drying eliminates 98-99% of water content in food. This process limit the availability of water to microorganisms hence ensuring food safety (Gaidhani *et al.*, 2015).

Vacuum Packing

Oxidation can be avoided by excluding oxygen from the packaging system through vacuum packing and high-barrier packaging materials (Patil *et al.*, 2020). This process can eliminate spoilage microorganisms and ensure food safety.

Bio-Preservation

Utilizing beneficial or fermenting bacteria against the pathogens is bio-preservation. Bio preservatives can produce toxic chemicals detrimental to pathogens (Singh, 2018).

Irradiation

Food irradiation is a method of exposing food to ionizing radiation, breaking chemical bonds and potentially exposing harmful microbes in meat, poultry, and seafood. It is used as a preservation method because it can de-infest spices, increase the shelf-life of fresh fruits and vegetables, and inhibit the sprouting of tubers and bulbs like potatoes and onions (Joshua Ajibola, 2020).

Hurdle Technology

It is a revolutionary concept that combines various preservation strategies to produce safe, nutritious, and economical food. It involves salt, lowered pH, reduced water activity, heat treatment, and adequate packaging. Hurdle technology was invented to ensure a reasonable shelf-life, acceptable taste, and desired consistency (Singh & Shalini, 2016).

This review aimed to provide a comprehensive overview of modified atmospheric packaging usage across various products and underscores the significance regarding food safety and preservation.

MATERIALS AND METHODS

Recent studies and reviews of publications and articles pertaining to food packaging and preservation were taken into consideration for this review. The study aimed to evaluate the efficacy of modified atmosphere packaging on different food products. Data was collected from electronic databases, including Google Scholar, Web of Science, Hindawi, Research Gate, Science Direct, and FSTA. Studies were selected from different years ranging between 2010 to 2024 using keywords' packaging,' 'food packaging,' 'food preservation,' 'food preservation techniques,' 'food packaging and preservation,' 'modified atmosphere packaging,' 'MAP and food preservation,' 'packaging methods.'

RESULTS AND DISCUSSION

Result

A total of 65 articles are included in this review from last 15 years highlighting the effectiveness of modified atmosphere packaging on various food products.

Discussion

Modified Atmosphere Packaging

The MAP is a method that alters the atmosphere around food during packing, ensuring safety and quality. It uses various gases, such as oxygen, carbon dioxide, nitrogen, and argon, in the best combinations to maintain the product's quality, as shown in Figure 1. MAP is a rare commercial-scale preservation technique that helps maintain quality and safety (Khan & Mittal, 2020). The application of MAP on various food products for food preservation dates back to 1927. Later, when meat carcasses were shipped to UK, it was used in Australia and New Zealand. The commercial application of this technology was first introduced in fruits and vegetables (Sebranek & Houser, 2017). The technology helped to double the shelf life of apples and pears. Later modifications were made to the technology for better results, including micro-perforation, anti-fogging layers, etc. (McMillin, 2020). In the past few years, there has been a considerable increase in the range of foods packed under MAP. Apart from fruits and vegetables, meat, poultry, fish, bacon, cakes, sweets, salad, sandwiches, snacks, and ready meals are among them (McMillin, 2020).

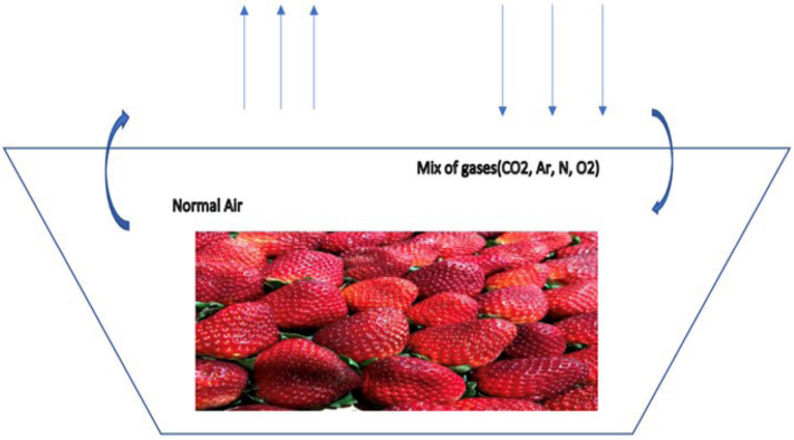

Figure 1: Modified atmosphere packaging of fresh fruit

Gases Used in MAP

MAP uses three main gases: carbon dioxide, oxygen and nitrogen. Carbon monoxide, argon, methyl cycloprene and sulphur dioxide are also used in some foods (Mullan & McDowell, 2011). These gases can be used in combinations. However, the selection of gas depends upon the food selected to pack under MAP, as shown in Table 1.

Carbon dioxide actively eliminates bacteria and moulds. About 0.03% carbon dioxide is present in the atmosphere. The increased concentration of this gas helps prevent spoilage and extend shelf life by slowing the growth of spoilage and pathogenic bacteria (Zahra *et al.*, 2016). The higher concentration increases the acidity in moist foods due to its solubility in water. Solubility increases with a decrease in temperature, which shows antimicrobial properties at low temperatures. However, the common disadvantage is a collapse of packaging due to gas formation (Zahra *et al.*, 2016).

Oxygen is responsible for the oxidation of oil and fat in food products, providing favorable conditions for the growth of aerobic bacteria and mould. The amount of oxygen in the atmosphere is 21%. Reducing the oxygen level in gas combination is advisable to reduce the aerobic bacterial growth because most of the bacteria and fungi grow in aerobic conditions. Oxygen promotes several types of deteriorative reactions, including oxidation, browning, and pigment oxidation. However, complete elimination of oxygen may lead to anaerobic or facultative bacteria growth, which can lead to food poisoning (Zahra *et al.*, 2016).

Nitrogen is an inert gas. This is the most abundant gas in the atmosphere with 78%concentration. The presence of nitrogen prevents package collapse in MAP processing, which occurs in the presence of a high concentration of carbon dioxide. Typically, the residual gas combination is mainly comprised of nitrogen (Alwazeer, 2019).

Argon is a noble gas with antibacterial properties. It is currently used in MAP due to its atomic size being similar to molecular oxygen, making it a potential substitute for nitrogen. The atmosphere contains 0.9% argon (Day, 2007; Han, 2005).

Table 1: Gas combinations and concentrations of MAP

Food Items	Percentage of different gases			Remarks
	Oxygen	Carbon di Oxide	Nitrogen	
Fruits	3-5%	5-20%	75-85%	Oxygen should be in low concentration to reduce the post-harvest respiration and transpiration
Vegetables	3-5%	5-20%	75-85%	Oxygen should be in low concentration to reduce the post-harvest respiration and transpiration
Red Meat	60-65%	15-40%	---------	Oxygen gives red colour.
Processed meat	-------	20-35%	65-80%	
Fish	30%	40%	30%	For fatty fish, nitrogen concentration can be increased.
Poultry	-------	25%	75%	Oxygen may lead to greyish tinges on meat.
Ready Meals	10%	40%	50%	Minimum level of oxygen needed to prevent anerobic bacteria.
Dairy products	-------	30%	70%	Oxygen causes oxidative rancidity.

Types of MAP

There are two main methods for creating MAP;

Active Packaging

This is done by draining all the gases in the package and creating a vacuum. Then, substituting the required gas combinations. This can be established by using ethylene scavengers or emitters. Active packaging helps to create a modified atmosphere very rapidly (Robertson, 2009).

Passive Packaging

Modified atmosphere is passively generated inside a sealed package due to product respiration utilizing oxygen and releasing carbon dioxide. This is, therefore, known as commodity-generated MAP (Costa *et al.*, 2011; Parry, 2012).

Equipment for MAP

The selection of appropriate equipment is a major criterion for modified atmospheric packing:

- Presentation
- Machine performance
- Versatility
- Pack format
- Operation cost
- Quality and ease of cleaning
- Equipment price

Form-filled seal machines, Chamber machines and snorkel machines are frequently used (Rao, 2015). There are two categories of MAP machines;

Pillow Wrap

The pillow wrap machines are made of two systems: horizontal form fill seal (HFFS) and vertical form fill seal (VFFS).

Chamber

Two different techniques are used in chamber processing: The thermoforming technique and the preformed container machine. The thermoforming machine is widely used, as shown in Figure 2. The machine is fed with two films, one for forming the tray base and the other for the lid. The food is placed on the tray after it is ready by heating in the thermoforming station. Then, a vacuum is created, and the gas mixtures are flushed before closing the lid. Then, the product is sealed with film.

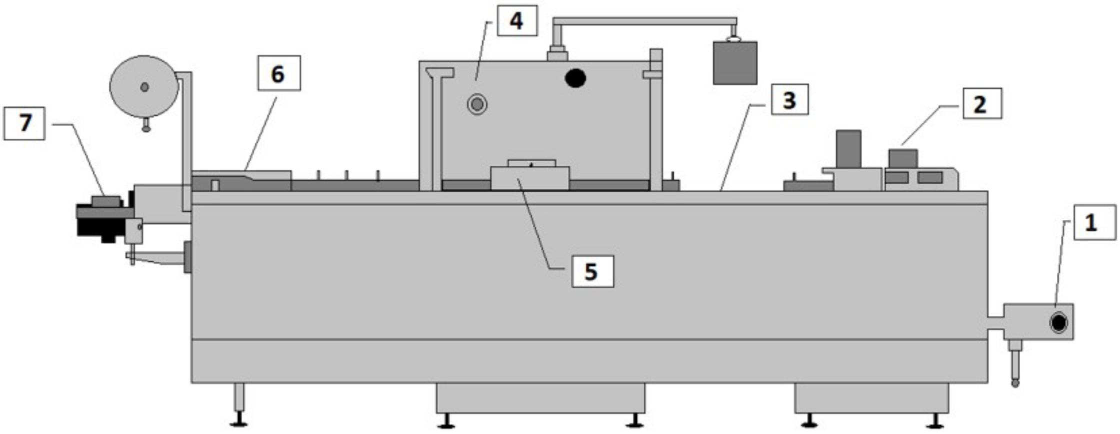

Figure 2: Thermoforming Equipment

1. The film necessary to form the bottom of the package is wound on a real machine equipped with a special device to ensure constant film tension during every machine repeat.
2. The film is heated in the pre-heating station and enters the forming station, where a perfect forming suction is made with the pump.
3. The packs are manually or automatically filled.
4. The top film is unwound to cover all packs and can be printed.
5. The package is sealed, and vacuum, and gas flushing are occurring.
6. The perfect shape of each pack is carried out at this cutting station.
7. The motorized outlet conveyor mesh brings the pack out of the machine.

Preformed container machines are almost similar to each other; the only difference is that here, the preformed trays are loaded to the machine.

Packing Materials Used in MAP

Plastic is the common choice for packaging food, but it is not eco-friendly. Polymeric films are used to pack fresh produce. Commonly used polymeric films are LDPE, LLDPE, HDPE, PP, PVC, polyesters, PET, PVDC, EVOH, Nylon, PCTFE, PVOH, PVOH, EVA, polycarbonate films, polystyrene, cellulose-based plastics, and biodegradable polymers. Sometimes, to achieve all the good properties of a packing material of MAP, a combination of materials also are used (Mangaraj *et al.*, 2009).

Biodegradable Packing Materials

Bio-based packing materials have been introduced to reduce the environmental issues due to the use of petrochemical products for packaging. Innovative packing materials definitely enhance the sustainability (Reichert *et al.*, 2020). Biodegradable packaging materials have a good barrier property and increase the shelf life of the packed products while helping in biodegradability. Biomers can be produced using different methods: directly from natural substances like polysaccharide proteins, polymerization of monomers derived from biomass such as PLA from lactic acid and microorganisms such as polyhydroxyalkanoate (PHA) (Thulasisingh *et al.*, 2021).

Poly Lactic Acid (PLA)

PLA is an aliphatic polyester with biopolymer properties suitable for MAP. It is a biodegradable and compostable thermos plastic polymer. This is produced by fermentation and distillation process from starch. The PLA will break down within twelve weeks compared to plastic, which takes centuries to degrade. Hence, PLA is environment-friendly (Tawakkal *et al.*, 2014).

Types of Polymeric Films for MAP

Three types of polymeric films for MAP are developed;

1. Micro perforated or non-perforated films
2. Macro perforated polymeric films
3. Perforation-mediated packaging systems

Micro-perforation allows the proper carbon dioxide and oxygen concentrations in the package headspace to extend shelf life. The gas permeability in this type is controlled by the number of perforations and their size. By adjusting the size and density, the packing films can be customized for specific products (Hussein *et al.*, 2015). Normally, the perforation size is 50 to 200 micrometers in diameter. Conversely, macro perforation has a higher permeability rate than micro-perforated materials. This is a simple technique that involves only punching, which helps in better gas diffusion. Perforation-mediated packing system offers the benefit of avoiding in-package anaerobiosis, extending the shelf life and maintaining the quality of fresh or minimally processed produce (Hussein *et al.*, 2015; Winotapun *et al.*, 2015).

Selection Criteria for Packing Material for MAP

1. Type of packing whether it is flexible, rigid or semi rigid.
2. Permeability or the barrier properties.
3. Machinability and strength
4. Clarity
5. Durability
6. Heat sealing property
7. Extend of fogging especially when transpiration occurs in fresh produce.
8. Sealing reliability
9. Rate of water vapor transmission
10. Resistance to chemical degradation
11. Chemically inert
12. Non-toxic
13. Commercially suitable
14. Economic feasibility.

Table 2 presents the packaging materials and their properties used during MAP.

Table 2: Various packing materials used in MAP

LDPE (Low density polyethylene)	• Soft, flexible and strong • Resistance to chemicals • Easy to seal • High oxygen and carbon dioxide permeability • Low cost
PE	• Strong, flexible, tough • Good barrier properties • Not suitable for application involving exposure to heat. • Low cost

PP (Polypropylene)	• Strong, dense, transparent • Favorable response to heating • High clarity and durability • Moderate barrier properties • Low cost
PET (Poly ethylene terephthalate)	• Excellent transparency-glass like • Good barrier properties • Good resistance to chemical degradation. • High cost
PVC (Polyvinyl chloride)	• Strong, transparent • Good gas barrier • Excellent resistance to chemicals • Extensively used as packing film • Inexpensive
PVDC (Poly vinylidene chloride)	• High gas barrier properties • Heat sealable • Used in retorting, hot filling, low temperature storage. • Expensive
PS (Polystyrene)	• Excellent transparency • High tensile strength • Poor barrier properties- so used as 'Breathable' film • Inexpensive
NYLON 6 (Polyamide)	• Strong • Good barrier properties • Excellent performance in high temperature • Costly
EVOH (Ethylene-vinyl alcohol)	• Excellent gas barrier properties • Used as oxygen barrier material • Maintains product quality for oxygen sensitive products • Costly
EVA (Ethylene vinyl acetate)	• Excellent transparency • Good heat seal • Good adhesive properties • Used as adhesive in multilayer films • Inexpensive
PLA (poly lactic acid)	• Biodegradable • Hydrolysable • Suitable for MAP especially fresh produce • Expensive

Advantages in MAP

Modified atmosphere packaging provides many benefits, which include;

- Shelf-life extension is possible in various food items
- Retaining quality of the product like color and flavor
- Maintaining the nutritional values
- Minimizing growth of spoilage and pathogenic microorganisms
- Best method for preserving perishable foods
- Ensure food safety
- No added preservative in this method
- Product presentation will be excellent when packed in MAP

Microbiological Effects of MAP

Microbes in food, including fungi, yeast, and bacteria, can be beneficial or hazardous. Some species can cause food deterioration, while others can cause food poisoning during storage. MAP can alter these growth patterns, increasing shelf-life by adjusting the gases needed. Furthermore, oxygen is a significant factor in bacterial growth, which can be classified based on oxygen demand.

Aerobes

Which require oxygen for growth and development.

Microaeropliles

They need a low concentration of oxygen. Some pathogens can grow optimally in such conditions.

Facultative Aerobes

They can grow better in oxygen but survive without it. Many strains are psychrotrops.

Anaerobes

They cannot live in the presence of oxygen. Complete removal of oxygen in MAP may not be useful for shelf life extension because pathogenic bacteria like Clostridium may survive, which can cause food poisoning.

Consequently, carbon dioxide, when present in a minimum of 20% concentration, may indefinitely extend the lag phase of microorganisms while exerting bactericidal effects on the bacteria and molds, making it the most commonly used gas to limit bacteria and mold growth (Yan *et al.*, 2022).Biochemical changes with MAP

Lipid Oxidation

Unsaturated fatty acids oxidize when exposed to oxygen, and the rancidity process accelerates. The reaction is caused by oxygen joining with unsaturated fatty acids. Removing oxygen and replacing carbon dioxide and nitrogen will dissuade rancidity in food products (Laguerre *et al.*, 2020).

Discoloration of Meat

Red color of meat is preferred by the customers, which occurs due to the presence of oxy-myoglobin. MAP in the opaque pack is suitable as light can cause discoloration due to chemical changes. Low oxygen concentration is advisable in cured meat for color retention (Cenci-Goga *et al.*, 2020).

Oxidative Off Flavor

Usually, this occurs during chilled storage. Meat, poultry, fish, and dairy products are highly susceptible to oxidative processes. MAP can delay developing off orders at low oxygen concentrations (Gorris & Peppelenbos, 2020).

Photo-Oxidation of Chlorophyll

Oxidation of chlorophyll occurs in fruits and vegetables, which turn green to brown or grey. Low-concentration and opaque packets can reduce this effect in MAP (Mullan & McDowell, 2011).

Physical Changes

The following physical changes can occur in food products during packaging. Therefore, MAP helps to reduce physical changes in food.

- Spoilage
- Water Loss
- Wilting
- Weight Reduction
- Textural Changes
- Syneresis in Dairy Products

Role of Modified Atmospheric Packing in Achieving SDG's

The role of technology in sustainability is clearly understood here. MAP can contribute to many sustainability development goals, such as SDG 2: zero hunger, SDG 12: Responsible consumption and production, and SDG 13: Climate action set by the United Nations (Lemaire & Limbourg, 2019).

Food waste is a significant issue globally, with billions of tons wasted daily. However, one-third of this waste comes from production (Lemaire & Limbourg, 2019). MAP technology aims to minimize food waste and extend shelf life, contributing to sustainability goals like zero hunger. Responsible production involves reducing chemicals and synthetic materials, achieving SDG 12. MAP also introduces biodegradable packing materials, promoting an eco-friendly system. By reducing plastic packaging and increasing shelf life, MAP technology contributes to environmental sustainability and SDG 13 (Lemaire & Limbourg, 2019).

MAP of Fruits and Vegetables

Passive MAP minimizes respiration rates in fruits and vegetables, which have high perishability, rapid quality decay, and limited shelf life. MAP helps delay post-harvest ripening and prevents early spoilage (Oliveira *et al.*, 2015). It is widely used in fresh-cut farm produce, maintaining TSS, juice content, and surface color. MAP can also prevent enzymatic browning in high oxygen concentrations (Tinebra *et al.*, 2021). Various studies showed that MAP can retain quality in plums, strawberries, kiwi, litchi, table grapes, cherries, and blueberries. MAP can also reduce water loss and wilting in green leafy vegetables like spinach, parsley, and dill and help retain chlorophyll (Soltani *et al.*, 2015; Thompson *et al.*, 2018).

MAP of Poultry and Meat

Meat is a highly perishable product, and minced meat is susceptible to bacterial growth due to the disruption of meat's cellular structure throughout the surface. Due to cross-contamination, meat can be contaminated with Salmonella during slaughter, dressing, deboning process, transportation and storage. Therefore, MAP technology was used to decrease the count of Salmonella in minced meat (Djordjević *et al.*, 2018). MAP is a technology used to preserve the color of fresh meat cuts by maintaining the pigment even in an oxygen-rich environment. This process is particularly useful for sliced beef, a quality criterion that commands high market prices (Singh *et al.*, 2011). The primary cause of red meat deterioration is microbial growth and oxidation of the oxymyoglobin pigment (Bekhit *et al.*, 2019). However, the oxygen level must be decreased to prevent microbial proliferation, while maintaining a low oxygen concentration is crucial (Danijela *et al.*, 2013). MAP ensures the appropriate concentration of gases, inhibiting microbial growth and preserving the product's color (Gill, 2018). Further, poultry primarily focuses on prolonging its shelf life, and MAP treatment has shown a significant reduction in bacterial growth (Ibrahim *et al.*, 2020). Moreover, chilled storage and nitrite as a preservative can also reduce post-processing contamination in meat and poultry products. Thus, prevent food spoilage and poisoning (Papadochristopoulos *et al.*, 2021).

MAP of Fish and Seafood

Aquaculture has become a global phenomenon, with fish and shellfish being highly perishable due to bacterial action. Typical icing and refrigeration methods only extend shelf life by a few days. Aerobic microbes spoil processed fish, leading to spoilage. MAP inhibits spoilage flora, increasing shelf life significantly (Kontominas *et al.*, 2021). Microbes are found in fresh catch's surface, gills, and intestines, causing spoilage quickly. Chemical changes, such as auto-oxidation or enzymatic hydrolysis, can result in off orders in fish (Tavares *et al.*, 2021). Tissue enzyme activity can also lead to unacceptable softening. Trimethyl Amine Oxide (TMAO) in fish muscle can be degraded to TMA at chilled temperatures, causing a spoiled fish smell (Debbarma, 2022). Studies on seasoned cobia sticks show that cobia sticks remain safe and of good microbiological, chemical, and biological quality for a longer period when packed in MAP. The extended shelf life of fish depends on species, fat content, initial microbial load, gas mixture, and storage temperature (Gonçalves & Santos, 2018). Despite a smaller shelf life, high demand for spoiled fish products persists.

MAP of Dairy Products

Milk-based products, such as sweets, fat-filled milk powders, cheese, and fat spreads, are in high demand due to their high consumption (Oliveira *et al.*, 2019). However, these products suffer from spoilage due to oxidative rancidity and microbial growth. They have limited shelf life due to deteriorative changes during storage. These products are mainly consumed fresh and undergo biochemical, physical, and microbiological changes, making them unfit for human consumption (Lu & Wang, 2017). MAP has been studied to enhance the shelf life of these dairy products. Cheese products can be packed using MAP, as the combination of gases ensures shelf life and quality, maintaining the seal tight without excessive pressure on the packing seal (Atallah *et al.*, 2021).

Future Prospects

Many novel technologies, such as active packaging and hurdle technology, are associated with MAP products to increase safety and shelf life further. Active packaging is an emerging technology in which food packages and the environment interact using gas emitters and absorbers. Hurdle technology is a combined process that is an intentional combination of preservation techniques in order to establish a series of preservative factors (hurdles) that any present microorganism cannot overcome. It can be a storage temperature, water activity, pH, redox potential, bio conservation, MAP, Ultra pressure treatment, and edible coatings. The use of combination processes with MAP is nascent and needs further development. Furthermore, smart packing, such as TTI (time-temperature indicators), is a technology that can be combined with refrigerated MAP products. This ensures food safety with strict temperature control over time.

CONCLUSION

In conclusion, this study underscores the significance of modified atmosphere packaging for various products. MAP technique is crucial for food preservation, preventing food waste and ensuring food security. MAP is a modern preservation technique that helps extend the product's shelf life by retaining its quality and flavor. It reduces food waste, extends shelf life, and maintains nutritional value. MAP is linked to zero hunger, responsible consumption, and climate action goals in sustainable development. It is versatile and effective for various food products, including vegetables, fruits, meat, poultry, fish, and dairy. For all these products, MAP has proved to provide significant barrier properties and improved shelf life to a longer extent. MAP is not only a solution for food preservation but also accelerates the future demand for environmentally friendly packaging materials and technologies.

Limitations and Strengths

The study limitations may include generalizability and study selection bias. However, this review highlights the use of MAP in food preservation, its application across various food categories and its relevance to SDGs. It provides a comprehensive overview of MAP technology and its practical implications for stakeholders in the food industry.

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