Review Article

Modified Atmosphere Packaging as an Effective Technology for Inhibition of Food-Borne Pathogens Throughout Food Preservation

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Abstract | Recently, it has been shown the survival of many food-borne pathogens in meat, dairy products, and other foods. Several survived microorganisms are discussed in this review such as *Staphylococcus aureus, Bacillus cereus, Listeria monocytogenes, Campylobacter* spp., *Clostridium* spp., *Salmonella* spp., *Aeromonas* spp., and mold fungi. The aim of this study is to show an effective method of preservation to extend the shelf life of foods. Currently, multiple traditional methods of food preservation have been reported, mainly chilling, freezing, curing, cooking, smoking, drying, fermentation, pickling, canning, and thermal processing. However, these traditional methods possessed certain disadvantages as they are non-available during transportation of foods for long periods. Hence, packaging of meat, poultry, and other foods in modified atmosphere has shown promising results. Throughout modified atmosphere packaging (MAP) a mixture of gases such as CO_2, N_2, and O_2 are used at certain concentrations based on the food type employed. MAP technology is recommended with cold temperatures and certain natural additives, including herbs extracts, modified proteins, and probiotics or their metabolites for preservation of fresh meat, processed meat, poultry products, and other foods. MAP keeps on food safety with nice sensorial properties during long storage periods.

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Introduction

In last years, there was a high incidence of pathogenic bacteria in foods (Enan, 2006a; Enan *et al.,* 2018, 2020; Sitohy *et al.,* 2024). Therefore, recent researches have continued to find out hygienic food additives; based on using natural safe antimicrobial agents such as plant extracts (Abdel-Shafi *et al.,* 2019a; Reda *et al.,* 2022), probiotics (Abdel-Shafi *et al.,* 2022; Abou-Elez *et al.,* 2023), nanoparticles, either singly or in combinations with other natural agents (Sitohy *et al.,* 2021), modified proteins (Al-Mohammadi *et al.,* 2020, 2023), and bacteriophages (El-Gazzar and Enan, 2020; Askoua *et al.,* 2021). In addition, to ensure safe food preservation with extended shelf life of the packaged foods, preservation of foods by MAP has been used.

Modified atmosphere packaging (MAP) is defined as the packaging of food in an altered atmosphere of fixed gases other than oxygen, which has shown to be effective in inhibition of food-borne pathogens and extending the shelf life of the packaged food (Kontaminas, 2014). Through MAP, a mixture of gases such as CO_2, N_2, O_2 and/or others are used at certain mixtures in food packages before preservation. The choice of gas mixtures depends on the kinds of food-borne pathogens that can grow in certain food types and the sensitivity of the food product to certain gases. For instance, on preserving low fat white fish (i.e., catfish, cod, sea bream, and sea bass), a gas mixture of 30 % O_2/40 % CO_2/ 30 % N_2 is recommended (Bae *et al.,* 2011).

Modified atmosphere packaging is the formation of modified atmosphere package in closed containers containing foods for their preservation. In MAP, aerobes can't grow because of the presence of CO_2 and also anaerobes can't grow due to the presence of O_2 and/or other gases that suppress their growth (Czerwiński *et al.,* 2021).

Modified atmosphere packaging was used since the middle of the 19th century for preservation of both fruits and beef during transport of holders of ships (Czerwiński *et al.,* 2021). However, this technology of MAP in this time was done without standards gases used in the package; but was based on using an anaerobic atmosphere containing CO_2. The MAP technology has developed in many countries and certain machines have been used in many countries to pump gases mixture with standard concentrations such as CO_2, N_2, O_2 and others. The gas mixture has become designed using soft CD made by artificial intelligence to concur with preliminary results of inhibition of pathogenic microorganisms and extend the shelf life of many foods (Scarabottolo *et al.,* 2020).

Microorganisms contaminating foods with special reference to meat products

Meat and meat products have important roles in the human diet, and are important sources of essential nutrients such as proteins, fats, minerals, and vitamins for most people in many parts of the world (Wang *et al.,* 2024). Jasna *et al.* (2018) study showed that the meat includes of 72–75 % water, 21 % nitrogenous compounds, 2.5–5 % lipids, 1 % vitamins, carbohydrates, and 1 % ash. Lipids are the most variable compounds, with amounts that range from 1 % to 15 %. Also, Zhang *et al.* (2023) reported that the composition of adult animal mammalian muscles contain a high amount of water 75 %, protein contents 19 %, lipids 2.5 %, glycogen 0.1 %, glucose and glycolytic intermediates 0.2 %, lactic acid 0.9 %, inosine monophosphate 0.3 %, creatine 0.6 %, amino acids 0.35 %, and dipeptides 0.35 %, pH (5.5).

Han *et al.* (2024) reported that food consumption is correlated with economic growth, where the Food and Agriculture Organization (FAO) expectations has expressed that meat consumption has been increased continuously in developing countries. It is proposed that in a few decades meat consumption in developing countries will move towards that of developed countries where consumption remains stagnant at a high level.

In human meals, meat is the most important one within protein sources and its consumption depends on several factors; the most important are social and economic factors, ethics, religious beliefs, and traditions. For instance, pork consumption is low or absent within Muslims, but it increases in other nations. In general, most of meat sources are arranged in the following descending manner worldwide: pork > poultry > beef > sheep and goat > plant sources (FAWSTAT, 2014).

Consumers in all markets need protected and healthy food products that are of high quality. Therefore, quality from a consumer's point of view is subjective and thus assessments of food quality can vary across individuals, societies, and cultures. In this way, it is not surprisingly that investigating food quality is complex because of its wide and all encompassing concept characters (Troy *et al.,* 2016).

Because of its chemical composition and biological attributes, meat is highly perishable food that represents amazing source for development of numerous risky microorganisms that can cause human diseases and meat spoilage (Barbuddhe *et al.,* 2000). Microbial contamination occurs because of wrong techniques during slaughtering process, blemished cutting practices, and deficient sanitation projects that cause contamination.

The microbial food pollution may occur due to several reasons, including its storage at room temperature, handling without care, and exposure to dust and polluted winds (Liu *et al.,* 2024).

Li *et al.* (2023) reported that food contamination with foodborne pathogens is a dangerous problem to public health. The expanding volume of exchange and travel is considered as a potential hazard factor encouraging the worldwide transport and scattering of pathogenic microorganisms in food, where the imported animal products are a clear example. Children, infants, elderly, and pregnant women continue to be at greater risk of foodborne diseases (Linscott, 2011).

Microbiological decay of meat and poultry is principally attributed to the action of psychrotrophic microorganisms that deliver off-flavors, off-scents, and unfortunate appearance at refrigeration temperatures (Li *et al.*, 2023; Liu *et al.*, 2024). Various organisms are utilized for red meat generation, including dairy cattle, swine, sheep, goat, deer, camel, and horse. Meats are liable to be contaminated by an extensive variety of microorganisms, including Gram-positive and Gram-negative bacteria, yeasts, and mold fungi (Jay *et al.*, 2005).

The survival of food-borne pathogens in foods is affected by the methods used for sampling and packaging, the health hazards of the environment, and the season, either winter or summer. In winter, growth of the microorganisms is decreased due to the decrease of temperature to low levels (Kammenou *et al.*, 2003). The microorganisms contaminating foods are discussed below:

Escherichia coli

Escherichia coli strains are Gram negative and facultatively aerobic rod-shaped bacteria. The *E. coli* strains are classified into three groups, mainly enteroinvasive, enterohaemoragic, and enterotoxigenic. They are commensals of intestinal gut and may cause enterocolities and diarrhoea with abdominal cramps in the immunocompromised people (Zavišić ., 2024).

Datta *et al.* (2024) studied the prevalence of *E. coli* in vegetables and herpes, where the prevalence percentages were 40.7 %, 23.30 % in lettuce leaves and cucumber respectively. The average prevalence of this bacterial species in all the tested samples of vegetables and herbs is around 32 %. Several studies stated that *E. coli* strains are isolated from contaminated meat, poultry, and dairy products, and ready to eat foods, chips, and corn flaxes (Jaradat *et al.*, 2024). In addition, *E. coli* strains are founded and isolated from polluted drinking water (Enan *et al.*, 2013a, b).

Because of the unsanitary slaughtering practices through airborne, rodents, insects, and other animals, meat can be also infected by *E. coli* strains during the animal slaughtering process (Aladhadh, 2023).

Aladhadh (2023) reported that serious illness and death of individuals may be cause due to consumption of meat infected by *E. coli* Consumption of contaminated and/or uncooked meat displayed the risks of acquiring food borne *E. coli* causing a serious public health concern (Abdel-Shafi *et al.*, 2013; Enan *et al.*, 2013c).

Also the retail meat products are frequently polluted with *E. coli*, and thus the poultry and pork meat may represent a potential source of extra intestinal pathogenic strains of *E. coli* (Manges *et al.*, 2007).

Listeria monocytogenes

Listeria monocytogenes is a Gram-positive, rod shaped, and non-spore-forming bacterium. It is found in a variety of environments, including soils, water, silage, sewage, and plant and animal food products such as poultry, meat, and dairy products (Enan *et al.*, 2012; Abdel-Shafi *et al.*, 2019b; Sitohy *et al.*, 2024). The Genus *Listeria* is composed of six species, with *L. monocytogenes* as the primary cause of human infections Ismaiel *et al.* (2014).

L. monocytogenes is a dangerous pathogen as it can grow at low temperature of refrigeration and after ingestion of the contaminated food, a listeriosis disease develops (Cornu *et al.*, 2006).

In human, food-borne listeriosis causes high rate of serious illness and death in influenced individuals. This bacterial species is of high risk as it causes food contamination, and after its consumption, it causes listeriosis of pregnant women, neonates, immunocompromised patients, and the elderly. In any case, listeriosis may occasionally happen in those people who have no predisposing underlying condition. Up to 30 % of adults with listeriosis may be immune competent (Koopmans *et al.*, 2023).

Moreover different studies showed that the detection of *L. monocytogenes* in foods may cause clinical courses of meningoencephalitis and septicemia in human body on consumption of those foods that it contaminates (Elmalı *et al.*, 2013).

Bacillus cereus

The bacterial strains belonging to *Bacillus cereus* are Gram positive and sporulating rods, which are classified following Genus *Bacillus* and Family *Bacillaceae* (Enan *et al.,* 2020; Osman *et al.,* 2020).

The approved dose of *B. cereus* that can cause disease is 10^5-10^5 cfu/ ml. After consumption of such dose in either contaminated food or water, certain symptoms may appear on the patients such as vomiting, abdominal pain, diarrhea, and nausea (McDowe *et al.,* 2025).

Staphylococcus aureus

Staphylococcus aureus strains form golden-yellow colour on mannitol salt agar medium and are grape like Gram positive cocci. It is isolated from different contaminated foods such as meat, poultry, dairy products, and others (Tessema, 2017; Attia *et al.,* 2024).

Staphylococcus aureus can grow in foods stored at mesophilic temperature and produce enterotoxins (Argaw and Addis, 2015; El-Didamony *et al.,* 2016), which are of proteinaceous nature and are heat resistant (Enan *et al.,* 2020b; Saber *et al.,* 2021).

It is isolated from different foods, including meat products, ready-to-eat foods, dairy products, cooked vegetables, chips, and corn snakes (Saber *et al.,* 2021).

The *Staphylococcus aureus* strains can cause several diseases such as skin infections, absceses, cystitis, pyelonephritis, pharyngitis, sinusitis, and otitis media (Agraus and Addis, 2015). *Staphylococcus aureus* enterotoxins can be detected *via* agglutination tests, ELISA, polyarcylamide gel electrophoresis, PCR, and

Salmonella spp.

The *Salmonella* bacterial genus is classified as belonging to the damily *Enterobacteriaceae*. *Salmonella* spp. include many serovars, mainly of two species *Salmonella enterica* (*S. enterica*) and *Salmonella bongori (S. bongori). Salmonella* typhi and *paratyphi* are the most important spp. as they cause the typhoid and paratyphoid diseases, respectively, after consumption of contaminated meat and other foods (Addis *et al.,* 2011; Abou-Elez *et al.,* 2021).

The salmonellosis is caused by consumption of foods mainly of animal origin and other foods. Transmission also occurs by drinking of water and consumption of food contaminated with processing equipment (Dhama *et al.,* 2013). The non-typhoidal *Salmonella* serovars are predominantly associated with foods of animal origin such as milk, eggs, poultry, beef, and pork (Enan *et al.,* 2022). The incubation period of salmonellosis ranges from 12 to 72 h (Dhama *et al.,* 2013). The severity of infection by *Salmonella* spp. ranges from self-limiting gastroenteritis to septicemia. The severity of salmonellosis depends heavily on the host susceptibility and the virulence of the serovar (Lamichhane *et al.,* 2024).

Symptoms of salmonellosis are nausea, vomiting, abdominal cramps, and watery greenish or bloody diarrhea with mucous. Other symptoms include headache, prostration, fatigue (muscle weakness), and moderate fever (Addis *et al.,* 2015). Salmonellosis may cause serious and dangerous complications in children and immunocompromised individuals (Dhama *et al.,* 2013). Reactive arthritis, sickle-cell anemia, and osteomyelitis due to *Salmonella* sp. infection are much more common in the general population (Addis *et al.,* 2015). Therefore, safe preservation of meat and other food-products by MAP is of interest.

Campylobacter spp.

Campylobacter was firstly reported in 1886 by Theodore Escherich who described it as a non-culturable spiral-shaped bacterium. The Genus *Campylobacter* is of interest in human and veterinary medicine. *Campylobacter* spp. are the leading cause of campylobacteriosis, a worldwide bacterial-derived food-borne diarrheal disease in humans resulting mainly from the contamination of food of animal origin contaminated mainly by either *Campylobacter coli* or *Campylobacter jejumi. Campylobacter* spp. can colonize the human gut (Mughal, 2018).

Worldwide, *Campylobacter* spp. are the leading cause of human and animal bacterial black diarrheal disease (Dadi *et al.,* 2009). The risk of campylobacteriosis is mainly during travelling as the infected patients can be suffering from continuous diarrhea after consumption of undercooked poultry and other meat products. The incubation period varies from 3 to 5 d (Al-Mohammadi *et al.,* 2022). The symptoms of campylobacteriosis are abdominal pain, malaise, and watery and bloody diarrhea; with greyish colour, cramps, and vomiting (Mughal, 2018).

Links Researchers

Clostridium spp.
Clostridia are sporulating Gram negative bacteria and their spores can contaminate sandwiches in banks and buffets, if there is no care, and after consumption they can survive and cause botulism (Bilska *et al.,* 2024).

The *Clostridium perfringens* intoxication occurs after consumption of foods contaminated with its spores, which can be converted to vegetative cells after being shocked by gastric acidity. In turn, the bacteria may secrete several toxins and induce gas gangrene in the intestine or the blood vessels (Enan, 2006b, c).

The consumption of contaminated cooked products with *Clostridium botulinum* spores causes botulism with the onset diarrohea, abdominal cramps, vomiting, and neural disorders (Sobel *et al.,* 2004).

Aeromonas spp.
Aeromonas spp. have been found as potential food-borne pathogen for many years. *Aeromoas* spp. are Gram negative motile bacteria, polluting fresh water, fish, meat products, dairy products, and vegetables. They are transmitted by animal feces. The major diseases caused by *Aeromonas* spp. are gastroenteritis and wound infections, which are induced due to infection with *Aeromonas hydrophila*. These infections are treated by antibiotics such as tetracyclines and ciprofloxacin (Enan *et al.,* 2023).

Yeast and molds
Yeasts and molds are able to grow in foods. Many food products are contaminated by fungal spores such as bread starchy foods, meats fish, and other foods (El-Gazzar *et al.,* 2024). The most important side effects induced by the mold food spoilage is the formation of mycotoxins (*i.e.*, aflatoxins) (Enan *et al.,* 2015a, b; Sui *et al.,* 2024). The more and most common hazardous kinds of mycotoxins are the aflatoxins; cancer causing poisons (El-Gazzar *et al.,* 2025). Moreover, during the growth of yeasts, they metabolize some food components and produce deleterious metabolic end products. This causes the change in the physical, the chemical, and the sensible properties of the food and the food becomes spoiled (Morshdy *et al.,* 2015; Sui *et al.,* 2024).

High moisture contents of the food material, mesophilic temperature of storage, and bad handling of bread, onions, orange fruits, and others lead to germination of fungal spores and appearance of mold rotting in this food (Abdel-Shafi *et al.,* 2020).

In addition, a previous study demonstrated that the dynamic changes in bacterial composition of reduced-salt sausages inoculated with different yeast strains could provide a foundation for in-depth study of fungal–bacterial interactions in fermented foods (Sui *et al.,* 2024). Therefore, there is an urgent need for continuous work to search for novel effective protocols to preserve meat products and other foods and protect them against microbial infection.

Traditional methods used for food preservation

Chilling/refrigeration: Chilling/refrigeration using refrigerators at 4°C are used at homes for preservation of fresh cooked foods for certain periods depending on the food type. The lower temperature inhibits growth of the microorganisms as it depresses the metabolism of their cells (Pal, 2014). Generally, fresh meat remains in a good condition for a period of 5-7 d if kept refrigerated at a temperature of 4 ± 1°C.

Freezing: Freezing is a common used method for preservation of fresh foods, including raw meat, fish, poultry, turkey, duck, juices, tomato paste etc. The temperature of freezing ranges from -5 °C to -20 °C. In freezing, water is converted to ice and hence the water activity responsible for life and growth of the microorganisms is stopped and hence growth of any microorganism is stopped (Heinz and Hautzinger, 2007).

Curing: Curing is the use of salting or saccharification of foods. Salting is the addition of NaCl, $NaNO_3$, lactate, benzoate or other salts to cooked meat, poultry. and fish. Salting increases the osmotic pressure of foods and decreases the water activity where microorganisms can't grow (Dave and Ghaly, 2011). High sugar concentrations of food possessed the same effect (Sindelar and Houser, 2009). However, this way of preservation is not preferable as it has shown dangerous risks on human health (FAO, 2014).

Smoking: Smoking is the formation of dry surface of cooked meat, poultry, and fish. This dry surface contains dehydrated surfaceswhere microorganisms can't grow. Smoking is made by cooking of meat slices in boiled oil with high NaCl concentrations (Pal, 2014). However, we still need to do such preservation of raw foods *via* drying by MAP.

Cooking: Cooking is the oldest preservation method used by humans, which kills all the microorganisms attached with fresh foods through raising the temperature above or equal 100 °C (Myhrvold, 2017).

Recently, cooking methods use steam under pressure where the water vapour enters the meat tissue for 20 min., giving completely sterile cooked meat. It also uses many other ways such as frying, roasting, and baking (Myhrvold, 2017). Unfortunately, cooking is used once and other ways are still needed to preserve cooked food in the refrigerator. Using MAP is a safe way for such cooked meat during transport for long periods.

Drying: Drying is the removal of moisture from foods, decreasing water activity. This leads to stopping of microbial metabolism and in turn giving preserved foods for longer periods. Since 50 years ago, fruits of apricots and similar fruits were stored in sunlight for certain days to be dry. Similarly in the Egyptian countryside, onion and garlic are left in sunlight to be dry and, hence, can be stored with decreased deterioration in dry places (Shephard, 2006; Rahman, 2007).

Currently, drying can be achieved by making high osmotic pressure and using hypertonic medium without water activity; either by salting or saccharification. The food surface becomes isolated from the environment by a dried layer, where microorganisms can't grow (Shephard, 2006).

Fermentation

In fermentation, microorganisms such as yeasts and lactic acid bacteria consume monosaccharide's and produce pyruvate *via* glycolytic pathways, where pyruvates and acetyl CoA molecules are converted anaerobically into ethanol. Many fruit juices are fermented to produce wine; a preserved natural liquor (Zaghloul *et al.*, 2021). Fish and meat are also fermented, producing fermented fish and meat products that are desirable by the consumers (Reda *et al.*, 2018).

Pickling

The word pickling may come from the Dutch word "pekel" or German "pokel"; meaning brine or salt. Pickling of vegetables such as onions, carrots, cucumber, olives, lettuce is known since many years ago. Vegetables are immersed in brine containing 6 % NaCl and firmed with 2 % starter bacterium like *Lactobacillus plantarum*.. The bacterium colonizes the vegetable material and then consumes and ferments sugars, producing organic acids with preserved pickles in the brine environment (Wu *et al.*, 2016). Recently in the Middle East countries, fish and meat are pickled by the same pre-mentioned ways (Wu *et al.*, 2016).

Canning: Canning is way of preservation used in the developed countries, where it takes high cost and canned foods are preserved during transport of foods in long periods (Nummer, 2002). For making canning of foods, the subjected foods are exposed to heating followed by sudden cooling, leading to a shock of proteins and bacterial enzymes, which could be degraded and thus causing bacterial inactivation (Bolatito, 2011).

Each type of food is processed for canning by certain way depending on many factors such as time of heating, nature of food components, and nutrient contents. The fresh healthy products, water activity of the food type, and pH value are considered during food canning.

Thermal processing

Thermal processing is necessary for sterilization of liquid foods such as milk and soap. It is achieved by heating of food to almost 75 °C and then cooling suddenly. Mostly, milk is pasteurized before making yoghurt or cheeses (Pal, 2014). Cooking by thermal treatments using dry and moist heat is used for most foods, which can kill most microorganisms and denature the bacterial spores. Dry heat *via* ovens is used for many starchy potatoes and other starchy foods and breads (Bajuvic *et al.*, 2012). This clearly shows that there is a need to find out an effective safe method for food preservation. In this regard, MAP is considered as a safe technology for food preservation.

Preservation of food by modified atmosphere packing (MAP)

The advantage of using packaging innovations is safety of the preserved food, food protection, and increasing the shelf life of foods without changing the food properties Czerwiński *et al.* (2021). It was found that the meat slices preserved by MAP food possessed accepted sensorial evaluation regarding many standards (Eilert, 2005). MAP is used for foods packaging with coated food materials and antimicrobial agents (Realini and Marcos, 2014). In this way foods are protected by the formation of antimicrobial membranes and packaged in the same time in modified atmosphere, increasing the shelf life of preserved foods.

Preservation of meat by MAP

Fresh meat and their processed products are preserved by vacuum packaging, MAP, and air-permeable packaging (Lee *et al.*, 2009). MAP is a safe technology and keeps the meat products without changes, safe, and increases the shelf-life of meat (Martínez-Ferrer *et al.*, 2002). The application of MAP on refrigerated meat has diminished its deterioration and helps in reducing ecological influence during storage (Van Velzen and Linnemann, 2008).

MAP can be categorized into two types: Active and passive atmosphere modification. The first is accomplished *via* the displacement of gases in the package, and their replacement with a desired mixture of gases. In the passive atmosphere modification, the food product is packaged utilizing a chosen film type, and a desired atmosphere develops naturally as a result of either the products respiration or the diffusion of gases through the film (Moghimi *et al.*, 2018).

Carbon dioxide, oxygen and nitrogen are basically utilized in MAP preservation of meat. CO_2 is used as an inhibitor of most bacteria and mold development, while O_2 acts as an inhibitor of anaerobic microorganisms, essentially in certain types of fish and vegetables, while keeping fresh and natural color in red meat and respiration in fruits and vegetables. Lastly, N_2 is utilized to reject air and avoid the collapse of packs for the high-moisture and the fat-containing foods. These gases are usually combined in three different ways: inert blanketing utilizing N_2, semi-reactive blanketing using CO_2/N_2 or $O_2/CO_2/N_2$ or completely reactive blanketing utilizing CO_2 or CO_2/O_2 (Czerwiński *et al.*, 2021).

Modified atmosphere packaging of meat and meat products results in products with an improved shelf life, safety, and quality. Typically, fresh red meats are stored in MAP containing 80 % CO_2 and 20 % O_2, while cooked meats are stored in 70 % N_2 and 30 % CO_2 (Smiddy *et al.*, 2002). MAP system which depends on high oxygen levels (e.g. 50 % CO_2, 50 % O_2) has been used to preserve the color stability and decrease the microbial spoilage of the products on display (Scarabottolo *et al.*, 2020). High level of oxygen concentrations in MAP has become most spread in recent decades for red meat (Jeremiah, 2001).

Other gases, for example, CO_2, nitrous and nitric oxides, SO_2, chlorine, and ozone, have additionally been utilized. However, they were experimentally tried at first with certain care because of safety and regulatory reasons; along with cost restrictions and considerations (Czerwiński *et al.*, 2021).

Despite of the improved technology and certain practices in created nations at all phases of poultry and beef meat production, food-borne contaminations stay as a continuous goal to human and animal health. The extension of antibiotic resistance in bacteria is likewise an emerging public health risk due to the compromised adequacy in the treatment of the infectious diseases (Helmy *et al.*, 2017). *Salmonella* isolates from chicken meat and organs in Egypt, demonstrated high resistance to various antibiotic classes (Ahmed *et al.*, 2021).

Consequently, to prevent contamination during the creation, sale, and distribution and extend the shelf life of raw and/or processed foods, synthetic additives should be utilized. However, there is a strong discussion about the safety aspects of these chemical preservatives since they are considered responsible for numerous cancer-causing and teratogenicity attributes due to their residual toxicity (Czerwiński *et al.*, 2021). Consequently, safe additives should be added such as plant extracts, herbs, modified proteins, and bacteriocins (Enan *et al.*, 2014a, b; Osman *et al.*, 2021; Al-Mohammadi *et al.*, 2023). These are in addition to preservatives obtained naturally from plant sources that have been utilized for a considerable length of time as a part of food preservation. Natural extracts are considered as easily decomposable sources of antimicrobial agents (Osman *et al.*, 2021).

Cereal and confectionary packaging

Cereals and their starchy products are also preserved by MAP (Belitz *et al.*, 2004), and have no changes regarding their chemical, physical, and biological properties, and also they possessed accepted sensorial evaluations. This is very useful to keep the cereals preserved with safety during transport (Konstantas *et al.*, 2019). The quality of cereals and their nutritional contents preserved by MAP does not change along the time frame.

Modifying the atmosphere inside a package can maintain the quality of a product over an elevated timeframe. The structure of the products, the associated residual oxygen in the packaging, such as the pores, and the collapse of the product are frequent challenges (Belitz *et al.*, 2004).

During packaging of cereals to be preserved by MA, the initial atmosphere is removed and then several gases such as CO_2, N_2, and low O_2 levels are pumped into the packages (Czerwiński *et al.*, 2021).

Hence, a modified atmosphere is designed to be non-suitable for microbial growth, keeping on the quality of cereals during transport. N_2 and CO_2 gases used in in cereal MAP do not show any deterioration effect on the cereal quality. Little O_2 is not used in MAP of cereals; however, it is of importance in meat packaging (Czerwiński *et al.*, 2021).

Preservation of hard and semi-hard cheeses by MAP

Increasing the shelf-life of semi-hard and hard cheese is very important and this is achieved traditionally by cold temperature in winter and dry heat in summer (Khoshgozaran *et al.*, 2012). In recent years, cheeses are made from pasteurized milk, ripened for different periods, and then kept in cold temperature. However, due to survival of some psychrotophic bacteria in cheeses, other preservation ways are necessary, achieved by the addition of certain salt concentrations. Therefore, many studies have been conducted to use starter lactic acid bacteria to make cheese and produce antimicrobial proteins (Enan *et al.*, 2023). To preserve cheese during transport, it is necessary to find out on effective technology preserving cheeses (Enan *et al.*, 2013a). Recently, hard and semi-hard cheeses are preserved as packages with MAP during their import and export (Nájera *et al.*, 2021).

The gases used for MAP of cheeses are mixtures of CO_2, N_2, and low levels of O_2. These gas mixtures are usually used together with refrigeration temperatures, thus combining preservative effects are used (Rodriguez *et al.*, 2011). Among gases, CO_2 is the most used one as it inhibits the growth of many microorganisms, including spoilage bacteria (Czerwiński *et al.*, 2021). It is highly effective against aerobic Gram negative bacteria and mold growth, and to a lesser extent against Gram positive bacteria and yeast growth. A concentration range of 20-60 % CO_2 in the atmosphere is required for an antimicrobial effect. CO_2 also causes the development of the lactic acid bacteria (LAB), which can produce organic acids having a preservative effect. High concentrations of CO_2 are used; particularly in hard and semi-hard cheeses, to suppress microbial growth (Czerwiński *et al.*, 2021). Mixtures of CO_2 and N_2 are common atmospheres used in hard and semi-hard cheese packaging, but the results depend on the cheese variety (Trobetas *et al.*, 2008).

Modified atmosphere packaging has shown to extent the shelf-life of cheeses and keeps on the consistency of cheese pieces without texture changes. In addition, the preserved cheeses do not show distinctive changes in their flavor, odour, and/or taste. MAP of cheeses with low temperature (4°C) has shown promising results as the microbial count obtained from cheeses has been significantly reduced (Jalibzadeh *et al.*, 2015).

Seafood packaging

Seafood such as fish, crustaceans, and mollusks has high nutritional values and is rich with phosphorus, proteins, vitamins, minerals, and omega fatty acids, which are very important for human health as they are precursors of prostaglandins. Seafood is of almost neutral pH and contains high water activity. Hence, its immediate preservation is necessary. It was found that MAP with low temperature extends the shelf-life of fish products during transport for long periods. It has been shown that food spoilage is decreased distinctively with foods preserved by MAP, and the risk of growth of pssychrotrophic microorganisms has completely decreased (Sivertsvik, 2003).

Preservation of semi-dry fruits by MAP

Semi-dry fruits are used extensively especially in the Middle East countries where dates, cashews, raisins, pista, and bigs are often used. MAP (100 % N_2 and 30 % CO_2 + 70 % N_2) followed by cold storage has shown a decreased or diminished growth of surface microorganisms (Czerwiński *et al.*, 2021). MAP has suppressed the growth of aerobic mesophilic bacteria, yeasts, and mold fungi in semidry fruits. Moisture contents and firmness values have merely changed during storage and are not affected by any of these treatments. Sensory characteristics such as colour, taste, and odour are generally acceptable (Sivertsvik, 2003). Therefore, both MAP with cold temperature are recommended to maintain the quality of semi-dry fruits.

Safety of modified atmosphere packaging (MAP)

It is necessary to keep foods especially meat products with complete safety from slaughtering to consumption. Therefore, certain necessary procedures should be done to ensure food safety. The increase in shelf-life of MAP meats through inhibition of spoilage bacteria is economically important for many companies. However, the packaging system with modified atmosphere can ensure the safety of foods, However, MA must be justified preliminary, followed by pumping of gases and cold temperature together with using certain natural food additives are preferred (Samchez-Escaalante *et al.*, 2003).

Conclusions and Recommendations

As foods are subjected to microbial contamination by successions of pathogenic microorganisms such as *Escherichia coli, Listeria monocytogenes, Bacillus cereus, Staphylococcus* spp., *Clostridium* spp., *Aeromonaas hydrophila*, and molds; it is necessary to find out an innovative ways for food preservation. Many traditional methods are used for food preservation, as discussed herein; but none of them can serve food storage with safety during food transportation in either exported or imported foods. Therefore, MAP of foods using certain levels of N_2 and CO_2 is beneficial to keep foods with a safety state. The use of MAP with low storage temperature and certain natural additives such as plant extracts, modified proteins, and/or probiotics or their metabolites are highly recommended for food protection during long storage periods and for extended shelf life without change in food properties.

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Novelty Statement

Modified atmosphere packaging of foods using certain levels of N_2 and CO_2 is beneficial to keep foods at a safety state. The use of MAP with low storage temperature and certain natural additives is highly recommended for food protection during long storage periods and extended shelf life without changes in food properties.

Conflict of interests
The author have declared no conflicts of interest.

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