Food packaging and modified atmosphere – roles, materials and benefits

M Milijasevic1, J Babic Milijasevic1, B Lakicevic1, M Lukic1, B Borovic1, S Veskovic1 and B Baltic1

1Institute of Meat Hygiene and Technology, Belgrade, Serbia

E-mail: milan.milijasevic@inmes.rs

Abstract. Packaging is an integral element of the system that brings safe food to consumers. Although packaging has sometimes been viewed as an inconsequential act of inserting food into a film or box, this attitude has been a prime source of product failure. Meat packaging is the most dynamic area of meat technology today and it continues to configure the future of this branch of food industry. Retail meat packaging should fulfil specific technological and hygienic demands, as well as demands such as attractive packaging appearance, appropriate meat colour, consumer acceptability, etc. Consumers are also very sensitive with regards to the use of food additives in the food industry. During the last two decades, modified atmosphere packaging has become a dominant retail meat packaging technology. The purpose of this technology is to prolong the shelf life of foodstuffs by preventing or inhibiting biochemical reactions (fat oxidation, metmyoglobin formation), growth of spoilage bacteria and degree of product respiration. This technology is opening up new markets and offers the possibility of successfully establishing new products and thus extending product ranges. This paper critically reviews the most important aspects of packaging foodstuffs in modified atmosphere.

1. Introduction

Effective packaging begins with an understanding of the requirements of the product and its marketing. These needs can then be logically connected to materials and machines to create a packaging system. A study of a broad range of food product requirements and packaging can be a stimulus to applying more profitable, optimal packaging to food. By any measurement, packaging is a large industry in size, diversity and complexity. Mere enumeration of the amount of materials consumed or money volume of machinery sold would fail to account for the numbers of persons who package products each day. Entire industries are, in reality, not manufacturers but packagers of products made by or assembled by others. When food packaging is the topic at hand, the impact of packaging on shelf life, which is a very important factor in food industries, must be considered [1].

The shelf life of perishable foods as meat, poultry, fish, fruits and vegetables and bakery products is limited in the presence of normal air by two principal factors – the chemical effect of atmospheric oxygen and the growth of aerobic spoilage microorganisms. These factors both individually or in association with one another bring about changes in odour, flavour, colour and texture leading to an overall deterioration in quality. Chilled storage will slow down these undesirable changes but will not necessarily extend the shelf life sufficiently for retail distribution and display purposes. Food spoilage is defined as changes that make a product unacceptable for human consumption. Such changes include visible bacterial growth, slime formation, physical damage or off-odour. The process collectively known...
as food spoilage is a very complex event, in which a combination of microbial and biochemical or chemical activities interact.

Packaging of food now performs beyond the conventional protection properties and provides many functions for the contained product [2]. During the last two decades, modified atmosphere packaging (MAP) has become a dominant retail meat packaging technology. The main factors stimulating MAP development are the continuous increase in consumption of fresh meat, an increase of urban populations and exhaustion of natural food resources. Developments in packaging materials and technologies have made the application of MAP on a larger scale to meat and meat products feasible [3]. Packaging a perishable product in an atmosphere that has been modified so its composition is other than that of air is termed as MAP. This refers to a system where the normal atmosphere, assumed to be approximately 78% \( \text{N}_2 \), 21% \( \text{O}_2 \), and <1% \( \text{CO}_2 \), is intentionally changed to some other identified gas composition.

The main purposes of MAP of meat and meat products and other foodstuffs, are two-fold: to ensure the microbiological shelf life and the sensory quality of the product, including the colour, door and palatability. Many meat packaging systems currently exist, each with different attributes and applications. These systems range from overwrap packaging for short-term chilled storage and retail display, to a diversity of specified MAP systems for longer-term chilled storage and display, to vacuum packaging, bulk gas flushing or MAP systems using 100% carbon dioxide for long-term chilled storage. Preservation using MAP has been known for more than 100 years, but it was not commercially used until the latter part of the 20th century [4]. MAP was first used to extend the shelf life of apples by storing them in atmospheres with reduced oxygen and increased carbon dioxide concentrations. In the 1930s, MAP was used to transport fruit in the holds of ships. However, the technique was not introduced commercially for retail packs until the early 1970s. MAP techniques are now used on a wide range of fresh or chilled foods, reflecting the increase in consumer demand for longer shelf life foods and less use of preservatives. Through the use of natural gases and adequate packaging materials and machines, the quality of foodstuffs is maintained and their shelf life enhanced. During recent decades, MAP of various food products has been well studied and documented [5,6].

2. Gases used in MAP technology

Although gases such as nitrous and nitric oxides, carbon monoxide, sulphur dioxide, ethylene, chlorine, ozone and propylene oxide have been investigated for use in MAP, they have not been applied commercially due to safety, regulatory and cost considerations.

2.1. Oxygen

Oxygen has an important role in MAP, especially in packaging of fresh meat [5]. The colour of fresh meat is determined by the condition of myoglobin in the meat. When an anaerobic atmosphere is applied, myoglobin is transformed to metmyoglobin, producing a brown colour that is undesirable to consumers. It is, therefore, essential that oxygen is included in the applied gas atmosphere when fresh meat is packaged. This will ensure the myoglobin is oxygenated, resulting in an attractive bright red colour [6]. Oxygen is a fairly active molecule and is associated with the process of the oxidation, i.e. the change of the chemical state of some biological molecules. The chemical breakdown of lipids is the primary degradation process in dry or in dehydrated foodstuffs and in high fat fish. This is due to the oxidation of unsaturated fats in the presence of atmospheric oxygen, causing the product to turn rancid. Reduced oxygen concentration within the package can prevent or slow down oxidative reactions such as lipid rancidity in meats, fish and bakery foods, which would result in off odours and flavours, or the browning reaction in cut fresh fruits due to the action of polyphenol oxidase. However, complete absence of oxygen is not desirable either. For example, the gaseous mixture used for fresh meat usually contains 80% oxygen in order to maintain the fresh bright red colour.

2.2. Carbon dioxide

Carbon dioxide is the most important gas in the field of MAP technology. Carbon dioxide is a quite active gas as opposed to the inertness of nitrogen. Carbon dioxide can inhibit the growth of several types
of microorganisms, especially those that cause slime and off-odours in refrigerated foods. This gas is both water- and lipid-soluble and although it is not a bactericide or fungicide, carbon dioxide has bacteriostatic and fungistatic properties. The bacteriostatic and fungistatic properties of carbon dioxide have been widely recognized since the 1920s, when it was used in shipments of beef, mutton and lamb from Australia and New Zealand to England. Its solubility increases with decreasing temperature and higher food pH. The precise mechanism of carbon dioxide action is still a subject of considerable interest and is not as well understood as mechanisms of other external factors acting in food, such as water activity and pH. What usually happens to perishable products stored in elevated levels of carbon dioxide is a change not only in the numbers of microorganisms, but in the types of organisms present. Very often, this shift is from Gram-negative genera to Gram-positive bacteria such as *Streptococcus* and *Lactobacillus* [7]. The intensity of carbon dioxide activity depends on concentration of gas, initial bacterial contamination of foods, storage temperature and nature of packaged food [8,9]. Carbon dioxide also has the advantage that it is relatively nontoxic to humans. If carbon dioxide is part of a modified atmosphere where its bacteriostatic effect is desired, the minimum concentration of this gas should be 20%.

2.3. Nitrogen

Nitrogen has been used in MAP for many years due to its inert property. It is an inert, tasteless gas. Nitrogen can displace oxygen in MAP, thus extending food shelf life. It prevents fat rancidity and inhibits the growth of aerobic microorganisms. Moreover, use of nitrogen in MAP can prevent package collapse due to this gas’s low solubility in both the water and fat phases of foods [10]. The gas has no direct effects on colour of food. Also, the role of nitrogen in MAP is to act as filler gas and keep flexible packages from developing a vacuum [11].

3. Packaging materials

The optimisation of packaging is a decisive factor for the efficiency of MAP. The packaging must have appropriately low oxygen/gas permeability and tight seals, otherwise too much gas can penetrate. Packaging materials, primarily polyamides, have the potential of not only approaching the desirable properties of animal and other natural casings, but also of serving as a basis for new achievements in food packaging applications. This is largely due to the analogies and similarities between the physical and chemical properties of polymers, especially those of polyamides and biopolymers. Only the great progress in chemistry and technology after the Second World War enabled serious developments in the manufacture of more sophisticated synthetic polymer materials, generally used for packaging high volume food items. New, alternative packaging materials, production methods, novel applications and permanent innovations of existing materials and ways to use them are continually being investigated and verified by the food processing industry in the pursuit of producing better quality products, more economically and more successfully.

The production and use of polymer materials require knowledge from various and diverse sources to understand possible utility or validity of the materials, and polymer use aims to create new, technologically more satisfying and economically more acceptable food products. Such an eclectic approach starts with the development of polymer processing technology and ends with complex food production systems, including numerous safety, technical, technological, environmental, nutritional, biochemical and other advancements.

The chemical nature of monomer units, methods of polymerization (synthesis), length of chain formed (molecular mass), and intermolecular forces within the polymer chain are deciding factors in determining many polymer processing properties. The properties of different polymer macromolecules are determined by the chemical nature of monomer groups and the length of chains. The chemical nature of the monomer unit and its functional groups determine polymer toughness, stiffness, transparency, gas and water vapour permeability and other basic properties of the polymer. Especially, the polymer resistance to deformation, its rigidity and its barrier properties depend largely on the polarity of the polymer pendant group.
Numerous man-made polymers are used for the manufacture of packaging materials that are in use for MAP. They are polyethylene (PE), ethylene vinyl acetate copolymer (EVA), ethylene vinyl alcohol copolymer (EVOH), polypropylene (PP), polyvinylidene dichloride (PVDC), polyethylene terephthalate (PET), polyamides (PA) and some more.

Polyethylene (PE) is the most common polymer used in food packaging. It has good sealing properties and is of relatively low cost. Polyethylene is formed by the addition polymerization of ethylene gas. Polyethylene exhibits good resistance to chemicals, it has good moisture barrier properties, but it is a poor barrier for oxygen and many organic chemicals. Depending on the reaction conditions, three types of polyethylene are produced: low density (LDPE), high density (HDPE) and low linear density polyethylene (LLDPE).

Ethylene vinyl acetate (EVA), the most common and cheapest copolymer of ethylene, is widely used as adhesive in coextrusion, for example, between polyamide and polyethylene layers. It has similar properties to PE, but much greater toughness.

Ethylene vinyl alcohol (EVOH) is a copolymer of ethylene and vinyl alcohol. EVOH has increasing application as the oxygen barrier layer in multilayer polymer films and casings.

Polypropylene (PP) is widely used in manufacturing fibres, packaging films and moulded and extruded articles.

Polyvinylidene dichloride (PVDC) is a crystalline thermoplastic polymer of vinylidene dichloride. It can be formed into waterproof and chemically resistant filaments, films, fabrics, etc.

Polyethylene terephthalate (PET) is the most important polymer in the class of polyesters. PET is the polycondensation product of terephthalic acid and ethylene diol. PET has excellent mechanical strength. It is a heat-stable crystalline polymer with a high melting point of 258°C to 262°C.

Polyamides (PA) include a very broad group of polymers used as fibre, engineering plastics, adhesives, inks, coatings, films and in other applications requiring high heat and chemical resistance.

Some of the most important properties of the polymer films are shown in Table 1.

Table 1. Important properties of different 25 µm-thick polymer films [2]

|                  | PE     | EVA   | PP         | EVOH | PVDC  | PET    | PA6     |
|------------------|--------|-------|------------|------|-------|--------|---------|
| Melting point    | °C     |       |            |      |       |        |         |
|                  | 100-140| 85-110| 150-165    | 176  | 158   | 260    | 220     |
| Tensile strength | MPa    |       |            |      |       |        |         |
|                  | 23-35  | 10-20 | 30-40      | 25   | 100   | 100    | 80-90   |
| Tensile modulus  | GPa    |       |            |      |       |        |         |
|                  | 100-300| 50-120| 1500-3000  | 1000 | 800   | 2000   | 1500    |
| Elongation at    | %      |       |            |      |       |        |         |
| break            | 500-800| 600-900| 250-600   | 150  | 90    | 250-600| 300-500 |
| Water vapour     | g/m² d |       |            |      |       |        |         |
| transmission     |       |       |            |      |       |        |         |
|                  | 0,5-5  | 2,10  | 1-5        | 50   | 2-5   | 15     | 40      |
| Oxygen transmission (dry) |       |       |            |      |       |        |         |
|                  | ml/m²d |       |            |      |       |        |         |
|                  | 4000   | 5000  | 2500       | 0,1-1| 4     | 160    | 40      |
Oxygen transmission (85% relative humidity) bar

| Oxygen transmission | 4000 | 5000 | 2500 | 3-10 | 4 | 160 | 80 |
|---------------------|------|------|------|------|---|-----|----|

PE, polyethylene; EVA, ethylene vinyl acetate copolymer; EVOH, ethylene vinyl alcohol copolymer; PP, polypropylene; PVDC, polyvinylidene dichloride; PET, polyethylene terephthalate; PA6, polyamide 6.

Polyamides show a variety of different properties, potentially useful for sausage casing production. It has already been emphasized that they have impressive mechanical and thermal resistance, allowing their use as engineering thermoplastics. In addition, many of these properties, such as melting point, toughness, and resistance to cracking and other stresses can be modified and tailored by adequate combinations of aromatic and long-chain aliphatic dicarboxylic acids with bulky cycloaliphatic diamines.

Polyamides absorb considerable amounts of water. The amount of absorbed water depends on relative humidity and temperature of environment, the exposure time, polyamide type and its crystallinity and thickness of the film. Water is inserted into the hydrogen bonds, weakening these strong intermolecular forces and reducing strength and stiffness of polyamides, while increasing their flexibility and elasticity. However, migration of water into polyamide is a relatively slow process. Microcrystalline polyamides are milky white in colour and differ from transparent polyamides that are characterized by very low or non-existent crystallinity. Most of the semicrystalline aliphatic polyamides are transparent in film thicknesses below 0.5 mm. The properties of transparent polyamides are little affected by temperature. Light transmission can be reduced by addition of particulate additives. The transparency of polyamides can be improved by increasing the number of spherulites through addition of nucleating agents: fine-grain crystallites of average diameter below the wavelength of visible light will provide highly transparent film.

Polyamide films are used in food packaging both in single layer and in multilayer structures with other materials (polyethylene copolymers, polyethylene, polyvinylidene chloride, etc.). The multilayer structures are produced by coextrusion of the two or more plastic materials.

4. Conclusion

The use of MAP in food packaging has been practiced for about 100 years, but the potential that can be achieved using this technology has still not been realized completely. MAP, if used properly for the right commercial reasons, offers sufficient benefits to both food industries and to consumers. This suggests MAP is one of many alternatives that industry should consider and use as part of applied marketing programs for high quality food. Only the highest quality food products should be used to benefit from the extended shelf life advantages afforded by MAP. The use of this technology to make up for defects in product quality and limitations in transportation will only lead to consumer dissatisfaction. The use of MAP does not eliminate the need for proper control of storage conditions, especially temperature, nor for the adequate training of food handlers at every stage of the food preparation process.

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