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Effects of Modified Atmosphere Packaging on Quality and Safety of Fresh Meat

Slavica Grujić[1], Radoslav Grujić and Karmela Kovačić
University of Banja Luka, Faculty of Food Technology, Banja Luka
University of East Sarajevo, Faculty of Food Technology, Zvornik

Abstract: Consumers today expect long shelf life of food products as well as good nutritive and sensory quality and safety. The objective of this study was to review available published researches related to maintenance of fresh red meat quality and safety using packing gases as food additives. Sensory quality and especially colour of meat are the most important indicators for freshness at the moment of purchasing. Recent advances in modified atmosphere packing have focused on finding the best gas mixture that keep fresh meat initial colour, its stability, and shelf life of product, to minimize microorganisms growth, lipid oxidation and provide product safety. To fulfill these goals, food industry developed modern technology of using modified atmosphere for food packaging.

Keywords: modified atmosphere packaging, fresh meat quality, safety

Introduction

In the last decades human life style has changed in a variety as have our expectations. Therefore food industry has developed new modern technologies of packaging to satisfy consumers' demands. Most quality concepts are based on the individual expectations and consider nutritive and sensory food quality and safety and they are crucial to product acceptance and product development (Dransfield, 2005; Radetić et al., 2007). Economically developed societies have undergone major changes in lifestyles and consumers eat more meals away from home, use food items that need minimal preparation, fresh-like properties, and of long shelf-life. Shelf-life is defined as the period of time a product can be stored without being sensory unacceptable or becoming a health risk (Koch et al., 2009). In this definition are also included deteriorations due to chemical and microbial contamination.

Meat quality and safety

Food quality, safety and nutrition are strongly interrelated. Food safety became more and more actual, due to changing eating habits, changing of products, changing of the population and increased food infections (Vandendriessche, 2008; Grujić and Spaho, 2010). Eating habits moved more and more from hours cooking to convenience, ready-to-eat products. This change in the market initiated new meat products and product presentation with demands for the cold chain.

Food safety systems must be implemented so to fulfill special standards and requirements for food products with acceptable quality level. Vacuum packaging and modified atmosphere packaging (MAP) are recent innovations that have been gaining importance as preservation techniques to improve the shelf-life of meat and other foodstuffs (Farber et al., 2003). In vacuum packaging, air is completely removed. MAP provides alterations of atmospheric gas concentrations in the pack. Controlled atmosphere packaging is

[1] Corresponding author: e-mail: grujicslavica@yahoo.com; Phone: + 387 65 880 191

also MAP, wherein the selected atmospheric concentration of gas is actively maintained throughout the storage period. Retention of meat colour is better in MAP than in vacuum packaging. Microbial profiles of MAP and vacuum packed meat do not differ significantly (Narasimha and Sachindra, 2002). MAP of meat offers several advantages for retaining the desirable market quality of products and it can be improved by coupling with hurdle technology and proper preservation systems. Active packaging is a significant area of advancement of MAP technology to improve the safety of meat products and other foodstuffs important in human nutrition.

Quality of chill-stored fresh meat may be affected by colour change, lipid and protein oxidation and spoilage by microorganisms, but implementation of different standards can help in its protection (Meinert et al., 2009). Quality and acceptability of foodstuff consumer will judge by the sensory quality characteristics at the first place. The findings of McCarthy and Henson (2005) suggest that consumer perceptions of the risks associated with beef relate not only to concerns about health and safety. Also the financial, psychological performance and social consequences impact on the choices made at the point-of purchase (Bruhn, 2005).

Quality and safety of products packed in modified atmosphere depend of the quality and hygiene of raw materials used for half prepared or prepared foodstuff, type of inert gas or mixture, the quality of equipment used for packaging and packaging materials. The objective of this study was to review available published researches related to maintenance of fresh red meat quality and safety using packing gases as food additives.

Packaging gases as food additives

In European Union and according to that in Bosnia and Herzegovina, use of food additives is subject of strict control and supervision. The Directive 89/107/EEC repealing in near future with Regulation (EC) No 1333/2008, applies on any substance used as food additives with the various functional categories and which are not normally consumed as a food in itself and not normally used as a characteristic ingredient of food, whether or not it has nutritive value, the intentional addition of which to food for a technological purpose in the manufacture, processing, preparation, treatment, packaging, transport or storage of such food results, or may be reasonably expected to result, in it or its by-products becoming directly or indirectly a component of such foods (Directive 89/107/EEC; Regulation (EC) No 1333/2008; *Službeni glasnik BiH, 83/08a)*.

The Directive No 95/2/EC, is a specific Directive forming a part of the comprehensive Directive 89/107/EEC, and applies to packaging gas additive category, which are in group of additives other than colours and sweeteners. According to the Directives, packaging gases are defined as gases other than air, introduced into a container before, during or after the placing of a foodstuff in that container. The substances usually used as packaging gases are carbon dioxide E 290, argon E 938, helium E 939, nitrogen E 941, nitrous oxide E 942, oxygen E 948, hydrogen E 949, and may be added to all foodstuffs, with some exceptions, following the *quantum satis* principle (Directive 95/2/EC; *Službeni glasnik BiH, 83/08b)*.

In order to ensure that consumers receive adequate information, it is necessary to provide compulsory indication for certain foodstuffs. If packaging gases are used in packaging of certain foodstuffs that should not be regarded as ingredients for the purposes and therefore should not be included in the list of ingredients on the label. However, consumers should be informed of the use of such gases in, as much as this information enables them to understand why the foodstuff they have purchased has a longer shelf life than similar products packaged differently. So, foodstuffs whose durability has been extended by means of packaging gases on label or package must include additional particular "Packaged in a protective atmosphere" (Grujić, 2005; Directive 2008/5/EC).

Predicting the shelf-life of chill-stored fresh meat is important for producers in order to ensure good nutritive and sensory quality, shelf-life and optimal and flexible retail distribution. General models describing both the growth of microorganisms and shelf-life could be generated based on data from shelf-life studies (Narasimha and Sachindra, 2002; Meinert et al., 2009). The models validated using shelf-life studies with various cuts collected at different commercial plants are very useful for predicting the shelf-life of chill-stored fresh meat both for research purposes, for daily use in the meat industry, for improvement of shelf-life along the distribution chain, for determining realistic use-by dates and for developing new packing concepts.

Packaging technology developed to reduce oxygen concentration surrounding the food product, today is known as Modified Atmosphere Packaging (MAP). It could be qualified as leading technology in maintenance of quality and safety of food products. Principle of method is relative simple, as normal atmosphere from the packaging is replaced by a gas mixture that is appropriate, suitable for packaging food in question. Modified atmosphere packaging (MAP) is well-known as a method for extending the shelf life of a variety of foods, including fresh meat. Atmospheres usually combine oxygen (O_2), carbon dioxide (CO_2) and nitrogen (N_2) in different proportion to maintain the quality of fresh red meat, both from a microbiological and sensory point of view. MAP is most effective when used with refrigeration, because low temperature slows microbiological and other kinds of food products spoilage (Aksu et al., 2005; Lund et al., 2007; Djenane et al., 2009; Radetić et al., 2007). MAP is a method used to protect food product of oxidation, especially fat and aromatic substance as foodstuff constituents (Parket al., 2008), increasing of shelf life, preservation of product quality, easy separation of sliced products, clear visible product, little or no need for chemical preservation, increased distribution area and reduced costs (Phillips, 1996). Also, as disadvantages of MAP could be mentioned cost of gas packaging equipment, gases, packaging materials and analytical equipment, required temperature control, potential growth of food borne pathogens due to temperature abuse by retailers or consumers.

The substances common applied to fresh meat and meat products as packaging gases are oxygen (E 948), carbon dioxide (E 290), nitrogen (E 941) and carbon monoxide.

Oxygen (E 948)

Oxygen is perhaps the major factor determining the shelf-life of meat products. It is the essential gas being used metabolically by aerobic spoilage organisms (Narasimha and Sachindra, 2002). Because consumers use meat colour as an indicator of wholesomeness, recent advances in MAP have focused on finding the correct blend of gases that maximizes initial colour, colour stability, and shelf life, while also minimizing microbial growth, lipid oxidation, and gaseous headspace. One of the major functions of oxygen in MAP of meat is to maintain myoglobin in its oxygenated form, oxymyglobin. It is responsible for the bright red colour, which most consumers associated with fresh red meat, but it can reduce the shelf-life of meat due to oxidative rancidity in certain oxygen-sensitive products and the growth of aerobic spoilage microflora. High-oxygen atmospheres with 80% O_2 promote pigment oxygenation, maintains redness during storage, so rancidity often develops while colour is still desirable (Mancini and Hunt, 2005). If ultra low-oxygen atmospheres is used, oxygen needs to be less than 1% for pork and less than 0.05% for beef (Mancini and Hunt, 2005; Brandon et al., 2009). The levels of 1–2% O_2 are too high. Ultra-low-oxygen atmospheres minimize lipid oxidation and aerobic microorganism growth.

The meat industry has adopted injection enhancement of fresh meat to help ensure a colour stability, more consistent, juicy, and tender product. The objective of Seyfert and co-workers (2004) study was beef round muscles MAP packaging. They find that high partial pressures of oxygen, in the high-oxygen system, created a deep layer of oxymyoglobin on the meat surface, resulting in a very bright, more cherry-red appearance and stable colour even with extended display periods. The low-oxygen system requires much greater control to achieve success (Paulsen et al., 2006). As oxidation to brown metmyoglobine is promoted under low partial pressure, fresh meat in low-oxygen MAP systems has longer storage life due to the carbon dioxide and an oxygen-free environment.

Storage in high-oxygen atmosphere cause decreased meat tenderness and reduced content of free protein compared to packaging without oxygen, showing that meat proteins are in fact oxidized when stored in high-oxygen atmospheres (Lund et al., 2009). Myosin was found to crosslink in meat stored only in high-oxygen atmosphere, and these results indicate that the reduced tenderness of meat is caused by oxidative modification of structural proteins. The selected antioxidant systems effectively inhibited lipid oxidation (Balev et al., 2010). Assessing the aroma of beef steaks stored under different levels of O_2 in MAP, Resconi and co-workers (2009) find that no significant effect of the different concentration of O_2 was observed in sensory attributes, although values for rancid flavour and lipid oxidation increased with storage time.

High levels of oxygen present in food packages may facilitate microbial growth and although oxygen sensitive foods can be packaged under MAP or vacuum conditions. Such techniques do not always facilitate the complete removal of oxygen, but O_2 absorbers applied to meat product packaging can prevent the growth of moulds, aerobic bacteria and oxidative damage of muscle pigments and flavours to avoid discoloration (Coma, 2008). Residual oxygen can be responsible for various degradation phenomena, so O_2-scavenging technology may be used appropriately to remove residual O_2 after MAP or vacuum packaging.

Changes in the quality of a product on storage, the integrity of packages, and the efficiency of operation of the packaging lines, may be determined by identifying the residual levels of oxygen in each pack (Fitzgerald et al., 2001). Conventional methods of assessing the oxygen content in packaged meat products and other food packages have been difficult, expensive, and normally require destruction of the package, so different kind of oxygen sensors development for commercial use and testing is required (Smiddy et al., 2002).

Oxygen concentration increase from 20% to 70% in the packaging had positive influence on colour stability of microconfectioned parts of beef leg (Milijasevic et al., 2008). That was probably due to formation of higher quantity of oxy-myoglobine in meat which was in proportion to higher oxygen concentration in the mixture of gases. Slices of beef packed in mixtures containing high percentage of carbon dioxide acquired unacceptable dark green colour due to formation of metmyoglobine. Samples packaged in gas mixtures with higher percentage of carbon dioxide showed lower pH values. That can be explained by dissolution of carbon dioxide in meat liquid phase and consequent formation of carbonic acid which leads to pH value decrease.

As factor influencing quality and stability of fresh meat and their products packed in MAP, pH must be considered. Extreme progress in pH during the conversion of muscle to meat influence the colour characteristics of red meat and provided the basis for two of the most well-known inferior meat quality grades, namely dark, firm and dry and pale, soft and exudative meat (Lindahl et al., 2006a; Lindahl et al., 2006b). Higher pH protects myoglobin from heat denaturation, allowing the maintenance of red or pink colour of meat during and after cooking (Mancini and Hunt, 2005)

Modified atmosphere packaging with a high level of oxygen (70-80% O_2 and 20-30% CO_2) is increasingly used for retail packaging of fresh meat (Lund et al., 2009). The packaging method is advantageous as it preserves the bright red colour of fresh meat and reduces microbiological spoilage, but the high concentration of oxygen in the packaging atmosphere holds the risk for increased oxidation of both lipids and proteins. Protein oxidation of meat is associated with texture deterioration.

Carbon dioxide (E 290)

Carbon dioxide extends the shelf-life of perishable foods by retarding bacterial growth. CO2 increases both the lag phase and the generation time of spoilage organisms. CO2 is effective due to its ability to penetrate the bacterial membrane causing intra-cellular pH changes of greater magnitude than those resulting from similar external acidification that can be effectively buffered by the organism (Narasimha and Sachindra, 2002).

Modified atmosphere packaging (MAP) has become more common and applied to different meat products (Santos et al., 2005) as it solved some disadvantages of vacuum packaging technique for foodstuffs. Use of vacuum or a gas mixture in packaging may inhibit the strictly aerobic microorganisms which cause spoilage of fresh meat, but this technology does not guarantee fresh colour appearance and stability during display.

Carbon dioxide has been proposed for meat MAP due to its ability to increase shelf life in meats stored at low temperatures by reducing microbial growth, especially when used at high concentration up to 100% CO_2 (Viana et al., 2005). Carbon dioxide is the gas highly soluble in muscle and fat tissue (Jakobsen and Bertelsen, 2004). The absorption of CO_2 is dependent on the moisture and fat content of the product. If product absorbs carbon dioxide, the internal volume of the package will be reduced, giving a vacuum package look known as ‘’pack collapse”. Also the dissolved CO_2 may reduce the capacity of meat to retain the water, producing by consequence liquids on the bottom of the packaging (Phillips, 1996; Lund et al., 2007). The absorption capacity is related to biological factors, i.e., pH, water and fat content, but also to a large extent to the packaging and storage conditions, specifically CO_2 partial pressure, headspace to meat volume ratio and storage temperature. For meat preservation, CO_2-generators are mainly used because of their inhibitory activity against a range of aerobic bacteria and fungi. For most applications in meat and poultry preservation, high CO_2 levels (10–80%) are desirable because high levels inhibit surface microbial growth and thereby extend shelf-life, because CO_2 is the only gas with a direct antimicrobial effect (Coma, 2008).

Microbial efficacy of carbon dioxide is reduced when associated with other gases, especially O_2. Efficacy of CO_2 depends on the microbial growth phase. The major disadvantage of high CO_2 concentrations in meat MAP is associated with a certain degree of darkening as a result of metmyoglobin formation, especially when low O_2 concentrations are present (Viana et al., 2005). The gas combination typically used in beef MAP varies from 75 to 80 % of O_2 and 20 to 25 % of CO_2 (Resconi et al., 2009), but increasing package oxygen content to levels higher than 55 % may not provide additional benefits to colour deterioration, because a high oxygen level can promote rancidity, which could develop off-flavours.

The choice of gas mixtures for MAP is influenced by the product sensitivity to oxygen and carbon dioxide, the colour stabilizing requirements and the microbiological flora capable of growing on the product. The presence of O_2 is very important in the storage of fresh meat as it maintains the meat pigment myoglobin in its oxygenated form, oxymyoglobin, which gives fresh meat its bright red colour, but it is not desirable in the gas mixtures for long term storage of pork (Martínez et al., 2005). CO_2 is mainly responsible for the bacteriostatic effect on microorganisms in modified atmospheres influenced by the concentration of CO_2, the age and load of the initial bacterial population, the storage temperature and the type of product being packaged. In aerobic systems, such as are used for meat display packs, atmospheres containing 20–30% CO_2 are used to prevent growth of aerobic spoilage bacteria. In anaerobic systems, used to extend the storage life before meat is prepared for display, atmospheres of 100% CO_2 may be used.

Nitrogen (E 941)

It is well known that the composition of modified atmosphere systems (O_2, N_2 and CO_2) can be an effective means to restrict and/or inhibit growth of aerobic spoilage organisms of perishable foods such as meat, fish and their products, as well as to sustain the visual quality of red meat. The three principal gases used in MAP are carbon dioxide (to inhibit bacteria and moulds), and oxygen (to prevent anaerobic growth), nitrogen as inert filler (to avoid oxidation of fats and pack collapse) (Tsigarida et al., 2000; Narasimha and Sachindra, 2002; Stetzer et al., 2007). The primary principle of MAP is the exclusion of oxygen (which limits the shelf-life of meat by causing oxidative rancidity and/or by enhancing the growth of spoilage microorganisms) by using a barrier film or by modifying the gaseous environment surrounding the meat.

Nitrogen is an inert gas with a low solubility in both water and fat. Its use in MAP is mainly to displace oxygen and it indirectly influences the shelf-life of perishable foods by retarding the growth of aerobic spoilage organisms. "Pack Collapse," which is common in MAP packs due to absorption of CO_2 into meat tissue, can be prevented by using nitrogen in combination with CO_2 as inert filler. Nitrogen has no antibacterial properties and does not affect meat colour. Modification of atmosphere within the package by reducing the oxygen content and increasing the level of CO_2 and/or N_2 has been shown to significantly extend the shelf-life of perishable foods at chill temperature. Combinations of gas mixtures have been tried for MAP of meat. Beef packaged in pure CO_2 and CO_2/N_2 was found to retain excellent colour, microbiological quality, chemical composition, and sensory properties (Narasimha and Sachindra, 2002; Stetzer et al., 2007). Many of these principles have been used for the development of new technologies or strategies to control either spoilage or food-borne outbreaks. Master packaging of meat in retail trays, over- wrapped with high O_2 permeable film, in gas-impermeable bags back-pushed with carbon dioxide (CO_2) or nitrogen (N_2) has potential for providing such sufficient storage life to facilitate centralized meat cutting and packaging operations.

Carbon monoxide

Food law in European Union and Bosnia and Herzegovina isn't including carbon monoxide on list of packaging gas additive category or for use as a component of aren't mixture in a MAP system (Directive 95/2/EC; *Službeni glasnik BiH, 83/08b)*. Carbon monoxide (CO) has been very effective in maintaining the red colour in fresh meat due to the formation of carboxymyoglobin. CO has no effect on bacterial growth. However, due to its toxicity it has not been approved by regulatory agencies, except in EU in Norway (Narasimha and Sachindra, 2002). In USA, legal status of carbon monoxide is different. The Food and Drug Administration (FDA, 2004) has received the notice for scientific procedures for carbon monoxide use as a component of a modified atmosphere packaging (MAP) system for case-ready fresh beef and pork. The level of CO in that MAP system is 0.4 percent. During storage in the MAP improve beef colour without masking spoilage. The other components of the MAP system are carbon dioxide (20-100 percent) and nitrogen (0-80 percent). The level of CO in this MAP system is 0.4 percent and other components of this MAP system are carbon dioxide (30 percent) and nitrogen (70 percent). This packaging system is used for packaging fresh cuts of muscle meat and ground meat to maintain wholesomeness, provide flexibility in distribution, and reduce shrinkage of the meat. According to the scientific procedures FDA confirms that carbon monoxide is GRAS for use as a component of a gas mixture in a MAP system as previously assigned. The most recently approved system in the US (FDA, 2004; Cornforth and Hunt, 2008), allows the meat to be sold with carbon monoxide in the retail package atmosphere. The open date code established for products packed in the MAP system will not exceed 35 days following the date of packaging for intact muscle cuts and 28 days for ground beef.

Many consumers make purchase decision based on displayed colour and discriminate meat which is not red and bright (Mancini et al., 2009; Ballico et al., 2009). In fresh meat, myoglobin can exist in any of 4 redox states: deoxymyoglobin, oxymyoglobin, carboxymyoglobin, and metmyoglobin (Mancini & Hunt, 2005). Understanding myoglobin chemistry has promoted central packaging of case-ready meat products, which can increase colour life via the use of both modified atmosphere packaging and injection-enhancement technologies.

Meat colour can be preserved by the use of carbon monoxide (CO), so most meat researchers explain the formation of carboxymyoglobin simply by implicating deoxymyoglobin's strong affinity for carbon monoxide and producing a stable bright red colour to the muscle (FDA, 2004; Madsen and Clausen, 2006; Cornforth and Hunt, 2008). MAP with low concentrations of CO and high concentrations of CO_2 has been shown to improve beef and pork colour and other meat quality characteristics (Burrows and Brougher, 2007; Stetzer et al., 2007). The stability of carboxymyoglobin, once the molecule is challenged with an oxygen-enriched atmosphere, could be a matter of molecular affinity and the relative partial pressures of oxygen and carbon monoxide. This concept suggests that myoglobin may prefer to hold onto oxygen rather than carbon monoxide what is particularly important when packaging beef steaks in carbon monoxide. Extension of fresh meat shelf life could be achieved packaging it in modified atmosphere containing 1% CO was employed which is a definite advantage for extending meat displaying shelf life (Viana et al., 2005). MAP with 100% O_2 shows the lowest shelf-life extension with greater growth of aerobic microorganisms and meat discoloration after 20 days of storage. MAP with CO_2 or CO produced no additional antimicrobial effect compared to the vacuum packaging and meat colour was better preserved throughout storage.

To eliminate the disadvantages of commercial ultralow-oxygen MAP, carbon monoxide has been added to packages because of its high affinity for myoglobin and its ability to form a bright-cherry red colour on the surface of beef. The objective of the Mancini and co-workers study (2009) was to assess the effects of lactate enhancement in combination with different packaging systems on beef steak colour and as result they find that packaging steaks in CO did not counteract the darkening effects of lactate. Nevertheless, CO improved colour stability compared with high-oxygen packaging.

Addition of carbon monoxide at low levels counteracts undesirable colour changes associated with high levels of CO_2 (Martínez et al., 2005; Wilkinson et al., 2006). Modified atmosphere packaging with 0.4% CO is recommended for extended storage of fresh pork in a master-pack arrangement for the maintenance of a bright, pink-red fresh red meat colour. If care is taken to control product cleanliness at the time of packaging, MAP packaging with CO_2 and with or without CO can provide at least 8 weeks of spoilage-free refrigerated storage for retail-ready pork chops in a master-packaging system (Wilkinson et al., 2006).

Modified atmosphere packaging with carbon dioxide and oxygen is effective for prolonging shelf-life of fresh meat, provides the advantage of enhancing meat colour facilitating the shipment of fresh product to distant markets. However, the use of CO in meat packaging should be approved by regulatory agencies due to safety considerations, and its use in modified atmosphere for meat packing present no toxic hazard to consumers (Directive 89/107/EEC; Regulation (EC) No 1333/2008; *Službeni glasnik BiH, 83/08a)*.

Effect of modified atmosphere packaging on fresh meat quality

Consumer research provides information essential for designing and evaluating quality of product (Bruhn, 2005; Grujić and Spaho, 2010). The quality characteristics of meat products have been the subject of many research publications. Colour and fat content are mentioned most often where deterioration is related to loss of a bright red colour during display and modified atmosphere has influence and help in control of the appearance of meat colour, oxidation of lipid and microbiological stability.

Meat colour

Meat colour is the greatest quality characteristic that determines whether or not raw meat or meat products will be purchased. Meat can exist in many colour shades, including red, purple and brown as well as yellow and green. As meat purchasing decisions are influenced by colour more than any other quality factor, consumers use discoloration as an indicator of freshness and wholesomeness of meat or meat products.

In their study Jakobsen and Bertelsen (2004) analysed meat from 15 different species and found that the sensory colour attributes were most important in describing differences between species. The study also gives information about sensory characteristics of meat from young and old animals of the same species, namely cattle and showed significant differences in the sensory attributes colour and flavour.

Myoglobin is a watersoluble sarcoplasmic protein that determines meat colour, although other heme proteins may play a role in beef, lamb, pork, and poultry meat colour. Myoglobin structure and function in the meat muscle depend on the meat's temperature, oxygen partial pressure, pH, muscle's reducing capacity, microbial growth. Binds oxygen, water or carbon monoxide to myoglobin affects the formation of: deoxymyoglobin with purplish-red or purplish-pink colour, typically associated with vacuum packaged product and muscle immediately after cutting; oxymyoglobin with bright cherry-red colour; carboxymyoglobin with stable bright red colour; or metmyoglobin with brown, unattractive colour (Mancini and Hunt, 2005; Suman et al., 2005; Mancini et al., 2009).

Modified atmosphere packaging (MAP) is increasingly used for retail-ready meat packaging, as food producers are interested and support adding efforts in research to maintain attractive fresh appearance, for extending the shelf-life, quality and safety and increase the potential market (Viana et al., 2005; Santos et al., 2005; Djenane et al., 2009). Consumers associate a bright pink colour with meat freshness. Many experimental works should be undertaken to evaluate the microbiological, colour and sensory attributes of fresh meat packaged with different gas mixtures and stored at different temperature regimes (Brewer et al, 2006; Lindahl et al., 2006b; Hunt and Mancini, 2009), also considering that specific colour change in meat depends on myoglobin content, oxidation, reducing and denaturation of myoglobin, oxygen availability, tissue pH, as well as chemical characteristics of muscle.

Lipid oxidation

Animal fats oxidation is considered to be important factor that affect fresh meat quality and safety. These fats provide nutritional values, essential fatty acids, and desirable sensory characteristics. However, excess intake of food fat is the cause of increased incidence of obesity, high blood pressure, and coronary heart diseases (Campo et al., 2006; Park et al., 2008). The amount and composition of fats in meat vary depending on the location of meat cuts. Lipid oxidation during storage deteriorates food systems producing undesirable colour and flavour. To reduce lipid oxidation, meats and meat products are stored under low temperature without oxygen and refrigerated temperatures, but product quality may still be diminished due to discoloration, lipid oxidation, and textural defects (Seyfert et al., 2004; Viana et al., 2005; Campo et al., 2006).

Lipid oxidation is a major cause of deterioration in the quality of fresh meat and meat products as rancidity starts soon after the death of the animal and affects meat colour, taste, texture and nutrition value (Soares et al., 2009). Oxidation can occur in the stored triglycerides or in the phospholipids of the cell membrane. Metal ions and ascorbic acid may also function as prooxidants in meat in the presence of various factors such as light, abused temperature and oxygen. Fatty acids increase the unstable organic compounds content during autooxidation reactions and can initiate the meat lipid oxidation cycle (Campo et al., 2006; Soares et al., 2009). Cooked meat undergoes rapid deterioration due to tissue lipid oxidation. With increased consumption of pre-packaged raw meat and precooked convenience meat, control of oxidation has become increasingly important.

Food lipids oxidation is considered to be a risk factor for human health. The interest of researchers and consumers for the link between oxidation and health is now a topic of research and a number of metabolic disorders has been enrolled among the group of diseases directly or indirectly related with oxidation. Food scientists have been dealing with oxidation of lipids for a long time (Chizzolini et al., 1998). Autooxidation of fats, known as rancidity, has been a quality problem which could seriously impair foods desirability. Some lipid oxidation products and a few cholesterol oxides in particular, are considered atherogenic agents and appear to have mutagenic, carcinogenic and cytotoxic properties.

Oxidation of lipid in meat products is affected by various factors, as length and type of storage, processing procedures (heating, mincing, and mixing) and additives used (Suman et al., 2005). Cholesterol oxidation is faster in foods produced with a drying process and/or stored for some time (Chizzolini et al., 1998). Interesting field for future study remains the effect of natural antioxidants and interaction between sensory characteristics, toxic compounds, lipid oxidation and its products in food systems.

Microbiological stability of meat

Modified atmosphere packaging (MAP) is well-known as a method for extending the shelf life of a variety of foods, including fresh meat. Atmospheres used combine oxygen (O_2), carbon dioxide (CO_2) to maintain the microbiological and sensorial quality of fresh red meat (Phillips, 1998; Luno et al., 2000; Martínez et al., 2005). Packaging of meat in MAP containing low oxygen and high carbon dioxide levels can suppress the growth of foodborn pathogens as well as extend shelf life and preserve food quality. The ability of modified atmospheres to inhibit the growth of the microorganisms in foods under refrigerated storage is of vital importance for this type of packaging. There are many researchers reported about microbiological aspect of MAP and importance of high raw material quality and good hygiene and manufacturing practice. MAP is used to extend the shelf life of fresh meat and meat products by controlling microbial growth and chemical degradation (Tsigarida et al., 2000; Van-Velzen and Linnemann, 2008; Del Nobile et al., 2009). Elevated CO_2 and reduced O_2 levels can inhibit growth of various spoilage and pathogenic microorganisms.

Microbial profiles of MAP and vacuum packed meat do not differ significantly (Narasimha Rao and Sachindra, 2002). The high temperature cooking during product processing eliminates the vegetative forms of microorganisms and only bacterial spores survive the treatment. Handling of the product during cooling, leads to post cooking contamination by other bacteria on the surface of the product (Vandendriessche, 2008; Santos et al., 2005). Grinding of meat causes accelerated oxidation of myoglobin (Mb) and random homogenous distribution of any contaminating pathogenic bacteria (Suman et al., 2005; Del Nobile et al., 2009). Raw minced meat storage at low temperature and levels of CO_2 and O_2 in MAP affect growth of contaminants. The shelf life of ready-to-cook meatballs is limited by microbial spoilage as they can easily be contaminated by microorganisms from raw materials (ground beef and spices), equipments and employees (Ozturk et al., 2010). Methods, treatments, processes, interventions and hurdles applied for pathogen control should be managed properly (Sofos, 2008). Process control and management systems should be implemented on the basis of collaboration, cooperation and coordination among the various sectors involved in food production and processing.

Shelf-life of fresh meat and meat products

Throughout the supply chain for fresh meat and meat products, shelf-life is a crucial issue for all involved partners, also as an important economic factor which has strong commercial impact. On the market, economics concern the meat industry as well as retailers and the food service sector. They all need an efficient system for logistics throughout the supply chain in order to minimize losses and damage to the product that might lead to lack of supply, recalls of products and other inconveniences with great economic consequences. Supermarkets and consumers ask for long shelf-life as well as good quality level throughout declared shelf-life period. This is a challenge to the meat industry as they have to optimize processes in order to achieve the best shelf-life (Aksu et al., 2005; Viana et al., 2005; Koch et al., 2009). The dominating parameters in determining the shelf-life of the particular product will depend on the specific product, the processing and storage conditions.

Meat colour life, as important sensory quality characteristic related to product acceptability, is determined by numerous factors. Product can be classified as sensory acceptable but to contain an unacceptable number of pathogens which makes the product unacceptable for human consumption (Koch et al., 2009). The predominant reason for meat spoilage is microbial activity. Fresh sterile vacuum-packed meat could limit shelf-life by the activity of enzymes, but the meat becomes very bitter in taste. In ready-to-eat meat products the sensory shelf-life could depend of the microbial competition in the products, that why, slicing hygiene and storage temperature should be used as efficient parameters.

Conclusion

Today consumer gives a great importance to nutritive and sensory quality, attractive appearance and safety of meat products. In modern business conditions the meat industry has changed from being production-driven to becoming consumer-led. According to that, MAP is widely used commercially as a way of increasing the shelf life of meat and maintaining a desirable bright red colour, as important quality attribute, and biological contaminants could be controlled, as critical point related to the safety of meat and meat products. The challenge for researchers and meat producers in future will be to deal with further consumer-oriented research and improvements related to the MAP combined with new methods of fresh meat colour stabilisation, maintenance of fresh meat odour, slow-down of oxidative reactions and extending meat shelf life by inhibition of spoilage bacteria growth.

References

1. Aksu, M. I., Mükerrem, K. & Herbert, O. W. (2005). Effect of modified atmosphere packaging and temperature on the shelf life of sliced pastirma produced from frozen/thawed meat. Journal of Muscle Foods, 16, 192–206.
2. Balev, D. K. Staykov, A. S., Ivanov, G. Y., Dragoev, St. G. & Filizov, E. H. (2010). Color stability improvement of chilled beef by natural antioxidant treatment and modified atmosphere packaging. Am. J. Food Technol., 6, 117-128.
3. Ballico, S., Contò, M., Gaddini, A. & Failla, S. (2009). Effect of different blooming times on colour parameters and reflectance spectrum of beef. In Proceedings of the 55th International Congress of Meat Science and Technology (ICoMST). Copenhagen, Denmark.
4. Brewer, M. S., Novakofski, J. & Freise, K. (2006). Instrumental evaluation of pH effects on ability of pork chops to bloom. Meat Science, 72, 596–602.
5. Brandon, K., Beggan, M., Allen, P. & Butler, F. (2009). The performance of several oxygen scavengers in varying oxygen environments at refrigerated temperatures: implications for low-oxygen modified atmosphere packaging of meat. International Journal of Food Science and Technology, 44, 188–196.
6. Bruhn, M. C. (2005). Explaining the concept of health risk versus hazards to consumers. Food Control, 16, 487–490.
7. Burrows, K. V. & Brougher, C. (2007). Federal Regulation of Substances Generally Recognized As Safe (GRAS) and the Use of Carbon Monoxide in Packaging for Meat and Fish. Congressional Research Service Report for Congress. Available at:
8. <http://www.policyarchive.org/handle/10207/bitstreams/18820.pdf>. Acc. 30.09.2010.
9. Campo, M. M., Nute, G. R., Hughes, S. I., Enser, M., Wood, J. D. & Richardson, R.I. (2006). Flavour perception of oxidation in beef. Meat Science, 72, 303–311.
10. Chizzolini, R., Novelli, E. & Zanardi, E. (1998). Oxidation in Traditional Mediterranean Meat Products. Meat .Science, Vol. 49, No. Suppl. I, S87-S99.
11. Coma, V. (2008). Bioactive packaging technologies for extended shelf life of meat-based products. Meat Science, 78, 90–103.
12. Commission Directive 2008/5/EC concerning the compulsory indication on the labelling of certain foodstuffs of particulars other than those provided for in Directive 2000/13/EC of the European Parliament and of the Council, O.J., L 27, p. 12.
13. Cornforth, P. D. & Hunt, C. M. (2008). Low-Oxygen Packaging of Fresh Meat with Carbon Monoxide: Meat Quality, Microbiology, and Safety. American Meat Science Association, White Paper Series. Number 2.
14. Council Directive 89/107/EEC on the approximation of the laws of the Member States concerning food additives authorized for use in foodstuffs intended for human consumption. Official Journal of the European Union, L 40, p. 27. Amended by: European Parliament and Council Directive 94/34/EC. Official Journal of the European Union, L 237, p.1.
15. Del Nobile, M. A., Conte, A., Cannarsi, M. & Sinigaglia, M. (2009). Strategies for prolonging the shelf life of minced beef patties. Journal of Food Safety, 29, 14–25.
16. Djenane, D., Camo, J., Beltrán, J. A. & Roncalés, P. (2009). Effect of active packaging on the oxidative and microbial stability of beef aged for different times and stored in modified atmosphere. In Proceedings of the 55th International Congress of Meat Science and Technology (ICoMST). Copenhagen, Denmark.
17. Dransfield, E. (2005). Consumer importance in creating demands for meat and meat product safety. Tehnologija mesa, 46 (1-2), 3-10.
18. European Parliament and Council Directive No 95/2/EC on food additives other than colours and sweeteners. Official Journal of the European Union, L 61, p. 1
19. European Parliament and of the Council Regulation (EC) No 1333/2008 on food additives, Official Journal of the European Union, L 354, p.16.
20. Farber, J. N., Harris, L. J., Parish, M. E., Beuchat, L. R., Suslow, T. V., Gorney, J. R., Garrett, E. H. & Busta, F. F. (2003). Microbiological Safety of Controlled and Modified Atmosphere Packaging of Fresh and Fresh-Cut Produce. Comprehensive Reviews in Food Science and Food Safety. Vol. 2 (*Supplement*).
21. FDA. (2004). Agency Response Letter GRAS Notice No. GRN 000143 CFSAN/Office of Food Additive Safety July 29, 2004. Available at: <http://www.fda.gov/Food/FoodIngredientsPackaging/GenerallyRecognizedasSafeGRAS/GRASListings/ucm153974.htm>. Accessed 30.09.2010.

22. Fitzgerald, M., Papkovsky, D. B., Smiddy, M., Kerry, J. P., O' Sullivan, C. K., Buckley, D. J. & Guilbault, G. G. (2001). Non-destructive monitoring of oxygen profiles in packaged foods using phase-fluorimetric oxygen sensor. Journal of Food Science, 66, 105-110.
23. Grujić, S. (2005). Prehrambeni aditivi – Functionalna svojstva i primjena. Univerzitet u Banjoj Luci, Tehnološki fakultet. Banja Luka, BA.
24. Grujić, S. & Spaho, N. (2010). Potrebe potrošača i kvalitet prehrambenih proizvoda. Univerzitet u Sarajevu, Poljoprivredno-prehrambeni fakultet, Sarajevo.
25. Hunt, M. & Mancini, R. A. (2009). Colour stability of fresh meat. In Proceedings of the 55th International Congress of Meat Science and Technology (ICoMST). Copenhagen, Denmark.
26. Jakobsen, M. & Bertelsen, G. (2004). Predicting the amount of carbon dioxide absorbed in meat. Meat Science, 68, 603–610.
27. Koch, G. A., Christensen, H., Eides, S. P. & Meinert L. (2009). Requirements to shelf-life of fresh meat and meat products. In Proceedings of the 55th International Congress of Meat Science and Technology (ICoMST), Copenhagen, Denmark.
28. Lindahl, G., Karlsson, A. H., Lundstrom, K. & Andersen, H. J. (2006a). Significance of storage time on degree of blooming and colour stability of pork loin from different crossbreeds. Meat Science, 72, 603–612.
29. Lindahl, G., Henckel, P., Karlsson, H. A. & Andersen, H. J. (2006b). Significance of early postmortem temperature and pH decline on colour characteristics of pork loin from different crossbreeds. Meat Science, 72, 613–623.
30. Lund, M. N., Christensen, M., Fregil, L., Hviid, M. S. & Skibsted L. H. (2007). Effect of modified atmosphere packaging on strength of single muscle fibres from beef and pork. In Proceedings of the International Congress of Meat Science and Technology (ICoMST), Beijing, China
31. Lund, M. N., Lametsch, R., Miklos, R., Hviid, M. S. & Skibsted L. H. (2009). Protein oxidation in meat during chill storage in high-oxygen atmospheres. In Proceedings of the 55th International Congress of Meat Science and Technology, (ICoMST), Copenhagen, Denmark.
32. Luno, M., Roncales, P., Djenane, D. & Beltran, J. A. (2000). Beef shelf life in low O_2 and high CO_2 atmospheres containing different low CO concentrations. Meat Science, 55, 413-419.
33. Madsen, T. N. & Clausen, I. (2006). Sensory evaluation of beef steaks stored in MA combinations of CO, CO_2, N_2 and O_2. In Proceedings of the International Congress of Meat Science and Technology (ICoMST), Dublin, Ireland,
34. Mancini, R. A. & Hunt, M. C. (2005). Current research in meat color. Meat Science, 71, 100-121.
35. Mancini, R. A., Suman, S. P., Konda, M. K. R. & Ramanathan, R. (2009). Effect of carbon monoxide packaging and lactate-enhancement on the color stability of beef steaks stored at 1 °C for 9 days, Meat Science, 81 (1), 71-76.
36. Martínez, L., Djenane, Dj., Cilla, I., Beltrán, J. A. & Roncalés, P. (2005). Effect of different concentrations of carbon dioxide and low concentration of carbon monoxide on the shelf-life of fresh pork sausages packaged in modified atmosphere. Meat Science, 71, 563–570.
37. McCarthy M. & Henson S. (2005). Perceived risk and risk reduction strategies in the choice of beef by Irish consumers. Food Quality and Preference, 16, 435–445.
38. Meinert, L., Kock, G. A., Blom-Hanssen, J., Bejerholm, C., Madsen, T. N. & Christensen, H. (2009). Predicting the shelf-life of fresh pork and beef. In Proceedings of the 55th International Congress of Meat Science and Technology (ICoMST). Copenhagen, Denmark.
39. Milijasevic, M., Velebit, B., Turubatovic, L., Jovanovic, J. & Babic, J. (2008). The influence of different gas mixtures on shelf life of fresh beef. Tehnologija mesa, 49 (5-6), 165-168.
40. Narasimha, R. D. & Sachindra, N. M. (2002). Modified atmosphere and vacuum packaging of meat and poultry products. Food Reviews International, 18 (4), 263–293.
41. Ozturk, A., Yilmaz, N. & Gunes G. (2010). Effect of Different Modified Atmosphere Packaging on Microbial Quality, Oxidation and Colour of Seasoned Ground Beef Product (Meatball). Packaging Technology and Science, 23, 19-25.
42. Park, S. Y., Kim, Y. J., Lee, H. C., Yoo, S. S., Shim, J. H. & Chi, K. B. (2008). Effects of Pork Meat Cut and Packaging Type on Lipid Oxidation and Oxidative Products during Refrigerated Storage (8°C). Journal of Food Science, 73 (3), C127 - C134.
43. Paulsen, P., Hiesberger, J., Giefing, S., & Smulders, S. M. J. (2006). Modified atmosphere storage under subatmospheric pressure and beef quality: I. Microbiological effects. Journal of Animal Science, 84, 2448-2455.
44. Phillips, A. C. (1996). Review: Modified Atmosphere Packaging and its effects on the microbiological quality and safety of produce. International Journal of Food Science and Technology, 31, 463-479.
45. Phillips, A. C. (1998). The isolation of *Campylobacter* spp. from modified atmosphere packaged foods. International Journal of Environmental Health Research, 8, 215 – 221.
46. Radetić, P., Milijašević, M., Jovanović, J., Velebit, B. (2007) Modified atmosphere packaging for fresh meat – trend that lasts! Tehnologija mesa, 48 (1-2), 99-108.

47. Resconi, C. V., Escudero, A., Beltrán, J. A., Sañudo, C., Ferreira, V. & Campo, M. M. (2009). Effect of modified atmosphere in aroma development of beef. In Proceedings of the 55th International Congress of Meat Science and Technology (ICoMST). Copenhagen, Denmark.
48. Santos, M. E., Diez, A. M., Gonzalez-Fernandez, C., Jaime, I. & Rovira, J. (2005). Microbiological and sensory changes in ‘‘Morcilla de Burgos’’ preserved in air, vacuum and modified atmosphere packaging. Meat Science, 71, 249–255.
49. Savjet ministara Bosne i Hercegovine. 2008. Pravilnikom o uslovima upotrebe prehrambenih aditiva u hrani namijenjenoj za ishranu ljudi. *„Službeni glasnik BiH“, broj 83/08a.*
50. Savjet ministara Bosne i Hercegovine. 2008. Pravilnik o upotrebi prehrambenih aditiva u hrani, osim boja i zaslađivača, *„Službeni glasnik BiH“, broj 83/08b.*
51. Seyfert, M., Hunt, M. C., Mancini, R. A., Hachmeister, K. A., Kropf, D. H. & Unruh, J.A. (2004). Accelerated chilling and modified atmosphere packaging affect colour and colour stability of injection-enhanced beef round muscles. Meat Science, 68, 209–219.
52. Smiddy, M., Fitzgerald, M., Kerry, J. P., Papkovsky, D. B., O’ Sullivan, C. K. & Guilbault, G. G. (2002), Use of oxygen sensors to non-destructively measure the oxygen content in modified atmosphere and vacuum packed beef: impact of oxygen content on lipid oxidation. Meat Science, 61, 285–290.
53. Soares A.L., Marchi, D. F., Matsushita, M., Guarnieri, P. D., Droval, A. A., Ida, E. I. & Shimokomaki, M. (2009). Lipid Oxidation and Fatty Acid Profile Related to Broiler. Braz. Arch. Biol. Technol., 52 (6), 1513-1518.
54. Sofos, N. J. (2008). Challenges to meat safety in the 21st century. Meat Science, 78, 3–13.
55. Stetzer, A. J., Wicklund, R. A., Paulson, D. D., Tucker, E. M., Macfarlane, B. J. & Brewer, M. S. (2007). Effect of carbon monoxide and high oxygen modified atmosphere packaging (MAP) on quality characteristics of beef strip steaks. Journal of Muscle Foods, 18, 56–66.
56. Suman, S. P., Faustman, C., Lee, S., Tang, J., Sepe, H. A., Vasudevan, P., Annamalai, T., Manojkumar, M., Marek, P. & Venkitanarayanan K. S. (2005). Effect of erythorbate, storage and high-oxygen packaging on premature browning in ground beef. Meat Science, 69, 363–369.
57. Tsigarida E., Skandamis P. & Nychas G-J. E. (2000). Behaviour of Listeria monocytogenes and autochthonous flora on meat stored under aerobic, vacuum and modified atmosphere packaging conditions with or without the presence of oregano essential oil at 5°C. Journal of Applied Microbiology, 89, 901-909.
58. Van Velzen Thoden, E. U. & Linnemann, A. R. (2008). Modified Atmosphere Packaging of Fresh Meat – Sudden Partial Adaptation Caused an Increase in Sustainability of Duch Supply Chains of fresh Meats. Packag. Technol. Sci., 21 (1), 37-46.
59. Viana, E. S., Gomide, L. A. M. & Vanetti, M. C. D. (2005). Effect of modified atmosphere on microbiological, colour and sensory properties of refrigerated pork. Meat Science. 71, 696-705.
60. Vandendriessche, F. (2008). Meat products in the past, today and in the future. Meat Science. 78, 104–113.
61. Wilkinson, B. H. P., Janz, J. A. M., Morel, P. C. H., Purchas, R. W. & Hendriks, W. H. (2006). The effect of modified atmosphere packaging with carbon monoxide on the storage quality of master-packaged fresh pork. Meat Science, 73, 605–610.

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