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Review Article

EFFECT OF DIFFERENT NONTHERMAL PROCESSINGS ON FOOD PACKAGING: A REVIEW

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ABSTRACT
Advances in food packaging technology are required for implementation in novel food processes. Nonthermally processed food products have unique quality parameters compared to conventional food products processed by thermal treatment. Therefore, nonthermal processes have new requirements of processing and packaging to protect the quality of nonthermally processed foods. The conventional packaging design and materials should be changed accordingly for nonthermally processed foods. Critical protective barrier properties of packaging materials must remain to prevent chemical, physical, or microbial degradation of the contents after nonthermal processing. In this paper the critical role of information carried by packaging materials is discussed to make a new product produced by a novel process (Pulsed Electric Field, High pressure processing, antioxidant films and coatings, Irradiation, Active packaging) attractive to consumers.

***Keywords**: Nonthermal Processing, Packaging, High Pressure, Irradiation, Active Packaging, Pulsed Electric Field*

INTRODUCTION
Food is packaged for storage, preservation, and protection traditionally for a long time. These three are the basic functions of food packaging that are still required today for better maintenance of quality and handling of foods. In addition to these primary functions of food packaging, more superficial functions are required for food marketing, distribution, and consumer-related issues, which are to provide required information, handling and dispensing convenience, sales promotion, and stock management. No matter what new fancy function of packaging is explored, the first priority should be serving the basic functions of food packaging. Advances in packaging technology are required for implementation in novel food processes. A number of novel thermal and nonthermal processing methods are actively undergoing research and development in industrial, academic, and government laboratories. A key step that now needs addressing is finding the best packaging materials for commodities processed by nonthermal procedures such as high pressure, pulsed electric fields, ultraviolet (UV), irradiation, microfiltration, active packaging (oxygen scavenging or antimicrobial packaging), or biopreservation (antagonistic culture), which preserve the benefits of improved product quality imparted by these emerging preservation technologies. Food processors traditionally utilized thermal processes, that is, cooking, blanching, pasteurization, and sterilization, to inactivate microorganisms, enzymes, and other chemical reactions in food materials as well as to cook raw foods for extending the period of desirable quality and safety level. Because of numerous practical applications of heat treatments with various types of foods, from prehistoric age until today, many chemical and physical changes taking place in foods after the thermal process have been understood. Not only the changes in the nature of food products after thermal processes, but also the chemical interactions between thermally processed foods and common food packaging materials are well identified (Jung 2007). Among many alternative nonthermal pasteurization

treatments, pulsed electric field and high-pressure processing are the most investigated treatments despite their short history compared with other treatments such as irradiation and chemical treatments (Butz and Tauscher 2002). Both technologies allow the inactivation of vegetable microorganisms but fail to destroy spores when they are applied alone (Devlieghere *et al.,* 2004).

Concerns of Nonthermal Processing Bacillus stearothermophilus has been used as an index microorganism for the standard evaluation of thermal processes. For other specific foods with extreme conditions of pH, water activity, and solute concentration, other spore-forming bacteria have been used to verify adequate heat treatment. There are many but standardized data tables of the values of D (time) and Z (temperature) for these standard microorganisms, and the effect of these thermal treatments is evaluated based on their F value. Nonthermal processes can be applied as a part of combined processes with other nonthermal processes, heat treatments, or chemical treatments. In these combinations of multiple processes, it is harder to select the target microorganism as a standard because the other combined processes affect the resistance of the target microorganisms to the nonthermal processes. However, the effects of these nonthermal processes on microbial inactivation would be increased synergistically with other treatments by maintaining fresh-like taste and retaining color and nutrients of foods (Jung 2007).

Pulsed Electric Field (PEF) Processing

In the last decennia there is an increased interest in non-thermal preservation methods for liquid food products, which are normally pasteurized by heat treatment. One such non-thermal method is preservative Pulsed Electric Field (PEF) treatment, which is typically an exposure of the product to an electric field of 2–4 $kVmm^{-1}$for a short time 1–100 μs (Barbosa *et al.,*1998; Knorr, 1999). This food processing technique, which inactivates microorganisms under reduced temperature conditions, gained a lot of interest from the food industry (Mosqueda *et al.,* 2008). The main advantages over thermal methods are that the product has a fresher appearance, it loses less flavour, and in processing plants less aggressive cleaning fluids are needed (Lelieveld *et al.,* 2007). Nowadays Pulsed Electric Field (PEF) treatment of food needs to be performed prior to packaging, either hygienic or aseptic packaging is necessary. New techniques for PEF treatment after packaging can be considered when plastic conductive (film) electrodes can be integrated within the package, so that the package and the product can be treated as a whole. Roodenburg *et al.,* 2010 describes a newly developed treatment chamber, which can be used to test the ability of any arbitrary plastic packaging film to be used as electrodes for PEF treatment. Tests with a flexible commercially available electrically conductive copolymer film showed that reduction of *Lactobacillus plantarum* by PEF was possible. This heat sealable film obeys the mechanical properties of a polymer; however it has an electrical conductivity of 0.75 S $m^{-1}$and approximately 2.3% of the surface area is electrically conductive. The maximum obtained inactivation was 2.1 log10 with a specific energy of 17 Jml^{-1}. The microbial experiments gave a consistent outcome compared with finite element simulations and with models from literature. They showed that polymer composites can be considered as electrode material for newly to be developed PEF treatment concepts. With extensive research on food grade composite films the integration of cheap disposable plastic electrodes in food packages comes within reach.

Plastic packaging materials have been tested for packaging of PEF-processed foods. The shelf life of foods packaged into plastics depends on the permeation of gas and water vapor through packages because a significant amount of food deterioration results from oxidation and changes in the water content. This is also the case for PEF processed foods. Thus, the permeation values are very important in determining packaging materials for PEF-processed food products. Aseptic food packaging is considered the most appropriate way of packaging for PEF-processed food product. Plastics and paper-laminated materials are widely used as packaging materials for aseptic food packaging (Jung *et al.,* 2007).

High Pressure Processing

High pressure processing (HPP) is a non-thermal technology using pressures up to 1000 MPa for a variable time, to extend shelf life of food without modifying its sensory properties and nutrient content (Aghamohammadi *et al.,* 2014). HPP renders stable food due to its ability to kill spoilage and pathogenic microorganisms and to inactivate food enzymes (Morshedi *et al.,* 2014). The bactericidal effectiveness of

HPP depends on factors such as process parameters, strain and growth stage of microorganisms, and food matrix (Ghasemkhani *et al.,* 2014). The effects of HPP on packaging materials are important to be investigated because foods to be treated are generally packaged prior to high-pressure treatments (Ozen and Floros, 2001). Reversible response of a whole package to compression is crucial to the success of the high-pressure treatment. Packaging materials for HPP are required to be flexible enough to withstand the compression forces while maintaining physical integrity. They must recover their initial volumes after the pressure is released. This is a reason why metal cans, glass bottles, and paperboard-based packages are not well suited for HPP (Lambert *et al.,* 2000; Caner *et al.,* 2004). Due to the fact that air or gases are very compressible under high pressure, the more the headspace, the bigger the deformation strains on the packaging materials. The presence of headspace must be kept as small as possible (Jung *et al.,* 2007). Rivas *et al.,* 2009 investigated the effect of high pressure treatment (400 MPa, 10 min at 12 ^{0}C) on the volatile profile of minced beef and chicken breast, packaged with or without aluminum foil in a multilayer polymeric bag. The analysis of the volatile fraction was carried out by dynamic headspace extraction coupled to gas chromatography- mass spectrometry. Pressurization produced significant changes in the levels of some volatile compounds presumably coming from microbial activity. Some alcohols and aldehydes decreased, while other compounds, such as 2,3-butanedione and 2-butanone, were more abundant in high pressure processed meats. A significant migration of compounds from the plastic material was observed, mainly branched-chain alkanes and benzene compounds. Two functions built by the principal component analysis explained a high percentage of the variance and could be used to separate the samples into four distinct groups, according to high pressure treatment and packaging material (Jung *et al.,* 2007).

Application of Antioxidant Films and Coatings on Food Products

In the last decade, many edible materials have been tested as protectors against the deleterious effect of oxygen, both on high moisture (meat, fish, fruit and vegetables) and low moisture products (nuts). Some examples on studies performed on these foodstuffs are given in Tables 1.

Table 1: Application of antioxidant edible films to nuts (Bonilla *et al.,* 2012)

Film or coating	Antioxidant compound	Application	Analyses	References
Hydroxypropyl cellulose and carboxymethyl cellulose	a-tocopherol BHA, BHT	Pecans	Sensory analysis Hexanal	Baldwin and Wood (2006)
Native or heat denatured whey protein isolate, glycerol, lecithin, methyl paraben	Vitamin E	Pecans	Hexanal content	Lee and Krochta (2002)
Whey protein, glycerol, lecithin, methyl paraben	Vitamin E	Pecans	Sensory evaluation, hexanal content	Lee *et al.,* (2002)
Whey protein, glycerol (60:40 and 50:50), distilled acetylated monoglycerides	(none)	Pecans	Peroxide value, hexanal content	Maté *et al.,* (1996)

Nuts are rich in unsaturated fatty acids, which make them very prone to lipid oxidation. The most common indicators of lipid rancidity in nuts are the peroxide value (PV) and hexanal levels. Lee *et al.,* (2002) tested the effect of vitamin E addition into the formulation of whey protein isolate edible coatings by determining the hexanal content of non-coated and coated roasted peanuts. Vitamin E reduced hexanal levels, although the differences were not significant. As the storage time increased, the hexanal content was significantly correlated with the sensory score for rancid attribute, which corroborated that the hexanal measurement is a good indicator of rancidity in this type of products.

Oxygen could have a very negative effect on the colour of meat products, due to the spontaneous oxidation of myoglobin to form met myoglobin, which imparts brownish colour (Bekhit and Faustman 2005). For this reason, the application of antioxidant films and coatings to meat products may be beneficial. Ojagh *et al.,* (2010) developed chitosan coatings enriched with cinnamon oil with the aim of increasing the self life of cold-stored trout fillets. Their results revealed that chitosan coatings were effective in protecting lipids from oxidation. Moreover, these results coincide with the trend previously described by Jeon *et al.,* (2002) when applying chitosan-based coatings to herring and cod fillets. In this case, both the inherent antioxidant activity and the oxygen barrier properties of chitosan films may have contributed to the control of lipid oxidation in the fish fillets. Suman *et al.*, (2010) showed that coating ground beef patties with chitosan reduced TBARS values and improved the surface red colour of patties as compared to non-coated samples. The antioxidant property of chitosan is attributed to its ability to chelate free iron, released by myoglobin degradation during meat storage (Kamil *et al.*, 2002).

Oxygen can reduce the quality of plant products. The films and coatings prevent the enzymatic browning, which is caused by the enzyme polyphenol oxidase that in presence of oxygen converts phenolic compounds into dark coloured pigments. Lin *et al.*, (2011) treated litchi fruit with chitosan edible coatings, which resulted in a significant reduction in the activityof polyphenol oxidase during storage as compared with noncoated samples.

The antioxidant activity of edible films and coatings is greatly influenced by the water availability, which in turn is affected by both the moisture of the product and the ambient relative humidity. In dry conditions (low moisture products) the network structure of the film or coating is tightly packed and its oxygen permeability is very limited. This mechanism by itself may have positive effects on the preservation of the quality, because of the reduced oxygen availability in the coated product. In some cases, the addition of antioxidants can entail further protection due to the enhancement of the oxygen barrier properties of the film (Ayranci and Tunc 2003; 2004). However, in these conditions of reduced molecular mobility no chemical activity of the antioxidant agents can be observed and the only antioxidant effect is due to the oxygen barrier effect, as concluded by Atarés *et al.,* (2010). On the other hand, in wet systems the coating network is plasticised and mass transference is favoured. In this context, the oxygen permeability of the film or coating is dramatically increased and the specific activity of antioxidant agents could become more relevant.

Irradiation

Food irradiation is a new sterilization method which is effectively used for many packed food items. This process is wholesome as it is a safe process and does not produce a significant change in the nutritional and sensory quality of the food product. Irradiation process helps in extending the shelf life of the product under the recommended storage condition and is also possible to preserve the food product in fresh state. The irradiation process has got other applications like inhibitions of sprouting in bulbs and tubers like potato, Onion etc, disinfestations, prevention of ripening etc. The source used for the irradiation purpose is ionizing radiation which has the ability to ionize the product but the radiation energy is not high enough to make the exposed product radioactive. Ionizing radiations are Gamma rays, electron beam radiation and X-ray. Gamma radiation has got good penetrating property and is able to kill the micro organism by destroying the DNA bondage of the organism which ensures microbiological safety. Nowadays people are more conscious about the hygenity of the food products. People are willing to pay for irradiated food product as they find irradiation as a better food safety treatment compare to chemical treatment, disinfestations etc. . Irradiated food products are reasonably priced and are available in the market. The food packaging industries have got a problem of deterioration of sterilized food due to the attack of micro organism. This is due to the re-contamination of the food during packaging process. The recontamination after packaging can be avoided by sterilizing the packed foods. This will help to increase the shelf life of the food by killing the micro organism. Sterilization of the packed food is possible by irradiation process. It works by disrupting the biological processes that lead to decay. Gamma radiation has got good penetrating power that may disrupt the physical and chemical structure of the substrate so radiation stability is required for the packaging material (Asha *et al.*, 2011). Foods are generally prepackaged before irradiation to prevent recontamination. The use of irradiation is also becoming a common treatment to sterilize packages in aseptic processing of foods and pharmaceuticals (Jung *et al.*, 2007; Ozen and Floros 2001). Therefore, the effects of irradiation on the packaging materials, including any coextruded and laminated materials, must be studied. Any packaging materials must be accepted by FDA before use in food irradiation because gases (e. g., hydrogen) and low molecular- weight hydrocarbons and halogenated polymers formed during irradiation at doses accepted for food use have a potential to migrate into foods. Free radicals can be formed from plastics by irradiation, which can be incorporated in plastics in crystalline regions and age the plastics (Ozen and Floros 2001). Marque *et al.*, (1995) detected alkyl radicals, which were oxidized to peroxyl radicals in the presence of air after ionization treatment of PP at 40 kGy. Any toxic substances should not be transmitted from packaging materials to foods (Barbosa-Canovas *et al.*, 1998). Some chemical and physical properties of polymeric packaging materials can be changed by irradiation (Ozen and Floros 2001). The changes depend on the type of polymer, processing exposure, and irradiation conditions (Jung *et al.*, 2007). Predominant reactions during irradiation in most plastics used for food packaging [e. g., PE, PP, polystyrene (PS)] are cross-linking and chain scission (Ozen and Floros2001). Cross-linking can decrease elongation, crystallinity, and solubility and increase the mechanical strength of the plastics. Chain scission can decrease the chain length of plastic materials, providing free volume in the plastics, and can produce hydrogen, methane, and hydrogen chloride for chlorine-containing polymers under vacuum (Ozen and Floros 2001). In the presence of oxygen, additional chain scissions would be able to form peroxide, alcohol, and various low-molecular weight oxygen-containing compounds (Ozen and Floros 2001).

Active Packaging

Modified atmosphere packaging (MAP) is the removal and/or replacement of the atmosphere surrounding the product before sealing in vapor-barrier materials (Kenneth and McMillin, 2008). MAP can be vacuum packaging (VP), which removes most of the air before the product is enclosed in barrier materials, or forms of gas replacement, where air is removed by vacuum or flushing and replaced with another gas mixture before packaging sealing in barrier materials. The headspace environment and product may change during storage in MAP, but there is no additional manipulation of the internal environment while controlled atmosphere packaging (CAP) uses continuous monitoring and control of the environment to maintain a stable gas atmosphere and other conditions such as temperature and humidity within the package. CAP has most often been used to control ripening and spoilage of fruits and vegetables, usually in containers larger than retail-sized packages although some research has been conducted on packaging for individual fruits and vegetables (Kenneth W, McMillin 2008). Modified atmosphere packaging (MAP) is the removal and/or replacement of the atmosphere surrounding the product before sealing in vapor-barrier materials. While technically different, many forms of MAP are also case-ready packaging, where meat is cut and packaged at a centralized location for transport to and display at a retail store. Most of the shelf life properties of meat are extended by use of MAP, but anoxic forms of MAP without carbon monoxide (CO) do not provide bloomed red meat color and MAP with oxygen (O_2) may promote oxidation of lipids and pigments. Advances in plastic materials and equipment have propelled advances in MAP, but other technological and logistical considerations are needed for successful MAP systems for raw chilled fresh meat. Current MAP options of air-permeable overwrapped trays in master packs, low O_2 formats of shrunk film vacuum packaging (VP) or MAP with carbon dioxide (CO_2) and nitrogen (N_2) and their peel able barrier film derivatives, and high O_2 MAP each have advantages and disadvantages. Packaging technology innovations and ingenuity will continue to provide MAP that is consumer oriented, product enhancing, environmentally responsive, and cost effective, but continued research and development by the scientific and industry sectors will be needed (Kenneth W, McMillin 2008).

The new regulation will authorize the use of active packaging, provided the packaging can be shown to enhance the safety, quality, and shelf life of the packaged foods. Migration of Active and Intelligent Packaging depending on its function, active and intelligent packaging have a varying shape, size, and composition. Active and intelligent materials can be applied in several manners in packaging of food:

• active or intelligent packaging which is also the primary packaging;
• active packaging as a releasing material;
• active material as an absorber;
• intelligent material inside the primary packaging; or
• intelligent material outside the primary packaging.

Another variable to consider is the type of food in contact with the active or intelligent packaging. One can distinguish food contact with a liquid (e. g., for an oxygen-scavenging crown cork for beer), dry contact (e. g., a preservative releaser for buns), or with a semi-solid (e. g., an oxygen scavenger for processed ham) (Jung *et al*., 2007).

MAP provides a means to display meat in self-service meat cases in a manner attractive to consumers while providing processors and retailers with advantages of cost, distribution and storage life, and stability of many desired meat properties. Each low O_2 and high O_2 system has specific benefits and disadvantages, prompting development of multiple stage packaging systems to provide suitable meat traits until consumer purchase. Integration of meat characteristics with available packaging materials and equipment into current cold chain logistical and information systems has resulted in a sufficiently high state of complexity that has caused uncertainty and confusion among industry, regulatory agency, and consumer Segments (McMillin, 2008).

Conclusions

Nonthermal processes may substitute whole thermal processes. However, they will be used more frequently for food processing. The issue of packaging studies for the nonthermally processed foods is very important to preserve the quality of the extended shelf-life food products. These packaging studies may include the physical and chemical changes of packaging materials before/after nonthermal processes and the chemical interactions, such as migration, between nonthermally processed food ingredients and packaging materials. Effects of nonthermal processing on the packaging materials and effects of packaging materials on the quality of nonthermally processed foods during storage need to be studied for the selection of proper packaging materials and methods.

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