Advances in Active Packaging: Perspectives in Packaging of Meat and Dairy Products

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In the process of controlling the quality and safety characteristics of foods the essential step has been maintained by the packaging. The food packaging can protect the food products from the surrounding environment, increase the shelf-life of the product and provide proper product's information to the consumers. Numerous important characteristics of food can be lost as a result of the possible changes in the products throughout their storage and transportation. In order to supply longer shelf-life, safety, freshness and quality of the food products, novel packaging technologies, such as active packaging and nanotechnology have been developed in the market. Nanotechnologies and active packaging might be useful for extending the shelf life of food products by increasing the material barrier properties. Moreover, incorporation of natural antioxidants and antimicrobial agents into the food packaging materials decrease the process of oxidation, inhibits the growth of microorganisms on food (meat) surfaces and therefore increases their stability. This review informs about the principles of active packaging and their current application in the meat and dairy technology.

Introduction

Food packaging has been considered as a socio-scientific discipline which aims to obtain the safety of the food products and to ensure the consumers that goods have been derived in the best condition for further utilization [**1**]. *Daniloski et al.,* [**2**] proved that the packaging is essential to optimize food quality, to rise the shelf-life of the product, to decrease storage costs and to provide food security. Presently, the main objective of food packaging is not only adequate food product protection and convenience, but it aims to inform the consumer about the content of the packed product and enrich the packed food with natural additives that can positively influence the human health [**3**].

The main materials used for food packaging since the twentieth century have been known as plastics. Those materials were derived from petroleum and as a result of their strength, great barrier properties, flexibility, lightness, and stability are still used for packaging of food [**4**]. Due to the inappropriate managing, disposal and non-biodegradability of the plastics, in 2014 more than 30 % of the plastic waste had been cleaned from the land and approximately 8 million tons of plastics were found in the oceans [**5**]. Consequently, consumers today's demand is a food packaging that contains less synthetic additives, i.e. safe and environmentally friendly materials [**6**]. It is for these reasons, (nano)-composite films, or blended solution of packaging biomaterials, and nontoxic active packaging materials have been considered as a great alternative for synthetic plastic films, comparable or low cost, availability, and biodegradability [**7**].

The present advances in food packaging has been directed to the nanotechnology structuring which incorporated into the packaging material tremendously improved the barrier and/or mechanical properties of the films, enriched the antimicrobial and antioxidant properties, included sensors, improved biodegradability, and enlarged the functionalities of these materials [**8**]. Nanotechnology has a plethora of applications in food packaging including meat, dairy, poultry, fruits, vegetables and beverages. Nanotechnology as part of food packaging is presented in three different parts, such as: reinforced nanocomposite packaging materials with nanoparticles, nanofibers to improve packaging properties (flexibility, water and gas barrier properties, mechanical structure, thermal properties); active and intelligent packaging that incorporates (nano) particles or inclusions with antimicrobial or oxygen scavenging properties, nanosensors for sensing and signaling of microbial and biochemical changes, release of antioxidants, flavors to extend shelf life; and biodegradable polymer composites by introduction of inorganic particles, such as clay, into the biopolymeric matrix [**9, 10**].

Moreover, bio-nanocompostites (polysaccharide, lipid, or protein based) have good mechanical, thermal, biodegradable, chemical resistance, antimicrobial, and gas barrier properties and due to their biodegradability and low cost have received a great attention from the food scientists [**11**]**.** Novel techniques and improvements are expanding the science and the functionality of nanotechnology, helping to design packaging that can immediately detected when food has been spoiled or contaminated, inform and communicate with the consumer, study the core opportunities and problems within the area, and help to found the current state of the market and make predictions on where the market is going [**9**].

Active packaging has been considered as a modern packaging technology that prolongs the product stability and longevity, improve the microbial safety or sensory attributes while maintaining the quality of the packed food [**12**]**.** The main protective function of the active packaging can be prolonged by adding active antioxidant compounds, oxygen absorbers, carbon dioxide emitters and ethylene removers [**13**]. The classification of active packaging (AP) is divided into the non-migratory active packaging acting without intentional migration and active releasing packaging allowing controlled migration of non-volatile agents or emission of volatile compounds in the atmosphere surrounding food [**14**].

There are two common systems to reach the goal of AP. The first creates a vacuum and then uses a high barrier packaging material to try to prevent the entrance of new oxygen and the second completely removes the oxygen and then employs modified atmosphere packaging (MAP), which also requires a high barrier material [**15**]. Combining either of these systems with an oxygen absorber or an active antioxidant material will extend the shelf life of the product [**16**]. In many counties, including Japan, the US and Australia a number of active packaging products have been utilized mostly with oxygen scavengers [**13**]. Instead of the diverse roles that the AP could maintain, the most important actions to be applied to food products are antimicrobial and antioxidant activity [**12**]. The oxidation and microbial contamination present the main cause of food spoilage and decreasing the shelf-life of the product, whereas the well-known traditional methods, such as heating, pilling, pre-cooking lead to a different types of disadvantages in the packed food [**17**]. The active packaging is presented as an innovative packaging system/technology that allows the product and its environment to interact which result with the food product shelf life extension and/or to optimise and increase its microbial safety, while maintaining the quality of the packed food [**18**]. Antioxidant active packaging prevents oxidation by either absorbing components contributing to oxidation, such as oxygen or radicals, or by releasing antioxidants inside the packaging [**19**]. Based on the literature, it is preferable to add antioxidants to the packaging material, rather than eliminate molecular oxygen from foods using barrier materials or oxygen scavengers (this fact offers some advantages such as elimination of the potential safety risks and costs saving) [**20**]. In the presence of antimicrobial active packaging, migration of the agents is possible from the packaging material to the surface of the product, therefore it helps with maintaining the high concentrations of antimicrobials agents where they are needed.

Meat and milk together with their products (fresh and/or processed) well known as commonly consumed food in almost every country in the world, satisfy human nutritional needs as a result of their high amounts of fats, proteins, micronutrients and macronutrients [**21**]. For the proper growth and development of human body as part of the well-balanced diet these two foods are very important. Nonetheless, these products are prone to degradation due to the microorganisms and the processes of oxidation [**22**]**.**

Due to the meat products nutritional value, pH, and aw, they are a superb media for bacterial growth, which means that their safety is often endangered [**23,24**]. The chemical or biochemical reactions in which loss of electrons or hydrogen atoms or gain of oxygen are called oxidative processes. Oxidation is one of the main factors in the non-microbial degradation of meat and meat products [**25**]. Oxidative deterioration in foods involves oxidation in both the aqueous phase (e.g., proteins) and the lipid phase (e.g., polyunsaturated lipids). Formation of free radicals is an early event that occurs prior to the progression of oxidation and is most often associated with the aqueous phase [**26**]. Oxidation has been found to have severe consequences on the water-holding capacity of meat protein and on the tenderness of processed meat and meat products [**27,28**]. Furthermore, sulphur volatile compounds (dimethyl trisulfide, carbon disulfide) resulting from sulphur containing amino acid degradation generate off-odor [**29**].

The most imperative factors that can influence textural and the rheological properties of the dairy products and are part of the process of their manufacturing include: content of milk fat and milk proteins, heat treatment, acidification rate, incubation temperature, thickener type, and added stabilizers [**30,31**]. It is worth mentioning that the final yield of the manufacturing process is affected by different parameters such as the characteristics of milk, type of instrumentation, time of processes, number of processes, type and quality of additives and ingredients, and packaging conditions [**32,33**].

The aim of this paper is to give a concise review of packaging materials and methods usually applied in the meat and dairy industries with special emphasis on nanotechnology and active packaging technologies.

Packaging materials convenient for meat and dairy products

Different essential factors have to be taken into consideration (toxicity, compatibility with the product, resistance, maintenance of sanitation, odor and light protection, chemical inactivity, shape and weight requirements, marketing appeal, printability and cost) when choosing a packaging material for food products [**34**].

Namely, if the food product is prone to oxidation the material with high barrier characteristics is preferable in order to increase the product's storage life. Moreover, the dairy products usually need to be thermally treated after they have been packaged which leads that the chosen material has to be heat tolerant [**31**].

The most commonly used films used for meat and dairy products packaging are found in the literature [**31,35,36**].

Interaction between food and packaging

Based on the physic-chemical interactions and connections, such as migration, sorption, and permeation of substances released between the food products and packaging material, it has been proven that those substances can directly influence the food quality. This phenomenon depends on the barrier properties of the polymer or the packaging material, the type and nature of the substance and the composition of the food itself [**37**]. The migration process entails diffusion of the chemical substances from an area of higher concentration to an area of lower concentration, in precise, from food-contact layer to a food surface. The major steps which describe the migration process are: diffusion of chemical components through the matrix, desorption diffused molecules from the material surface, the sorption of the components at material-food interface and desorption of the compounds which migrated in the food [**38**]. Although many ingredients do not pose a high risk (they are nevertheless undesirable) as they pass, they build the concept of global migration. Specific migration refers to the constituents that pose a threat to consumer health that are present in foodstuffs in very small quantities [**39**].

Plethora of studies have been focused on the possible migrants in foods, mostly in dairy products such as lipid milk and cheese, infant formula, and milk powder [**40**]. Over the last five years there were presented a number of problems related to migration of bisphenol A (BPA) in different dairy goods, thus it is worth mentioning that this substance is tremendously harmful for the human health, especially infants and is widely utilized and easy to be detected in food [**41**]. In canned milk (infant formula) the highest amount of BPA was measured and approximately 21 – 43 ng g^{-1} BPa concentrations were detected in canned milk, yoghurt, butter, and cream (not in those products packed in other packages than can) [**42**]. As a result of the increased interest of milk consumption the transportation of milk rose as well, however, the only way to transport the milk from industry to the market place was in plastic containers. Even though, they were considered as a healthy place for milk storage, the new findings revealed that those containers made of PET might release BPA into the milk [**43**]. One study done by *Sakhi et al.,* [**44**] illustrated the lowest amount found of BPA in milk was in a Norwegian cardboard milk and the highest amount of BPA in a Spanish canned skimmed milk, with 0.02 µg kg^{-1} and 800 µg kg^{-1}, respectively. Moreover, secreted in cow milk BPA could be concentrated at very high levels especially in fat dairy products [**45**]. Regarding the styrene migration *Pilevar et al.,* [**46**] found out that this process was increased when the fat content of the packed dairy product was higher, proving that fat and the storage temperature are very important for realization of that migration. Furthermore, they proved that when whole milk and skim milk were heated, numerous of volatile contaminates, such as styrene, 1 – octane and ethyl benzene were detected in the packed milk, however, the whole milk contained more contaminants in comparison to the packed skimmed milk [**47,48**]. In addition, one study conducted by *Ruiz-Cruz et al.,* [**49**] showed an example of styrene migration from the package material to the hot milk and cocoa milk which dependent on the temperature of the drink and its fat content. Their results showed that the highest level of migration was noticed in hot cocoa milk.

Meat and meat products, similar to the dairy products contain more BPA when they are canned than fresh or vacuum packed [**50**]. As an example, diverse packed meat from Norway (BPA - 3.2 µg kg^{-1}) and Greece (BPA – 0.6 µg kg^{-1}) were evaluated and the results showed that those samples contained low levels of BPA [**44**, **51**]. On the contrary in the Spain market where the meat was canned, the test performed on BPA and BP derivate detection, it was found a tremendously high levels of BPA in the canned meat (BPA – 630.0 µg kg^{-1}) [**52**]. One study made in France measured BPA levels in meat products in three different periods, in 2007, 2009 and 2015. The results from that study presented that BPA levels were significantly higher in 2015 where 173 meat - based products, including polled liver (394.76 µg kg^{-1}), cooked veal (224 µg kg^{-1}) and pork meat (20 µg kg^{-1}), were investigated [**50, 53**]. Additionally, European Food Safety Authority (EFSA) revealed their declaration related to bisphenol A (BPA) found in unpacked meat products and fish with an average level of 9.4 µg kg^{-1} and 7.4 µg kg^{-1}, respectively [**45, 54**]. The levels of BPA in two different types of canned meat (beef goulash and meatballs) were estimated by using LC-MS over a period of 12 months in two different temperatures (20^0C and 40^0C), ranging from 3.2µg kg^{-1} to 64.8µg kg^{-1}. Therefore, the process of migration is dependent mainly on the coating of the inner surface of the can, however, the (correlation between storage time and BPA level in the canned meat samples have not been obtained [**55**].

Nanotechnology in packaging of dairy products

Nanotechnology represents the usage of materials that range from 1 nm to 100 nm in size [**56**]. One of the most frequently used ways of preservation in nanotechnology is the enrichment of the properties of the oxygen barrier in nanolaminates or nanocomposite of liquid nanocrystal enriched polymer films or bottles have shown to block or keep away oxygen, moisture, carbon dioxide therefore preventing their undesirable effects on dairy or meat products. These particles are a great asset in improving the longevity of the foods shelf life and are tremendously lighter and a better heat retainers [**57**]. By implementing silver-based nanoparticles possessing antimicrobial, selfsterilizing and bactericidal characteristics, obtained by mixing then into the polymer mixture for molding into the solid inflexible parts of the plastic packaging of milk, lastingness was achieved. Because of their passive nature it has been proved that there is little to no risk of separation from their bond and coming in direct touch with the milk itself [**47**]. There are established a lot of the modern day packaging for dairy products that includes the addition of metal based nanoparticles into the package itself in the form of coating. Nanocoatings are usually consisted of multiple chemically and physically bound layers that have nanometric dimensions and possess various beneficial properties that can be incorporated into them and the film as well [**58**].

There was observatory examination on the coating effect on the same hard *Brazilian Coalho* cheese that was brought to light by Medeiros. The analysis and results received from this evaluation implied that in the coating the lysozyme and alginates more specifically their gas like wall and antibacterial qualities have proven to increase the shelf life of the cheese [**59**]. Mainly it was ascertained that the coated *Coalho* cheese showed less loss of mass, pH, higher titratable acidity then the regular packed cheese after just 20 days. For the instability of nisin to be boosted higher there was a hybrid solution for conservation of dairy products suggested by *Zohori,* [**60**] which was distinguished by chitosan/alginate nanoparticles. A test was conducted on the raw and pasteurized milk injected with staphylococcus aureus or to be precisely accurate the test was focused on the antibacterial behavior of the nisin filled nanoparticles The assessment of the kinetic expansion of staphylococcus aureus determined that in fact his obstruction or hindering was way more effective with the nisin-filled nanoparticles that with the regular ones [**61**]. Thymol encapsulation was conducted in the proteins of the milk specifically sodium caseinate or better known as casein by doing a quick homogenization. This led to enhance the dissolving ability of the milk serum and was balanced by adding dissolvable soybean-polysaccharide. What was obtained from this was a pH stable and a see-through dispersion that was able to maintain its structure for 30 days in a room temperature [**62**]. Nanoencapsulation of cinnamaldehyde was obtained by stationing on a PLA film, liquid bilayers of polydiacetylene-N-hydroxysuccinimide nanoliposomes [**21**].

Nanotechnology in packaging of meat products

Usage of nanomaterial for the purpose of packaging is looking good in advancing the mechanical properties also implementing new roles in the packaging such as: antimicrobial, biodegradable, thermal processing heat resistance ability etc. In retail meat the conservation of the meat's freshness and avoidance of unsanitary juices is most commonly performed by implementing absorbent pads [**63**]. Their primary role as the name suggests is the collection of the water (drip) that is coming from the meat but despite this action there is still a potential threat because the juices are leaning towards spoilage and pathogenic bacteria [**64**]. Embedding silver nanoparticles into porous cellulose fiber gives an antimicrobial pad which is perfect for meat packaging [**65].**

A comparison test was made and it showed that the microbial load in the drip was 90% lower when the silver nanoparticle cellulose fibers were being used rather than the regular package material in minimally processed meat [**66**]. Besides silver being used in meat packaging there are also metal oxides, such as titanium dioxide (TiO_2), tungsten trioxide (WO_3), and zinc oxide (ZnO) that can be used for the same purpose [**18**]. Mainly TiO_2 nanoparticles have been used or better said implemented into polypropylene or a mix of petroxolin octadecanoic acid and OOP [**67,68**]. Also, on the subject of nanoclay as a way of packaging montomorillonite or MMT for short is a relatively affordable and broad material that is comprised of aluminum hydroxide between silica layers [**69**]. Mainly to make a translucent clay polymer material that will have oxygen barrier with a capacity of almost 100% thin layer of sodium MMT was accumulated on diverse substrates by applying layer by layer assembly [**70**]. One of the goals in the meat packing industry is to make consumable packaging that's why one of the numerous coating materials is chitin which is derived from the arthroponds and insects exoskeleton and presents an acetylated polysaccharide and chitosan that is attained by deacetylation with alkalis of the chitin [**12**].

A very debatable and concerning problem is the addition of natural antioxidant compound like essential oils and their association with the upkeep of the active film's mechanical and protection like properties [**71**]. A few researchers noted that the reason for a decrease in tensile strength and percentage expansion is due to the existence of minimum effective concentrations of antioxidants (thymol, carvacrol, eugenol) added to corn-zein LLDPE films, despite that the ground beef patties color improved while stored at 4°C in a time period of 14 days because of constrained liquid oxidation of the added hydrophobic antioxidant compounds into the corn-zein layer [**12**].

For instance, other researches cover the creation of nanobiocomposite films with upgraded mechanical properties obtained from natural antioxidants like thymol and MMT integrated into PLA, α-tocopherol nanocapsule postponement and so on [**36**]. In addition a considerable amount of researches have estimated the difference between the antimicrobial effect of PLA on its own and PLA with nisin on raw beef. In a long interval of refrigerated storage of ground beef and sausage Escherichia Coli O157:H7 has been suppressed using PLA films with pH3 and in beef while stored after irrigation Salmonella typhimurium [**72**].

Active packaging of meat and dairy products

Active packaging is defined as an innovative packaging technology that changes the conditions inside of the packaging and improve the food quality by incorporation of an active agent or compounds into the packaging film and/or packaging headspace [**19**]. Mostly, the active packaging contains synthetic antioxidants, such as butylated hydroxyanisole, that can protect the meat products from oxidation, however, presently consumers insist to consume natural products in order to protect themselves from today's non-communicable diseases [**18**]. *Rosa*, [**12**] in his study explained that active packaging can protect the food from the absorbed food-derived chemicals from food or the environment into the packed meat and release preservatives, antioxidants and flavorings into the packed meat. In one study conducted by Johnson *et al.*, [**73**] cow milk with 2% total fat packed into high-density polyethylene (PE-HD) enriched with 1.3% of titanium dioxide (TiO_2) was examined in order to decrease the light oxidation. Their results proved that the quality of milk was increased based on the sensory evaluation and volatile compounds during a prolonged period of lightning exposition. Moreover, one comprehensive review gave an explanation of active packaging materials used for application on fresh meat and meat products and the types of active packaging systems, including antioxidant and antimicrobial packaging, carbon dioxide emitters, and oxygen scavengers [**74**]. In contrast, according to Ščetar *et al.*, [**31**] the antimicrobial group of active packaging of dairy products was usually studied over the last decade and examples will be given in this review.

Antimicrobial active packaging of meat and dairy products

Meat is considered as an exceptional medium which provides great conditions for microorganisms growing and existence, thus active antimicrobial packaging tends to extend the shelf-life of the product and to establish the fresh meat and meat products safety and security [**18**]. Those microorganisms include bacteria, yeast and molds, and pathogenic micrograms, specifically Salmonella spp., S. aureus, L. monocytogenes, C. perfringens, C. botulinum, and E. coli O157:H7 [**75**]. In an active packaging, the antimicrobial components may be coated, incorporated, immobilized, or surface modified onto a packaging material. Numerous antimicrobial agents (silver ions, sorbates, nitrites, organic acids, bacteriocins, and phytochemicals from plant sources) have been researched for their efficacy after incorporating them into the polymer film [**76**]. Based on the literature there are four known categories of active antimicrobial packaging [**18**]. The first group is the incorporation of the antimicrobial components into a pads or sachet (to soak up the meat exudates and produce antimicrobial components by generating them in situ with a subsequent release) which can be found on the inside of the package [**77**]. Secondly, direct incorporation of the antimicrobial agent into the packaging film which can be attained by the conventional heat treatment (co-extrusion) method or non-heating method where the antimicrobial substance will be released from the packaging film to the food surface in order to impede the process of microorganism growing [**78**]. The third category is coating of packaging with a matrix that acts as a carrier for antimicrobial agents so that the agents can be released onto the surface of food through evaporation in the headspace known as volatile substances or migrate into the food known as non-volatile additives, through the process of diffusion [**79**]. Finally, the fourth group include naturally antimicrobial packages, such as chitosan and poly-l-lysine, where the charged amines will make a bond with the negative charges on the cell membrane of microorganisms which can lead to an apoptosis of the cell [**18,80**]. Preservatives that can be used in the active antimicrobial packaging are chemical preservatives (organic acids, parabens, sulphites, nitrites, chlorides, phosphates, epoxides, alcohols, ozone, hydrogen peroxide, diethyl pyrocarbonate, and bacteriocins) and natural plant antimicrobial components (green tea, olive oil, resveratrol, carvacrol, bacteriocins ect.) [**31,81,82**]. There is a study about chilled meat that was packed in the polyvinyl acetate (PVA) and polylactic acid mixed film which contained microcapsules with a natural antimicrobial agent which migrated from pack into the surface of the chilled meat resulting in increased fresh-keeping effects [**83**]. Vacuum packed fresh meat showed an increased shelf-life, improved taste, and enriched nutritional value as a result of the nano-preservation method through the vacuum packaging [**84**]. The plant extracts and phenolic compounds in essential oils (e.g. thymol), peptides, and nisin are known antimicrobial agents used for retaining the growth of the total viable counts and lactic acid bacteria in packed beef burger kept at 4^0C [**18**]. Over a period of five years, the essential oils have been utilized for incorporation into low-density polyethylene (LDPE), polypropylene (PE), and chitosan (CH) [**85**]. *Mehdizadeh & Langroodi*, [**86**] proved that combination of propolis extract (PE) and chitosan (CH) coating enriched with Zataria multiflora essential oil (ZEO) coated on polyethylene (PE) film aimed for chicken breast meat (CH-PE 1% - Z0.5% and CH-PE 1% - Z1%), significantly enlarged the antimicrobial activity in comparison with the control samples packed in chitosan, PE or ZEO alone. Therefore, one study presented that chitosan associated with natural preservatives could remarkably preserve the chicken meat safety [**87**]. In addition, the results from a study conducted by *Siripatrawan & Vitchayakitti*, [**88**] showed that chitosan film enhanced with propolis tremendously increased the inhibitory effect against all bacteria in active packed chicken breasts at 4°C for 5 days, in comparison with the control sample of chitosan without propolis [**89**]. The effect of one active antimicrobial edible film (0.2% κ-carrageenan/2% chitosan-based coating) with a deodorized oriental mustard extract has been examined on vacuum packed fresh chicken breasts store at 4^0C against C. jejuni cocktail (6.2 log10 CFU/g). After 5 days of examination it was noted that the bacterial count could not be detected in the chicken breasts [**90**].

Regarding the dairy products, lysozyme renowned as an enzyme which presents antimicrobial effect for both gram-positive and gram-negative bacteria is greatly used in dairy industries for packaging [**31**]. According to the study done by *Alvarez & Pascal*, [**91**] lysozyme was commercially utilised for cheese packaging and protection of cheese holes formation. In one examination, PE films boosted with nisin showed tremendously high protection against bacteria on the solid surfaces of the packed cheese [**92**]. In addition, PE films incorporated with nisin used for soft non-ripened cheese, significantly enhanced its shelf-life and decreased the number of microorganisms on the surface of the cheese [**93**]. *Martins et al.,* [**94**] illustrated the antimicrobial influence of nisin protecting Babybell cheese of *Listeria innocua* and Ricotta cheese from *Listeria monocytogenes.* The effect of packed skim milk into high density polyethylene (HDPE) coated with polylactic acid (PLA) and nisin was investigated and it was proven that the milk was protected of contamination with a L. monocytogenes [**31**]. *Dalhoff & Levy,* [**95**] examined the antifungal effect of natamycin produced by Strepomyces natalensis and its protection of fungal contamination on the cheese surface. Moreover, chitosan boosted with natamycin notably decreased the amount of yeasts and molds in cheese stored at 20 ^{0}C over a period of one week [**96**]. As a result of the antimicrobial nature of the chitosan it has been considered that it can be used as a polymer material for cheese packaging without enriching with any other antimicrobial components [**31**]. The influence of an egg white based coating fortified with sage and lemon balm essential oils with different concentrations was examined on one type of packed Turkish cheese. The authors established that sage oil had antimicrobial properties and lemon balm oil presented a great antifungal properties [**97**]. The efficiency of packed cheese into gelatine-based nanocomposite containing chitosan nanofiber and ZnO nanoparticles over a period of 12 days was examined against the total bacterial counts *(TBC)* and it was shown that after the storage period, the bacterial count slightly decreased in comparison with the control chitosan packed cheese (2.4 log CFU/g); 1.93 ± 0.15 and 1.66 ± 0.15 log CFU/g in CHINF and ZnONPs, respectively [**31**]. Other study examined the TBC value of skimmed milk acid coagulated cheese packed in chitosan and chitosan coated with titanium dioxide nanoparticles (TiO_2 - NPs) stored for 25 days at 4^{0}C. Based on their results the number of TBC in chitosan packed cheese in the last day was 8.3 ± 0.1 log CFU/g and in the cheese packed in chitosan coated with 3.0 % TiO_2 – NPs the TBC count was 7.5 ± 0.33 log CFU/g [**98**]. Cheese samples packed in linear low density polyethylene (LLDPE) and antimicrobial packaging films, such as furcellaran-whey protein isolate (FUR/WPI), furcellaran-whey protein isolate incorporated with yerba mate extract (FUR/WPI + YM) and with white tea extract (FUR/WPI + WT), were stored at 4^{0}C for 3 weeks. The active packages prolong the shelf life of the cheese and had lower TBC count (FUR/WPI – 7.3 ± 0.6; FUR/WPI + YM – 7.0 ± 0.6; FUR/WPI + WT – 7.1 ± 0.5) than the cheese packed in LLDPE on the 21 day of examination that counted 7.9 ± 0.3 log CFU/g [**98**].

Antioxidant active packaging of meat and dairy products

The processes, such as microbial growth, lipid oxidation, sensory changes, and nutritional losses can be simplified as a result of the present oxygen into the package. Thus, control of oxygen levels in antioxidant active packaging meat packaging is crucial to suppress the rate of such deteriorative and spoilage reactions [**99**].

The antioxidant active packaging has two important modes of action including emitters that release desired antioxidants into the food and environment surrounding the food or scavengers that absorb undesirable compounds (oxygen, food-derived chemicals, radical oxidative species, etc.) from the food or the environment. To be safe and inhibit meat oxidation, active compounds can be incorporated into the packaging material or in separate devices [**20**]. Most strategies to prevent oxidation in foods focus on eliminating molecular oxygen from the package [**20**]. There are two common systems. The first creates a vacuum and then uses a high barrier packaging material to prevent the entrance of new oxygen. The second completely removes the oxygen and then employs modified atmosphere packaging (MAP), which also requires a high barrier material. Combining either of these systems with an oxygen absorber or an active antioxidant material will extend the shelf life of the product [**39**]**.** It is proven that meat and meat products are prone to rapid oxidation. Antioxidant active packaging is particularly important for these foods and is widely accepted. Fresh meat is always the first target for active packaging, as its red color disappears in a very short period [**100**]**.** To maintain the fresh quality, the addition of some kind of additive is not permitted. Therefore, active antioxidant packaging could be a solution and among the different approaches explained above, and radical scavengers (e.g. essential oils) introduced into the packaging through a coating process is widely investigated [**101, 102**]**.** One low to no oxygen antioxidant packaging has been invented by *Holst et al.,* [**103**] aimed for fresh meat packaging. *Kumar et al.,* [**104**] in their study reported that 1 % - 2 % oregano extract in increased the storage time of fresh beef from 14 days to 23 days stored at 4^{0}C. In addition, one study done by *Pateiro et al.,* [**26**] showed that the process of microbial growth (TVC and Brochothrix thermosphacta) and oxidation in packed cooked ham stored at 2 ± 1^{0}C over a 24-day period decreased in the two different films contain antioxidant in their structure: active film contained 1% of a green tea extract and active film contained a mixture of 1% of green tea extract and of an oregano essential oil in contrast with the control group (vacuum packed cooked ham). *Cestari et al.,* [**105**] explained that chicken steaks packed in an active film with 1 % oregano did not change their nutritional characteristics regarding its antioxidant effect, even though, the samples were stored for 150 days in freezer at -18^{0}C. In order to prevent the undesirable changes in the milk product caused by the oxidation and to prolong the shelf-life of the dairy product the antioxidants are mainly presented in the package and this antioxidants will migrate in the food of the air space around the food [**79**]. Waxed papers, butylated hydroxy toluene impregnated packaging materials and tocopherols, essential fatty acids, and plant extracts obtained from plants such as rosemary, oregano, and tea have been utilized in antioxidant spreading systems in dairy products. Due to the antioxidative effects of Vitamins E and C, these natural components may be used in the active antioxidant packaging systems [**18,106**]. The results from one study determined that lipid oxidation dropped in whole-fat milk powder that was active-packaged by using α-tocopherol [**79**].

Modified Atmospheric Packaging (MAP) of meat and dairy products

What MAP represents is the alternation of the atmosphere around the product in vapour-barrier materials. The biochemical mechanism appearing in the packaging is the culprit in the transformation of the atmosphere in the passive MAP, whereas for the active MAP the change is due to the extraction of original gasses and their substitution with an already familiar mixture of gasses inside the package before sealing [**12**]. Despite microbial rapid reproduction being the primary factor in meat spoilage, oxidation of lipids and pigments in meats stored refrigerated surrounding is a pointer of the spoiling [**107**]. So accordingly the merging of antioxidants with numerous physical preservation methods (MAP, vacuum packaging, storing in low temperatures) of meat and meat products can postpone the oxidation and increase the edibility of the product [**64**]. Meat that is under the influence of the light that can be found in a refrigerated display for the purpose to encourage the sale in O_2 MAP-packed rich meat may be one of the bigger factors concerning its quality because of its crucial part in the photooxidation process of myoglobin and to advocate lipid oxidation as a photosensitizer [**12**]. A study conducted by *Marcinkowska-Lesiak et al.*, [**108**] examined pork loins in a commercially packed MAP or more specific the impact of fluorescent light on the meats physicochemical and microbial properties, and in the course of 12 days in a temperature ranging from 2±1 °C in the stored meat the atmosphere configuration and drip loss, microbial and physical chemical textural parameters were analysed. The MAP gas was comprised of 80% oxygen and 20% carbon dioxide and had a headspace to product ratio of 1:1 and the lux amount 1000 and color temperature of 2000 was equal to 3800K [**108**]. In MAP the high oxygen centralization used to maintain the wanted meat color can result in considerable oxidation of proteins or lipids and creation of off-flavour and smell therefore this packaging method is deemed costly. To enhance the meat's microbial quality vacuum packaging (VP) is more desirable but on the other hand these is a significant chance that the meat will begin discolouring [**28,107**]. The spoilage extend in milk and dairy products can variate depending on the product itself. More commonly observed are the moulds in hard cheeses due to the low water activity, on the other side of the spectrum physical splitting, yeast and bacterial spoil are monitored in high water activity dairy products like soft cheeses and cream [**79**]. In Graviera Agraphon cheese samples stored at 4°C and 10°C shifts in yeast, LAB of control and psychrotrophs were noted. The first results showed 2.5, 5.8 and 7.7 log cfu/g in molds, psychrotrophs, LAB [**109**]. The main difference is that while stored at 10°C psychrotrophs, molds, yeast and LAB in the MAP cheese samples were undoubtedly increased ($P>0.05$) after the 4th and 8th day, whereas while stored at 4°C the in MAP samples the LAB had no noteworthy or distinguishable changes but yeast, moulds, psychrotrophs were drastically higher after the 6th and 15th day [**109**]. It's crucial to document that visible marks of spoilage were examined when a 7 log cfu/g was hit by the population of molds and yeasts. Their growth is oxygen (O_2) dependent, where on the other hand an atmosphere with high quantity of carbon dioxide (CO_2) works opposite on their growth [**110**]. During storage at 4°C in the MAP cheese samples the initial middle pH value (5.52±0.2) proved no difference ($P>0.05$) to that of the controlled cheese that suffered no changes under the same conditions ($P>0.05$). Yet those same MAP and controlled cheese values were fairly decreased to 5.10±0.3 and 4.95±0.3 during the end of the 16th and 24th day of storage at a temperature of 10°C [**111**].

Conclusion & future perspective

Due to the increased consumer needs the packaging systems in the meat and dairy industries are involved in the tremendous change, challenge and a period of evolving over the last decades. In order to succeed in this objective, numerous technologies, including nanotechnology, antimicrobial and antioxidant active packaging, have been maintained to ensure the food microbial safety, less oxidation and achieve longer shelf-life. The application of nanotechnology is still a relatively novel and modernized term and practice that has yet to be more thoroughly explored and learned as the time goes on. Moreover, numerous of the proposed technologies are taking strategies in order to produce environmentally friendly packages, such as biodegradable and/or compostable packaging material, even if some mechanical and barrier properties have yet to assure comparable performances. Based on the literature, the novel components in meat and dairy packaging have not only been illustrating a protective effect on the food, but it has been proven that they can prolong the storage time, increase the nutritional value of the products, and promote value information for the packed food. Last but not least, the involvement of the recent knowledge in polymer science and nanotechnologies are focused to improve the technological performances of the novel dairy and meat packaging materials.

The authors' future objective intention for packaging of meat or dairy products is developing an active packaging enriched with nano-encapsulated natural antioxidants or antimicrobial components that will extend the shelf life of the product and will completely eradicate the possibility of microbial growth and oxidation in fresh or processed meat and/or milk products. The utilization of bio based and biodegradable packaging materials and/or their combination as well as edible materials where it is possible to be applied.

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Conflicts of interest

There are no conflicts to declare.

Keywords

Food products, active packaging, nanotechnology, meat, dairy.

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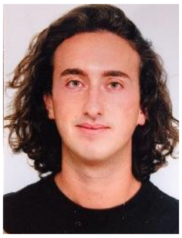
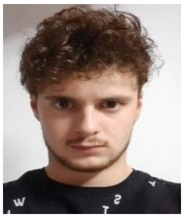
Authors Biography



Davor Daniloski, M.Sc. is a Food Science and Nutrion Educator and Amdinistarive medical assistant who is working on food science related problems, especially food contact materials and susbances. In the academic year 2016/2017, he had a traineeship sponsored with a scholarship where he investigated the permeability characteristics of polymer films aimed at meat packaging. Mr. Daniloski has been actively involved in research for maintaining state-of-the-art technological systems to handle key challenges in food scinece. Soon, he will commence his PhD studies in Food Sciences.



Davor Gjorgjijoski, B. Eng. graduated student at the St.Kliment Ohridski Univeristy in Bitola at the Faculty of Biotechnical Science. Specialized in food quality and safety on the subject of antioxidants, vitamins and minerals as food additives. Presently, he is working as a Practitioner Medical Coder at Taskforce BPO as a medical coder. This is his first scientific review on the subject of novel Nano technologies in food packaging.

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Graphical Abstract

The food packaging can protect the food products from the surrounding environment, increase the shelf-life of the product and provide proper product's information to the consumers.

Nanotechnologies and active packaging might be useful for extending the shelf life of food products by increasing the material barrier properties. Those systems have been maintained to ensure food microbial safety, less oxidation and achieve longer shelf-life.