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Innovations in packaging of fermented food products

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Chapter 16. Innovations in packaging of fermented food products

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Food packaging is designed to contain and protect foods, to provide required information about the food, and to make food handling convenient from distribution to consumer's table. The primary functions of packaging are to achieve preservation and the safe delivery of food products until consumption (Han 2014). Food packaging technology is continuously evolving in response to growing challenges from a modern society (Realini and Marcos 2014). Major current and future challenges to fast-moving consumer goods packaging include legislation, global markets, longer shelf life, convenience, safer and healthier food, environmental concerns, authenticity, and food waste (Kerry 2014). This background offers a unique opportunity to the packaging industry to offer innovative solutions to address the changing demands of the food industry and consumers as well as the increasing regulatory and legal requirements (Han 2014). This chapter will present innovations and trends applied to the packaging of fermented food products: optimisation of barrier properties, modified atmosphere packaging, adaptation of packaging to non-thermal preservation technologies, active packaging and sustainable design.

1. Barrier technologies for fermented food packaging

1.1. Barrier properties optimisation

For any given product, it is necessary to understand the most essential material requirements o achieve the targeted environment inside the package and the optimal food quality (Jansson, Gallet et al. 2002). Therefore, an adequate selection of the barrier packaging material can slow down the rate of food quality deterioration, thus extending the shelf life of the fermented food products (Steinka, Morawska et al. 2006). Vapours and gases produced or consumed during metabolic processes in fermented foods may require more complex packaging barrier than other products, so in these cases it becomes crucial to find the right balance between oxygen barrier and carbon dioxide permeability. High gas barrier films are generally represented as linear chains with aromatic or polar groups in high proportion and with high molecular weight.

Barrier layers made of polymers like PA (polyamide), PETP (polyethylene terephthalate) or PVC (polyvinyl chloride) with materials like EVOH (ethylene vinyl alcohol), PVOH (polyvinyl alcohol) or PVDC (polyvinilydene) embedded in the multilayered structure are frequently used as barrier systems in food packaging. However, the use of multilayered films including a barrier layer like EVOH might not be desirable in terms of material recyclability. New developments in transparent, eco-friendly and barrier films include the incorporation of silica oxide (SiOx) coating to the package, among other alternatives (Lee 2010).

Manufacturers of fermented dairy foods, such as yoghurt, face difficulty in maintaining the viability of bacteria over the shelf life of the products due to several factors including product acidity, pH, hydrogen peroxide levels, storage temperature and oxygen levels. High barrier to O_2 is needed as probiotic and lactic acid bacteria are predominantly anaerobic, and an increase in oxygen inside the package could be harmful. Miller, Nguyen et al. (2002) investigated the effect of different packaging materials on the amount and distribution of oxygen dissolved in stirred-type probiotic yoghurt. High impact polystyrene (HIPS) was used as a control and a high gas-barrier material consisting of a laminate made of HIPS and PE (polyethylene) as moisture barriers and intermediate layer of EVOH providing gas barrier was used for comparison. The use of packaging materials with enhanced barrier properties was shown to reduce the dissolved oxygen concentration in yoghurt over the shelf life, leading to a low and stable oxygen concentration below 10 ppm after 42 days at 4°C, while samples packaged in HIPS reached values of 50 ppm at the end of shelf life.

Shelf-life extension of cheeses with short maturation times represents also a huge area of investigation in terms of improving properties of packaging materials. Changing the light transmission characteristics of food packaging materials by colouring the materials may be a suitable way of reducing photo-oxidative quality changes in cheese. Mortensen, Sørensen et al. (2002) proved that oriented polyamide (OPA)/PE packaging in black laminates provided the best protection of Havarti cheese, followed by a OPA/PE white laminates.

An increasing concern in environmental issues has recently brought a growing number of biobased formulations in the field of food packaging as will be discussed later. Nevertheless, one of the main disadvantages of these environmentally-friendly materials is their poor barrier properties, thus such properties will have to be improved to be suitable to pack fermented food products. Peelman, Ragaert et al. (2014) evaluated the influence of the use of biobased packaging material on the quality and shelf-life of grated cheese packaged under 100% CO_2 atmosphere in PET-PE pouches as a conventional material and in (i) cellulose-starch and (ii) metalized cellulose-starch pouches as an alternative biobased packaging material with low oxygen and moisture permeability. The use of barrier improved biobased packaging materials contributed to improve the sensorial perception, quality parameters and microbial counts of grated cheese.

Fermented milk, a typically Swedish product, contains a bacteria culture that produces CO_2 that should be released to avoid quality losses. However, it is also crucial to limit the oxygen and light that reach the food to avoid oxidation. Jansson et al. (2002) studied the content of O_2 and CO_2 in fermented milk packed with high density polyethylene (HDPE) as control film and two different LDPE (low density polyethylene) multi-layer films containing EVOH (LDPE/EVOH32/LDPE, LDPE/EVOH44/LDPE) and an aliphatic polyketone (LDPE/PK/LDPE). EVOH32 pouches showed a lower CO_2 concentration and higher O_2 concentration after 8 days storage at 8 ^{o}C. The authors highlighted that CO_2:O_2 content ratio can be varied over a wide range by varying crystallinity and polarity materials.

Meat and meat products are highly susceptible to lipid oxidation and microbial spoilage, which lead to the development of rancid or off-flavours. Meat products are commercially packed using vacuum or modified atmosphere conditions in high barrier plastic multilayer films. Krkić et al. (Krkić, Lazić et al. 2012; Krkić, Lazić et al. 2012; Krkić, Šojić et al. 2013) investigated the possibility of extending shelf-life of traditional dry fermented sausage (Petrovac sausage) applying a biobased collagen-chitosan- based coating to the fermented sausage as a substitute of traditional collagen coatings. The chitosan-collagen coating showed lower O_2 permeability and was able to slow down moisture loss and lipid oxidation, resulting in better sensory scores. Working with the same type of dry fermented sausage, Ščetar, Kovačić et al. (2013) performed a different approach, by using a combination of different laminates as external packaging (LLDPE/EVOH/PET and PVDC/Polyester/PE) together with vacuum or MAP (100% N_2) at three different storage temperatures. The PE-LLD/EVAL/PET laminate, which had the lowest O_2 permeability, scored the best on sensory attributes of dry fermented sausage during storage (0-120 days) at 4°C packaged under 100% N_2 atmosphere.

Pressure built up in packaged fermented vegetable products may result in volume expansion and leakage problems. Therefore, optimal packaging for red pepper paste needs to meet the roles of alleviating volume expansion and preserving product quality. In the study carried out by Lee, Hwang et al. (2003), fermented red pepper paste was packaged under air and MAP of 30% CO_2/70% N_2 and 100% CO_2. The MAP conditions were applied with a high gas barrier film (Nylon/EVOH/LLDPE) and with a gas permeable film (coextruded multilayered Nylon). Difference in internal atmosphere among the packages existed only in the initial period of storage. The balance between CO_2 production from the red pepper paste and permeation through the film with high O_2 and CO_2 permeability made the atmospheres of all the packages also reach similar gas compositions after 50 days. Other authors studied the effects of CO_2 absorption on the packaging material used to pack kimchi, a fermented vegetable dish made of salted Chinese cabbage with spices. Barrier properties were improved by Shin, Cheigh et al. (2002) by fabricating plastic sheets made of PS (polystyrene) or PE and incorporated with Na_2CO_3-zeolite powder (20 w/w%), which were uniformly distributed in the polymer matrix. When sodium carbonate was used along with zeolite, the CO_2 absorption of the latter was helped due to the reaction of the former with water, alleviating pressure build-up and volume expansion of kimchi packages while maintaining a low stabilised CO_2 partial pressure.

1.2. Modified atmosphere of fermented food products

1.2.1. MAP principles

Food spoilage is mainly due to moisture loss or uptake, fat oxidation and microbial growth. Storage of foods in a modified gaseous atmosphere can maintain quality and extend product shelf life. The function of modified atmosphere packaging (MAP) is to exclude oxygen and moisture from the packaged food and thereby slow oxidative rancidity (meat, dairy, baked products), retard growth of spoilage microorganisms (meat, dairy, baked products), maintain crispness (baked products) and maintain food colour (meat products) (Aidlin, Arch et al. 1997).

Selection of the most appropriate packaging materials is essential to maintain the quality and safety of MAP foods. MAP requires the use of high barrier materials such as the ones described in the previous section.

MAP relies on gases that are safe, common, cheap and readily available. The gases used in MAP of fermented food products are carbon dioxide and nitrogen. Carbon dioxide (CO_2) is used in MAP of foods for its bacteriostatic and fungistatic properties. It is particularly effective against moulds and Gram-negative, aerobic spoilage bacteria such as Pseudomonas sp., but it is much less effective in controlling yeasts or lactic acid bacteria (Robertson 2013). CO_2 dissolves readily in water to produce carbonic acid resulting in a pH reduction. As with all gases, the solubility of CO_2 increases with decreasing temperature and therefore the antimicrobial activity of CO_2 is markedly greater at lower temperatures (Robertson 2013). The high solubility of CO_2 in high moisture/high fat foods can result in package collapse due to the reduction of headspace volume. Optimum levels of CO_2 to control the bacterial and mould growth are in the range of 20–30% (Mullan and McDowell 2003). Nitrogen (N_2) is a relatively un-reactive gas. It is used to displace air and, particularly oxygen, from the package. Oxygen removal results in growth inhibition of aerobic spoilage microorganisms. N_2 is also used to balance gas pressure inside packs in order to prevent the collapse of packs containing high moisture and high fat food products (Mullan and McDowell 2003). Noble or inert gases such as argon are also commercially used as filler gases; however the literature on their application and benefits is still limited (Mullan and McDowell 2003).

The proper combination of food, gas mixture and package material will result in extension of shelf life and improved food quality.

1.2.2. MAP of fermented food products

Deterioration of fermented meat products during storage is mainly due to discoloration, fat oxidation and microbial changes (Lawrie and Ledward 2006). Nitrosomyoglobin (NOMb), the pigment of cured meats, is stable in the absence of O_2, but its oxidation to metmyoglobin is very fast in the presence of O_2. The rate of NOMb oxidation increases directly with increasing O_2 tension and is accelerated by the action of light (Robertson 2013). The key aspect to improve the quality of packaged fermented meat products is to reduce the presence of oxygen which can be achieved by means of vacuum packaging and MAP (20-30% carbon dioxide and 80-70% nitrogen). These atmospheres reduce discolouration, fat oxidation and inhibit the growth of microorganisms. Esturk & Ayhan (2009) reported better quality and sensory scores in sliced salami packed in the absence of O_2 (100 N_2, 50% CO_2/50%N_2). Other authors have reported reduced production of biogenic amines (putrescine) in fermented sausages (a_w=0.915) packed with 70% CO_2/30%N_2 (Tabanelli, Montanari et al. 2013). Meat products are commonly packed in MAP using semi-rigid and rigid trays and the gas replacement is obtained by the vacuum procedure. To better maintain the integrity of the package, total pressure inside the package is maintained slightly below 1 atm (Toldrá, Gavara et al. 2004). MAP though is not an ideal choice for long storage mould-ripened sausages. Packaging in high barrier materials prevents moisture to evaporate from the surface the product becomes wet, resulting in mould loosening and giving the product a bad appearance (Incze 2004).

Microbial growth and rancidity are the primary causes of quality deterioration in dairy products. The type of spoilage will depend on the characteristics of the particular product.

The main limitation for the shelf life of yogurt and fermented milk is the spoilage by bacteria, moulds and yeasts that grow at refrigeration temperatures. In addition, syneresis and oxidation have been pointed as the main limiting factors for yogurt shelf life (Entrup 2005). N_2 flushing of package headspace has proved to be able to extend the shelf life of yogurt. On the other hand, CO_2 addition through modified atmosphere packaging or direct injection as a cost-effective shelf life extension strategy is used commercially worldwide (Hotchkiss, Werner et al. 2006). Liquefied or compressed CO_2 gas can be incorporated directly into a flowing stream of product. This process has advantages over conventional MAP in that no headspace is required and the amount of dissolved CO_2 can be carefully controlled (Hotchkiss, Werner et al. 2006). Wright, Ogden, & Eggett (2003) determined that the threshold of carbonation in yogurt to extend shelf life without changing sensory properties was around 5.97 mM. Yogurt produced under regular conditions has a shelf life of 10-14 days at 4-6°C that can be extended to 22-25 days when packed in MAP of 0-30% CO_2/ 100-70 % N_2 (Linde Gas).

Hard cheeses with relatively low water activity are normally affected by the growth of moulds, while products with high water activity such as soft cheeses are more susceptible to fermentation and rancidity. MAP was proven to be useful in prolonging the shelf life of cheese samples in terms of microbiological and sensorial aspects. The selection of gas mixtures depends on cheese type, cheese manufacturing conditions, initial microbial load, packaging materials, and storage conditions, as well as post-processing handling. (Khoshgozaran, Azizi, & Bagheripoor-Fallah, 2012). Modified atmosphere packaging (MAP) is used particularly for cheeses that are more prone to deteriorative changes such as portioned and sliced hard with a large surface area exposed to light and O_2 (Robertson 2013). Hard and semi-hard cheeses, such as cheddar, are commonly packed in 100% CO_2 or N_2/CO_2 mixtures in order to prevent mould growth (Hotchkiss, Werner et al. 2006). Favati, Galgano & Pace (2007) reported that Provolone cheese packed with CO_2 and N_2 (30:70) extended its shelf life to more than 9 months at 8°C slowing down the proteolytic and lipolytic phenomena typical of cheese ripening. Other authors also observed inhibition of *E. coli* and total viable counts in Graviera cheese packed in MAP (Arvanitoyannis, Kargak et al. 2011). MAP is also used for sliced and grated cheeses to inhibit mould growth and to facilitate separation of the portions. Soft cheeses are also packaged in atmospheres with increased carbon dioxide levels and low oxygen levels to inhibit bacterial growth and rancidity. However, for soft cheeses as the water content is higher, the concentration of CO_2 has to be limited to 40 % to avoid collapse of the package and as well as formation of undesirable flavours during storage (Zhao 2005).

The most common forms of deterioration of bakery products are microbiological spoilage and moisture loss or gain. MAP is the most common packaging technology used to extend the shelf life of bakery products that due to its high air content and fragile structure cannot be vacuum packed. A range of gas mixtures has been used to extend the shelf life of bakery products, from 100% CO_2 to 50% CO_2/50% N_2 (Robertson 2013). N_2 acts as a filling gas while CO_2 is used for its bacteriostatic and fungistatic action (García, Gago et al. 2006). Extensions of 3 weeks to

3 months at room temperature are achievable using appropriate mixtures of CO_2 and N_2 (Smith, Daifas et al. 2004). In this sense, Degirmencioglu et al. (2011) reported that sliced bread samples packed in MAP (100% N_2, 70% N_2/30% CO_2, 50% N_2/50 %CO_2, 30% N_2/70 %CO_2 and 100% CO_2) showed no growth of moulds after 21 days of storage at 20°C and 60% RH, being MAP with 100% CO2 the most effective treatment for the inhibition of bacteria. Other authors have reported extensions of shelf life of 117 and 158% of sliced wheat bread packed in CO_2:N_2 (50:50) stored at 20-25ºC and 15-20ºC, respectively (Rodríguez, Medina et al. 2000).

Roasted coffee can easily loose its organoleptic properties if it is kept in contact with air and ambient moisture, thus after roasting it is immediately packed. During roasting CO_2 is produced and becomes trapped within the beans. Freshly roasted beans can give out CO_2 for several hours after roasting. During the filling process the packs are flushed with N_2 and are packed in packs with a valve that allows CO_2 to escape from the beans without allowing O_2 to entry (Subramaniam 1998). The problem of accumulation of CO_2 in the package is minimised in ground coffe, as most of the CO_2 produced during roasting is lost during the ground process. The main problem with ground coffee is its instability to oxidation and staling, therefore it needs to be packed in materials with higher barrier than the ones used for whole beans. As with ground coffee, instant coffee packs are flushed with N_2 in order to obtain low residual levels of O_2.

1.3. Effect of non-thermal food processing technologies on packaging materials

Non-thermal processing technologies comprise a number of novel techniques used to preserve and enhance the quality and safety of food by a less aggressive approach than traditional thermal preservation methods. These new food processing technologies are usually non-thermal, resulting in lower flavour and nutrient losses than traditional processing technologies. Most of these technologies are applied directly on the packaged food product in order to prevent post-processing contamination. However, to date little attention has been paid to the influence of these non-thermal treatments on food packaging materials with regards to mechanical, structural, thermal and barrier properties. Therefore, the assessment of packaging properties, mainly barrier properties, when subjected to different food processing conditions gains a particular relevance.

Among these technologies, high pressure processing (HPP), pulsed electric fields (PEF) and radiation are some of the main techniques currently being used at industry level. Others, like ionizing radiation, plasma or ozone treatment are presently in an emerging status, and many others such as magnetic fields, ultrasound, pulsed light, high voltage arc discharge, dense phase carbon dioxide, UV radiation, electron beam or pulsed X-ray represent a noticeable but minor alternative processing methods (Morris, Brody et al. 2007).

Foods can be irradiated after packaging by gamma radiation, e-beam, or intense light. Irradiation can inactivate microorganisms and change physiological responses of foods; however, it can also change the chemical structure of polymeric packaging materials (Min and Zhang 2007). For this reason packaging materials used for irradiation should be chemically stable under the radiation dose to prevent polymer degradation and low molecular weight hydrocarbons and halogenated polymers formation which can migrate into foods. Radiolysis products (RPs) formed upon irradiation of a polymer or adjuvant could migrate into food and affect odour, taste, and safety of the irradiated food. Radiation does not generally affect all properties of a polymer to the same degree. According to Mrkić, Galić et al. (2007) barrier properties of some monofilms (PE-HD, PE-LD, PS, BOPP) are not significantly changed by irradiation (Rojas Gante and Pascat 1990). As in the case of laminates, barrier properties either decrease, as in the case of BOPP/CPP and PET/PVDC/PE (Kim-Kang and Gilbert 1991; Mizani, Sheikh et al. 2009), or are not significantly affected, ex. PA/PVDC/EVAC, PET/PE/EVAL/PE and PET/PET/PE-LLD (Deschênes, Arbour et al. 1995; Riganakos, Koller et al. 1999; Mizani, Sheikh et al. 2009), with applied radiation doses.

HPP is used to reduce food spoilage and pathogenic microorganisms from solid and liquid food products, thus extending the shelf life and improving food safety with minimal impact of the quality and nutritional value of food. High pressure induced-damages in polymeric packaging materials can be split into two categories; direct and indirect effects. Direct effects are caused directly by the high pressure treatment while the indirect effects are caused by the compression of other substances in the package. A direct effect of high pressure treatment on polymers can lead to changes in crystallinity. Delamination and other changes may also occur in multilayer packaging which affect the overall functionality of the whole package. Multilayer systems that include inorganic layers frequently see direct damages to the inorganic layers and delamination at the interface between inorganic and polymeric layers with both of these problems caused by the discontinuity of the mechanical properties across the interface. Indirect effects of high pressure treatment on polymeric packaging materials are primarily caused by compressed gases which will initially cause thermal effects ranging from localised increase of crystallinity to more serious problems such as melting of the sealing layer (Fleckenstein, Sterr et al. 2014).

The effect of high-pressure processing (400 MPa for 30 min, at 20 or 60°C) on mechanical and thermal properties of four complex packaging materials (PE/EVOH/PE, metallized PET/PE, PET/PE, PP-SiOx) was studied by Galotto, Ulloa et al. (2008). Delamination and wrinkling were observed as a general consequence of the HP processing of multilayer polymeric systems. However, these effects did not affect mechanical properties of PE containing laminates. SiOx broke down after the HP treatment, thus causing significant modifications in PP-SiOx laminates. Other authors investigated the effects of HP pasteurization (25 ^{o}C) and HP sterilisation (90 ^{o}C) on the cause of onset delamination of bilayer films (PP/PA, PP/OPA, PP/PET) using water and solid carrots as food stimulants (Fraldi, Cutolo et al. 2014). Each of the three bilayer films that were tested was able to withstand HPP at 25 ^{o}C without showing any evident mechanical failures. Moreover, there was no delamination after high pressure sterilisation at 90^{o}C, even at 700 MPa for PP/PA (Figure 1c) and was barely present for PP/OPA (Figure 1d) for both food simulants. However, the PP/PET pouches showed signs of localized delamination after high pressure sterilisation over the entire investigated pressures range (Figure 1a and b). Authors concluded that the main cause of delamination could be attributed to the differences in the mechanical behaviour of the two films making up the multilayer structure and in their dependence on temperature and pressure.

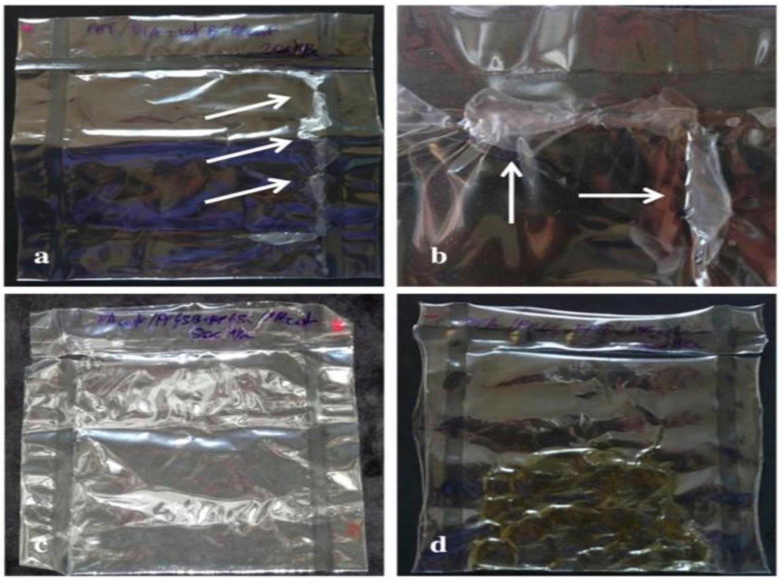

Figure 1. Photographs of pouches after high pressure treatment. a) picture of a PET/PP pouch after HP sterilization treatment at 200 MPa (food simulant: tap water), arrows indicating regions of delamination; b) detail of a delaminated region in PET/PP pouch with arrows highlighting the delamination zones; c) picture of a PA/PP pouch after HP sterilization treatment at 500 MPa (food simulant: tap water); d) picture of a OPA/PP pouch after HP sterilization treatment at 700 MPa (food simulant: solid carrots). (Fraldi, Cutolo et al. 2014).

Pulsed Electric Field uses short pulses of electricity to inactivate microorganisms, causing minimal detrimental effects to the food quality attributes. It can be used to preserve liquid food products that are normally pasteurised by thermal methods. New PEF treatments can be carried out after the packaging step, where conductive electrodes can be integrated into the package (Roodenburg, De Haan et al. 2013). In this regard, a research carried out by Roodenburg, de Haan et al. (2010) suggested that it was possible to get sufficient electric field inside a pouch made from any arbitrary packaging film. However, the direction of the applied electric field has a great influence on the electric field distribution and needs to be applied perpendicular to the surface of the film. In the thin slits and at sharp film slabs of the thermal seal, the electric field is concentrated. Variations in food product conductivity, below the conductivity of film and interfacial liquid, results in less electric field decrease inside the package. Therefore, authors recommended choosing the film conductivity equal to the highest existing conductivity of the treated food product. The shelf-life of foods packaged into plastics and processed by PEF treatment depends on the permeation of gas and water vapour through packages because a significant amount of food deterioration results from oxidation and changes in the water content (Akbarian M, Aghamohammadi B et al. 2014).

2. Sustainable fermented food packaging

2.1. Eco-design

The big challenge for the food packaging sector is to develop sustainable packaging systems that are able to minimise the environmental impact derived of packaging. Using as an example the plastic sector, the global production in 2013 rose to 299 million tonnes. In Europe, packaging represents the largest application sector for the plastics industry, with a 39.6% of the total plastics demand. The amount of post-consumer plastics waste produced in Europe in 2012 was 25.2 million tonnes, from which 62% were recovered (26% recycled and 36% recovered energy), and 38% ended up in landfills (Plastics Europe 2014). Although there is a positive trend observed in the recovery and recycling of plastics other strategies are needed in order to promote sustainable development.

Design is the most important and critical stage in the product development process with regard to producing better environmental outcomes, quality assurance, and consumer satisfaction (Park, Lee et al. 2014). Eco-design means the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle (European Union 2009).

The key principles that need to be considered in the design or procurement of packaging to improve its sustainability are: fit-for-purpose: designed to meet market and consumer needs, while minimising the net impact in a cost-effective way; resource efficiency: designed to minimise the use of materials and other resources without compromising product quality and safety; low-impact materials: designed to minimise the environmental and social impacts of materials and components; resource recovery: designed to maximise its potential for recovery and recycling (Australian Packaging Convenant 2014).

2.1.1 Eco-design tools

Several tools have been developed to help packaging designers to promote sustainable development. The Technical Committee on Packaging and Environment of the International Organization for Standardization has developed environmental standards for packaging based on established European Norms (EN) and proposed Asian guidelines. The series of ISO standards published provide guidance on how to best utilize packaging resources while maintaining packaging functionality and considering environmental effects (Grönman, Soukka et al. 2013; Park, Lee et al. 2014). On the other hand, a range of environmental profile analysis tools are available for eco-design, such as LCA (life cycle assessment), MIPS (material input per system), CED (cumulative energy demand), MET (materials use, energy use, and toxicity) matrix, and eco-design wheel (also referred to as life cycle design strategies (Park, Lee et al. 2014). The most widely used and comprehensive approach is LCA. This is a well-known method for evaluating the potential environmental impact of a product system, from the acquisition of raw materials through production, use, recycling, and disposal (Holdway, Walker et al. 2002).

Recent LCA have highlighted that the environmental impacts associated with packaging are small compared with the environmental impacts of the packed food. The challenge consists in finding the balance between the amount of resources invested in packaging and the resources saved through the protection it provides (Han 2012; Grönman, Soukka et al. 2013). Therefore, there is a clear need to include sensitivity analyses in LCAs for product/ packaging combinations in order to elucidate if a local optimisation does indeed contribute to global optimization (Lutters, Luttikhuis et al. 2013). Williams & Wikström (2011) showed that packaging that reduce food waste can be an important tool to reduce the total environmental impact, even if there is an increase in impact from the packaging itself. They stated that this fact was especially true for food items where the environmental impact of the food in relation to packaging is high such as cheese, and for food items with high losses such as bread. Other authors performed a LCA on the relative impact of the packaging (PET tray and PP lid) versus the impact of the content for a sliced cheese produced in the Netherlands and exported to Greece. In the overall picture, the influence of packaging represented about 4%, whereas the consequences of cheese leftovers being thrown away was estimated to be twice that value (Lutters, Luttikhuis et al. 2013). However, it has been proved that too often food is overpacked and that packaging materials can be reduced without compromising food shelf life. In a recent LCA, Siracusa, Ingrao, Lo Giudice, Mbohwa, & Dalla Rosa (2014) evaluated the environmental impact derived from a bi-layer (PA/LDPE) film bag for food packaging. The authors concluded that a reduction of film thickness from 85 µm to 65 µm would lead to a reduction of environmental damage of about 25 % guaranteeing food preservation.

2.1.2 Successful eco-design strategies for fermented food packaging

A selection of eco-design strategies addressed to minimise the environmental impact of packaging that have been successfully developed for fermented food products are listed below.

Source reduction

Source reduction consists in reducing the amount of materials used to produce food packaging which results in a reduction of the amount of waste derived from packaging. Material reduction can be achieved by reducing packaging thickness, by using alternative materials or by reducing the number of packaging elements used (Australian Packaging Convenant 2014). In this regard, Licciardello, Cipri, & Muratore (2014) proved that it was possible to reduce the thickness of the packaging used to pack industrial durum wheat bread (thermoformed bottom and lid) by about 20 % without affecting its shelf life standards. In another study made in partnership with WRAP, Coca-Cola Enterprises and Beverage Can Makers Europe (BCME) it was proven that beer and cider aluminium cans can be lightweighted by 5% without compromising the quality of the product (Waste & Resources Action Programme 2008).

Another strategy to reduce material consumption is to minimise the number of layers through the optimal combination of primary, secondary and transport packaging (Lewis 2008). As an example, UK supermarket chain Sainsbury's replaced the packaging of its own-brand garlic bread consisting of a plastic sleeve (primary packaging) and a cardboard carton (secondary) with a polypropylene film pack. Product redesign resulted in a weight reduction of 70 % and improved logistics efficiency by 20 percent (Holdway, Walker et al. 2002).

The use of flexible materials as an alternative to rigid packaging materials such as metal cans and glass contributes to significantly reduce the weight impact, resulting in transport efficiency savings and overall improvement in environmental performance. For example, the use of a laminated pouch for beverage packaging results in a drop of the weight impact of the packaging during transport from 52% to 6%. The weight impact relates directly to increased efficiencies in transportation and storage (Flexible Packaging Europe 2012). Bonfire Winery has successfully launched its 1.5 L wine stand-up pouch consisting of a three-layer film produced by Curwood. This novel design favours convenience thanks to a built-in tap, and represents an important material reduction compared to traditional glass bottles, Tetra Brik® or bag-in-box formats (Reynolds 2014).

Lightweighting can also be achieved through structural redesign of the package. In this sense, a number of UK-based, international lager beer brand owners took the challenge of making significant design changes to their bottles, achieving savings of 10,600 tonnes of glass. As an example, Cobra Beer successfully obtained a weight reduction of 20% of the 660 mL bottle and Carlsberg UK a 17% of the 275 mL bottle (Waste & Resources Action Programme 2008).

Food waste reduction

Packaging design should be user friendly in order to avoid food waste due to a difficult access. A recent study showed that in Sweden up to 10% of the content of yogurt cartons (74 tons of yogurt) is wasted every year because consumers find it difficult to use all the yogurt contained in traditional packaging cartons. In order to solve this food wastage, the Swedish packaging company Ecolean has successfully developed and launched a flexible package particularly suitable for dairy products which enables the consumer to squeeze out nearly all of the content (Eliasson 2008).

Use of recycled packaging materials

The use of recycled materials as raw materials can significantly reduce the environmental impact of packaging. It has been estimated that the embodied energy saving per kg in the production of recycled glass, HDPE, and PET is of 57, 79 and 76 %, respectively, compared to virgin product (Lewis 2008). In this sense, Siracusa et al.(2014) estimated that the use of recycled PA resin instead of virgin PA in the production of bi-layer (PA/LDPE) film bags for food packaging would lead to a reduction of about 15% of the environmental damage.

Improvement of the rate of recycling by changing the materials

One way of promoting sustainable development is through recycling and the adoption of more environmentally friendly packaging. In the dairy sector, large yogurt producers have increased their rates of recycling and the type of packaging has changed. Some yogurt manufacturers such as Muller have changed the materials used for yogurt lids from aluminium to paper with a foil coating, which is more biodegradable and has reduced the amount of plastic used in each pot through material reductions achieved in pot walls and rim (Dewick, Foster et al. 2007).

2.2. Biodegradable packaging materials

In the search for environmental-friendly packaging polymers, a wide range of biodegradable materials are being exploited. Biodegradable polymers break down into natural compounds, therefore they would reduce the carbon footprint and make the system sustainable (Scott 2002). Biodegradation takes place through physical decomposition and biological processes led by aerobic or anaerobic microorganisms, or under composting conditions. Biopolymers and biodegradable plastics are expected eco-friendly alternatives to petroleum based polymers. Their implications in the preservation of the environment are, however, not uniform, and need to be carefully considered (Yates and Barlow 2013). The choices in the group of eco-friendly polymers comprises biopolymers derived from natural sources which are biodegradable and compostable (Table 1), plastics made from renewable sources which are not necessarily biodegradable or compostable, and synthetic plastics not based on renewable sources which are biodegradable (Siracusa, Rocculi et al. 2008).

Table 1. Biopolymers with good perspectives in food packaging grouped by their origin:

Plant	Animal	Microbial
Carbohydrates: • Starch • Cellulose • Hemicelluloses • Pectins • Agar • Alginates • κ-carragennan Proteins • Gliadins • Glutenins • Zein • Soy	Carbohydrates: • Chitosan Proteins • Collagen • Gelatin • Caseinate • Whey	• Bacterial cellulose • Pullulan • Kefiran • Gellan • Polyhydroxyalkanoates • Polylactide

2.2.1. Wax, coatings, edible coatings and wraps

Coatings are applied in many food products to control moisture loss, to allow the selective exchange of gases or to control oxidative processes. In addition, they are linked to the possibility to achieve a personalized appearance and protection against microbial growth. In general, lipids are good in controlling water transmission, proteins provide excellent mechanical stability and polysaccharides are good oxygen barriers (Embuscado and Huber 2009).

Waxes have been used since the 12^{th} century to diminish water losses and to minimize mechanical damages in foods (Hardenburg 1967). In particular, melted paraffin or paraffin-carnauba mixtures are used to cover cheese. The length of the fatty acid hydrocarbon chain is relevant to achieve acceptable barriers to water vapour (Morillon, Debeaufort et al. 2002). Waxes will also decrease oxygen and carbon dioxide transmission and provide protection against microbial growth. In hard cheeses, polyvinyl acetate (PVA, PVAc), a thermoplastic biologically degradable synthetic polymer, is frequently used to facilitate wax adhesion.

Polysaccharides have very good structural stability and are excellent barriers to oxygen, but they are sensitive to water. At optimal conditions, their barrier to oxygen is so good that they can prevent oxidation. Among them, only cellulose derivatives have low water vapour transmission rates. Starch has hydrophilic character and moderate barrier properties. Starch blends have been studied to improve some of the physical properties of starch films (Kaseem, Hamad et al. 2012). Cellulose-based films also swell in contact with water and their properties vary at different relative humidity. Similarly to cellulose and starch, hemicelluloses have excellent oxygen barrier properties at low humidity, but show poor water vapour barriers due to their hydrophilic character (Hansen and Plackett 2008). Among them, modified xylans and galactomannans are being increasingly investigated in food packaging applications (Cerqueira, Bourbon et al. 2011). Pectins are methyl esterified acidic and water-soluble polysaccharides (Sriamornsak and Kennedy 2008) which form gels in the presence of divalent cations such as calcium ions. Their methylation degree is important to get insoluble films (Braccini and Perez 2001). Also agar and carrageenan are hydrophilic colloids approved as food additives. κ-carragennan forms clear but brittle films which can be blended with other materials to improve their physical and barrier properties (Ribeiro, Rodrigues et al. 2004). Alginates react with di- and trivalent cations to form films and produce gels with the help of calcium ions (Cha, Choi et al. 2002). And chitosan, prepared by the alkaline deacetylation of chitin, is soluble in acidic solutions with pH below 6.3 (No, Park et al. 2002). Chitosan forms films, which can be used alone or in blends with thermoplastic (van den Broek, Knoop et al. 2015) or biodegradable polymers (Krasaekoopt and Mabumrung 2008; Sangsuwan, Rattanapanone et al. 2008). Chitosan has the peculiarity of having intrinsic antimicrobial properties (van den Broek, Knoop et al. 2015).

Cellulose can be esterified or etherified. Those derivatives have excellent film forming properties and hydroxypropyl cellulose, hydroxypropyl methylcellulose, carboxymethyl cellulose and methyl cellulose have been used to produce edible films or coatings. The hydrophilic character of cellulose derivatives vary with the amount of hydroxyl groups and they can be blended to improve mechanical properties and permeability (Paunonen 2013). Furthermore, cellulose chains are strands of partially crystalline microfibrils and those fibres can be disassembled into microfibrillated cellulose, nanofibrillated cellulose and cellulose nanocrystals (Chinga-Carrasco 2011). Microfibrillated cellulose (MFC) is the most commonly used natural filler in bionanocomposites. They reduce gas and oil permeability in paper, and other packaging polymers (Gacitua, Ballerini et al. 2005; Mondragon, Pena-Rodriguez et al. 2015).

Films and coatings from proteins from wheat, corn, milk, soy, etc. show excellent physical stability and are effective barriers for oxygen but less effective to water. They can be stabilized by crosslinking with different molecules, such as glutaraldehyde, formaldehyde and transglutaminase (Sommer and Kunz 2012). Their mechanical and barrier properties can also be enhanced in polymer blends with nanoclays, proteins, lipids or polysaccharides. But proteins can be allergenic. Gliadins and glutenins from wheat have excellent film-forming properties and can be used to extend the shelf-life or retard the senescence of food products (Hernandez-Muñoz, Kanavouras et al. 2003). Collagen and its derivative gelatin are hydrophilic and must be crosslinked (Jongjareonrak, Benjakul et al. 2006) or emulsified with oils with oils (Satapathy, Singh et al. 2015). In the group of milk proteins, sodium caseinate is formed after removing the colloidal calcium phosphate from casein micelles and has good film forming properties. Its mechanical properties can be modified by calcium crosslinking or by the addition of lipophilic molecules (Avena-Bustillos and Krochta 1993; Avena-Bustillos, Krochta et al. 1997).

One of the most successful applications of biodegradable materials are meat casings. Casings must be strong but also shrinkable as they are important to determine shape and size of the final product. Collagen casings are frequently used in dry and semi-dry fermented meat products because they present excellent stability and are permeable to smoke and moisture (Gomes, Santos et al. 2013). Collagen casings are edible in most applications. Another option for the production of uniform and strong casings is regenerated cellulose made from solubilised cotton or wood pulp (Nicholson 1991). Cellulose tolerates curing and smoking, and substitutes animal casings in fermented meat products. Regenerated cellulose edible casings allow the diffusion of oxygen, moisture, smoke and nutrients (Sreenath and Jeffries 2011). Non-edible cellulose casings made of fibrous cellulose are also commercialized. They can shrink but they are not permeable to smoke (Toldrà 2014).

Some other applications of carbohydrate and protein based packaging materials in fermented food products are known. The potential of galactomannans as coatings of semi-hard cheeses was studied by Cerqueira et al. (2009; 2010). They lowered gas transfer rates and cheese respiration rates, resulting in colour stability and extended shelf-life. Kampf et al. (2000) tested different films from κ-carrageenan, alginate and gellan as coatings for semi-hard cheeses, finding a reduction in water vapour transfer and texture improvements. No et al. (2007) also showed a reduced microbial proliferation and staling in bread coated with chitosan. Blends of chitosan with starch (Mei, Yuan et al. 2013) and chitosan with sodium caseinate (Moreira, Pereda et al. 2011), were effective in the storage of Mongolian cheese, cheese wraps and salami.

2.2.2. Films and sheets

Different strategies are being developed to take advantage of the excellent gas and aroma barrier of polysaccharide based films. Most of the commercially available bio-based polymers are starch based polymers and starch blends (Cha and Chinnan 2004). Under the right combination of plasticizers, starch turns thermoplastic or forms a foamed material able to replace polystyrene (Zhang, Rempel et al. 2014). Mater-Bi® from Novamont used primarily corn starch. Other trademarks are available such as Novon® and Solanyl® (Solanyl Biopolymers Inc.). Another common source for biodegradable films and bags is cellulose. Innovia Films is producing a whole range of flexible cellulose based films under the trademarks NaturFlex™ and Cellophane™. NaturFlex™ provides tailored moisture vapour barrier properties for the storage of soft cheese, hard cheese, cheese slices and butter. Cellophane™ fulfils similar requirements than NaturFlex™ for soft cheeses, where surface flora development and O_2/CO_2 transfer are required.

Proteins do not typically have a thermoplastic behaviour, but many of them can be modified with plasticizers to achieve thermoplastic properties. Proteins such as wheat gluten, zein, soy, myofibrillar proteins and whey have been successfully transformed into films by extrusion and compression moulding (Hernandez-Izquierdo and Krochta 2008). An excellent example is the whey fraction of milk. Compression-moulded whey protein films plasticized with glycerol were flexible (Sothornvit, Olsen et al. 2003) and heat-sealable whey protein films could be thermoformed into pouches (Schmid, Mueller et al. 2014). Compression moulding and extrusion have also been applied to zein, showing excellent potential for the large-scale production of zein based edible films (Hernandez-Izquierdo and Krochta 2008). In fact, zein blends with cellulose, starch and polycaprolactone (PCL) are being commercialized under the tradename Envar, by Bioplastics Inc. for compost bags, mulch films and paper coatings (Niaounakis 2015).

Aliphatic polyesters are a group of materials with properties similar to polyethylene (PE) and polypropylene (PP). Among them, polyhydroxyalkanoates (PHAs) are naturally occurring biodegradable thermoplastic polyesters produced through fermentation of microorganisms from a carbon source under stress (Babu, O'Connor et al. 2013; Vijayendra and Shamala 2014). PHAs are not water soluble and can be thermoplastic combined with plasticizers (Bucci, Tavares et al. 2005). They could substitute PP for the storage of fat rich products, including cream cheese (Peelman, Ragaert et al. 2013). Metabolix has clearance from the FDA to be used in food contact applications (Babu, O'Connor et al. 2013). Furthermore, polylactic acid (polylactide, PLA), a biologically degradable thermoplastic derived by chemical synthesis from starches, is one of the green polymers with the greatest potential in the food packaging industry. Several brands are commercializing thermoformed PLA containers such as yogurt cups. PLA has also been tested during the carbonic maceration of wine, being able to replace glass for three months (Pati, Mentana et al. 2010). It is commercialized by NatureWorks LLC under the mark Ingeo®, and has excellent perspectives to be used alone or in blends with other polymers (Niaounakis 2015).

3. Active packaging

The concept of active packaging refers to packaging systems where certain compounds have been intentionally added to the packaging material or in the packaging headspace to enhance the performances of the packaging itself, to increase food safety and shelf-life. Active packaging includes non-migratory strategies, the controlled migration of non-volatile agents and the emission of volatile compounds into the packaging headspace (Dainelli, Gontard et al. 2008).

3.1. Oxygen scavengers

Oxygen compromises the shelf-life of food products due to oxidative processes and the action of aerobic microorganisms. Oxygen scavengers are able to reduce residual oxygen to less than 0.01% (Vermeiren, Herlings et al. 2003). The most extended commercial alternatives are sachets containing iron or ascorbic acid, and more recently, cerium and palladium. Many sorts of oxygen scavenger sachets are being commercialized under different trademarks. They have been recently reviewed by Realini and Marcos (2014) and include Oxy-Guard™ (Clariant Ltd.), OxyCatch™(Kyodo Printing Company, Ltd.), ATCO® (Standa Industrie), FreshPax® (Multisorb Technologies, Inc.). Most of them find applications in meat, bread, bakery products and dry foods (Legrand 2000). Salminen, Latva-Kala et al. (2009) reported that the microbial shelf life of sliced rye bread was extended considerably by packaging with ATCO O_2 absorbers.

However, individual sachets have limited applicability. They are not suitable for liquid foods and are not positively appreciated by consumers (Rooney 1995). Extruded scavenging films, scavenging bottle closures or enzymatic O_2 scavengers would be preferred (Floros, Dock et al. 1997). Moisture activated scavengers include a resin-bonded oxidable metal and oxidation promoters and fillers (Graff 1998). In dry foods, UV activated dyes can be incorporated (Nielsen 1997). Glucose oxidase and catalase are frequently used in bottled beer or wines (Hardwick 1995). Sulfate-based oxygen absorbers can also be incorporated into crown corks and plastic screw-on caps (Teumac 1995), such as beer bottles. The incorporation of oxygen scavengers has opened new applications for low barrier materials such as PET. Chevron Phillips LLC and Sealed Air developed oxygen scavenger multilayer flexible films, in particular the OSP™ and Cryovac® OS2000 (Speer, Edwards et al. 2009). OxyRx™ oxygen scavenging PET containers, have been developed by Mullinix. Oxbar™ is a system developed by Carnaud-Metal Box (now Crown Cork and Seal) used especially in the manufacturing of rigid PET bottles for packaging of wine, beer, flavoured alcoholic beverages, and malt-based drinks (Brody, Strupinsky et al. 2001). Other materials such as EVOH, which suffers retort-shock and loses barrier, can also be reinforced with oxygen scavengers. This is the case of EVAL™ (Kurakay Group).

3.2. Ethanol emitters

Modified atmosphere packaging of bakery products encounters a big problem associated to the large amount of pores in the matrix. They trap oxygen and favour the development of aerobic microorganisms (Galic, Curic et al. 2009). To solve this problem, some companies offer ethanol vapour generators. In those systems, absorbed or encapsulated ethanol is released from sachets or laminate films when moisture is absorbed. The released ethanol is helpful to retard the growth of moulds in bread and bakery products, especially in products with high moisture, but also in semi-moist and dry products (Franke, Wijma et al. 2002). They have an additional antistaling effect. The addition of vanilla and other aromas can mask the off-ethanol flavour (Galic, Curic et al. 2009). Ethanol vapour generators may also be efficiently combined with oxygen absorbers. The combined systems have successfully extended the shelf life of bakery products such as sliced rye bread (Salminen, Latva-Kala et al. 1996), sliced wheat bread (Latou, Mexis et al. 2010) and durum wheat bread (Del Nobile, Martoriello et al. 2003). Ethanol emitters such as Ethicap (Freund Industrial Co. Ltd), Oitech (Nippon Kayaku co, LTD), Ageless type SE (Mitsubishi Gas Chemical Co Ltd.) and some others reviewed by (Day 2008) and Rooney (1995) are commercially available.

3.3. Carbon dioxide scavengers and emitters

In modified atmosphere packaging, the headspace composition changes due to the higher permeability of polymers to CO_2 and the metabolic processes (Moller, Jensen et al. 2000; Kanehashi, Kusakabe et al. 2010). In addition, CO_2 is highly soluble in fats and moisture; therefore, it might be required to replace it to avoid package collapse (Rao and Sachindra 2002). CO_2 emitters in the form of sachets or labels usually contain ferrous carbonate or a mixture of ascorbic acid and sodium bicarbonate. Ascorbic acid absorbs oxygen and releases the equivalent amount of carbon dioxide (Waite 2003). This technology has been applied to the storage of bread and bakery products, rice cakes, and others. Mitsubishi Gas Chemical Co Ageless® is a carbon dioxide emitter. FreshPax R (Multisorb Technologies) has dual capabilities as oxygen scavenger and carbon dioxide emitter. On the other hand, carbon dioxide reacts with hydroxides to produce carbonates (Day and Potter 2011), being the basis for the most commonly used carbon dioxide absorbers. Carbon dioxide scavengers are typically applied in the packaging of ground coffee because coffee produces considerable amounts of CO_2 that can cause the packaging to burst (Hurme, Sipiläinen-Malm et al. 2002). The levels of carbon dioxide must also be controlled during storage of certain cheeses, such as Emmentaler cheese, to avoid unwanted blowing or the collapse of the package.

3.4. Moisture absorbers

The accumulation of water in the package might reduce the shelf-life of fermented food products affecting flavour, texture or accelerating the growth of moulds and bacteria. Several technologies have been developed based on the capabilities of desiccants such as silica gel, clay or lime. ATCO® (Standa Industrie) supplies a whole range of humidity absorbers. Multiform desiccants Inc. developed customised absorbers for moist, dry and refrigerated foods. FreshPax® S (Multisorb Technologies) are oxygen and moisture absorbers for bread, bakery, cheeses and other cultured dairy products that inhibit rancidity and retain the colour.

3.5. Antimicrobials and antioxidants

Packaging polymers may play a supplementary role as carriers of antimicrobial or antioxidant molecules able to control pathogens and food spoilage microorganisms and to retard the oxidative processes (Bastarrachea, Dhawan et al. 2011). The action of antimicrobial additives and antioxidants may be controlled with tailored polymer blends, nanoclay incorporation, polymer crosslinking or chemical bonding (LaCoste, Schaich et al. 2005; Fernandez, Cava et al. 2008; Duncan 2011). The impact of these technologies is however limited due to the restrictive regulation concerning active packaging (European Commission 2009). Besides, natural antimicrobials and antioxidants are sensitive to polymer processing temperatures and molecules required for chemical crosslinking are frequently toxic.

One of the most common surface preservatives in cheese and fermented meat products is natamycin (E235), a polyene macrolide antibiotic produced by *Streptomyces natalensis*. Natamycin is allowed to control mould development in cheese surfaces (El-Diasty, El-Kaseh et al. 2008). In semi-hard and semi-soft cheeses, natamycin can be added to PVA coatings applied before ripening. Natamycin can also be added to collagen or cellulose casings of dry and fermented sausages to prevent mould growth in the casing, for example, under the trademark SANICO® (Laboratories STANDA). Many studies focus on the combination of natamycin with biopolymers. Gliadin films crosslinked with cinnamaldehyde and incorporated with natamycin were efficient to reduce moulds in cheese slices (Balaguer, Fajardo et al. 2014). In another study, A sol-gel processing of PLA with tetraethoxysilanase and polyvinyl alcohol incorporating natamycin were tested on the surface of a semi-soft cheese with excellent results against mould spoilage (Lantano, Alfieri et al. 2014).

In edible films and coatings, preferred antimicrobials and antioxidants are bioactive natural compounds such as organic acids, essential oils, plant extracts, bacteriocins, enzymes or chitosan. Some examples illustrate the benefits of natural compounds in cheese edible coatings. Starch-based films coated with linalool, carvacrol or thymol were effective to eliminate *Staphylococcus aureus* inoculated on the surface of Cheddar cheese (Kuorwel, Cran et al. 2011). Cheese slices covered with edible pouches containing zein and oleic acid showed increased shelf-life (Ryu, Koh et al. 2005). Ayana and Turhan (2009) used methylcellulose/chitosan films containing olive leaf extracts to control *S. aureus* growth in Kasar cheese. Sodium alginate coatings containing *Lactobacillus reuteri*, or lysozyme (E1105) and EDTA (E385) extended the shelf-life of Fior di Latte cheese (Conte, Gammariello et al. 2009; Angiolillo, Conte et al. 2015). Galactomannan and nisin (E234) showed positive results for Ricotta cheese preservation (Martins, Cerqueira et al. 2010).

In addition, natural bioactive compounds in packaging materials can improve the quality of bread and bakery products. Chitosan coatings inhibited microbial growth and retarded bread oxidation and staling (No, Meyers et al. 2007). Other authors reported that carvacrol and thymol incorporated in polypropylene were able to increase the shelf-life of bread (Gutierrez, Escudero et al. 2009). Similarly, cinnamaldehyde can be incorporated in gliadin films to increase the shelf-life of sliced bread and cheese spreads (Balaguer, Fajardo et al. 2014). An active packaging with cinnamon essential oil combined with MAP was tested to increase the shelf-life of gluten-free sliced bread. Active packaging was better than MAP alone, maintaining the sensory properties of gluten-free bread (Gutierrez, Batlle et al. 2011).

The interest in metal-based micro- and nanocomposite materials is also growing. Among them, silver based antimicrobials are widely used in the USA and Japan, and could grow in Europe after their inclusion in the provisional list of additives for use in food contact materials and in the list of surface biocides in the framework of the Biocides Product (European Commission 2011; European Commission 2012). Several masterbatches containing silver particles are being commercialized (Biomaster®, AgIon®, Irgaguard®, IonPure®, and others). The applicability of silver as antimicrobial is however controversial since the concentrations necessary in foods are far above the recommended loads (Llorens, Lloret et al. 2012). Many works report on applications in contact with fermented foods, mainly cheese. Agar, zein and PCL films reinforced with silver-montmorillonite have been tested against several microorganisms (Incoronato, Buonocore et al. 2010). Among them, only agar loaded with silver nanoparticles was able to release silver ions due to the ability for water uptake, showing good perspectives to prolong the shelf-life of Fior di Latte cheese (Incoronato, Conte et al. 2011).

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