Chapter 3

Application of Phenolic Compounds for Food Preservation: Food Additive and Active Packaging

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http://dx.doi.org/10.5772/66885

Abstract

Phenolic compounds are well known for their health benefits related to antioxidant activity. In addition, this kind of compounds can be extracted from natural sources, such as olives, grapes, fruits, vegetables, rice, spices, herbs, tea and algae, among others. In this way, these compounds have increased their popularity and, little by little, the consumers are more interested in these compounds due to the fact that they come from natural sources and because they have health biological activity. In fact, other important characteristics associated to phenolic compounds are the antimicrobial activity, because phenolics have the capacity of retarding the microbial invasion in some products and avoiding the putrefaction of others, mainly fruits and vegetables. These properties allow phenolic compounds to be suitable for numerous food preservation applications. Therefore, different kinds of products can be fortificated with phenolic compounds to extend the shelf life of some foods, to turn them in functional food or to incorporate them in food packaging. Active packing is an innovative strategy where phenolic compounds can play an important role for improving the global assessment and extend the shelf life of commercial products.

Keywords: biopreservatives, sampling, antioxidant, antimicrobial, food packaging

1. Introduction

For the food industry, phenolic compounds have potential use as biopreservatives. In fact, phenolic compounds have been extensively studied for their application in the food industry for improving the shelf life of perishable products. The use of phenolic compounds from natural sources in food is an interesting opportunity for the application of their biological activities and allows the production of food without synthetic additives for consumers, because the current concern about the impact of food on health has been influencing the consumer choice of food based on its formulation.

The organoleptic properties and safety of perishable food could be altered by several processes, which include microbial spoilage or oxidation processes. The value of the food is decreased by the destruction of substances, such as proteins, vitamins or fatty acids that have beneficial properties. Production of off-flavors and odors is also decrease the value of the products and, in the worst case, foodborne illnesses transmission related to unsafe food intake. Moreover, changes in food consumption patterns and markets internationalization have caused changes in the retail and distribution practices, with an increased distribution distance and longer storage time. Accordingly, the improvement in the shelf life of perishable foods has become a challenge for the agri-food industry worldwide. The biological activity of phenolic compounds provides a protective effect against deterioration of foods.

In recent years, consumers demand natural food ingredients because of its safety and availability. In this sense, phenolic compounds are beginning to replace chemical additives in food and are perceived to be safer and claimed to alleviate safety concerns. There are many methods of application, but the main is direct addition of phenolic compounds to products. Despite this, a large amount of initiatives have been made to find alternative solutions to the aim of avoiding undesirable inactivation. Spraying, coating and dipping treatment of food are currently applied to product prior to packaging as valid options. The numerous experimental applications of phenolic compounds to various fresh perishable foods demonstrate that they are well-suited to be utilized as preservatives in foods and could be often valid alternatives to synthetic food additives.

Thus, the potential value of phenolic compounds as biopreservatives is considered for the safe extension of perishable products shelf life and these substances can be used to delay or inhibit the oxidation and growth of microorganisms. However, in food applications, the phenolic compounds could be influenced by food components, processing and storage. This chapter will be review the recent research on the application and mode of action of phenolic compounds in perishable food.

2. Phenolic compounds and antioxidant activity

Phenolic compounds, commonly known as polyphenols, are secondary metabolites of plants generally involved in defense against ultraviolet radiation or aggression by pathogens. This wide family of compounds can be found in an extensive range of food and by-products food, as well as beverages, medicinal herbs or spices. In the last part of twentieth century, the interest in food phenolics has increased due to their antioxidant and free radical-scavenging abilities [1] and a large amount of assays has been developed to measure these properties, including hydrogen atom transfer (HAT), single electron transfer (ET), reducing power, and metal chelation, among others. Total phenolic content is a parameter that provides an indirect measure of antioxidant activity. Last trend is the determination of antioxidant activities in food models [2].

http://dx.doi.org/10.5772/66885

There are many sources of antioxidant, and their values are going to be listed below:

Olives (*Olea europaea* L.) and olive oil are well known for their health benefits related to its large amount of phenolic compounds; verbascoside, ligstroside and oleuropein are some examples. The antioxidant ability of phenolic extracts of olive fruits in different maturation stages and different cultivars have been studied by many researches, like Ziogas et al. [3]. By-products obtained in the olive oil extraction are an excellent source of phytochemicals because of their low toxicity, limited costs, broad availability. In this sense, Ramos et al. [4] and Martín-Vertedor et al. [5] have studied olive mill and leaves extract like natural antioxidant, respectively.

Grapes (*Vitis vinifera* L.) and their products are particularly rich on phenolic antioxidant, Carlsen et al. [6] found an antioxidant content between 0.69 and 1.74 mmol/100 g in different grape juices. For its part, grape seeds contain polyphenols, mainly the monomerics catechin, epicatechin and gallic acid, and the polymeric and oligomeric procyanidins. Many authors have focused their investigations in the antioxidant potential of this by-product. Delgado-Adámez et al. [7] aimed to investigate the antioxidant activity of natural extracts of grape seeds extracted from juice and grape seeds extracted after wine manufacture. The antioxidant activity of olive and grapes is showed in **Table 1**.

Matrix	Antioxidant activity	Assay	Reference
Olive fruits	19.0–49.6 μmol AA/g FW	FRAP	[3]
Dry olive mil residue	EC50 24.7–29.56 μg/mL	DPPH	[4]
Olive leaves	15.60 mmol Trolox/kg extract	ABTS	[5]
Grape seed extracts	57.48 ± 3.6% inhibition	DPPH	[7]

Table 1. In vitro antioxidant activity of olives, grapes and their by-products.

The number of studies focused on other fruits and vegetables like natural antioxidant sources have been increased last years. Fruits such as pomegranate, cherry, berries or citrus and a wide range of by-products obtained from these peel, seeds or stones have been studied for this purpose. According to Brat et al. [8], vegetables with the highest polyphenol concentration were artichokes, parsley and Brussels sprouts. Other vegetables found in the bibliography because of their antioxidant activity were spinach, broccoli, cauliflower and eggplants. In **Table 2**, antioxidant activity[22] of many fruits and vegetables can be observed.

The healthy benefits associated with the regular consumption of whole grain products have been reported during the last decades. These healthy properties are due to the presence of secondary metabolites with high antioxidant activity, including phenolic compounds. In this sense, rice (*Oryza sativa* L.) and rice bran, a by-product, have been used to obtain phenolic extracts with antioxidant activity. Its antioxidant activity is mainly due at phenolic acids such as ferulic or *p*-coumaric acid [23]. Butsat and Siriamornpun found between 86.7 and 85.9% of inhibition in 1,1-diphenyl-2-picrylhydrazyl radical (DPPH) [9].

Matrix	Antioxidant activity	Assay	Reference
Pomegranate peel	5.50 μg/mL	DPPH	[16]
Cherry	EC50 6065.68 g.f.w./g DPPH	FRAP	
Blackberry	EC50 2142.42 g.f.w./g DPPH	FRAP	[17]
Strawberry	EC50 3778.94 g.f.w./g DPPH	FRAP	
Blueberry	EC50 7775.4 g.f.w./g DPPH	FRAP	
Orange	36.57 mg Trolox/L extract	ABTS	[18]
Artichokes wastewaters	43 mM de Trolox	DPPH	[19]
Parsley	EC50 2.62 mg/cm3	DPPH	[20]
Cauliflower	1.5 mmol TEAC/100 g f.w.	DPPH	[21]

Table 2. In vitro antioxidant activity of some fruits and vegetables.

The healthy benefits of tea are related to its high phytochemicals content with antioxidant properties. Among these, catechins are the most abundant and powerful compounds in tea [10]. Last years, many researchers have been aimed to obtain tea extracts with high polyphenolic content for different uses. In this way, new techniques as pulsed electric field treatment have been used in recent years [11] for the polyphenol extraction from fresh tea leaves with good yields. Moreover, Sousa et al. [12] suggest the use of ultrasound-assisted ultrafiltration process to purify catechins from green tea extracts.

Spices and herbs are traditionally used because of their antioxidant properties for food conservation. These properties are due, among others, to phenolic compounds. For example, rosemary extracts have been exhaustively investigated and applied due to its high concentration of two phenolic compounds, rosmarinic acid and carnosic acid. On the other hand, Carlsen et al. [6] found high antioxidant activities in clove, mint and cinnamon, among others. In the same way, Lu et al. [13] proved that antioxidant activity of black garlic come from phenolic compounds. In **Table 3**, we can observe the antioxidant activity of many spices.

Matrix	Antioxidant activity	Assay	Reference
Rosemary leaves	EC50 17 ± 9 μg/mL	DPPH	[22]
Clove	277.3 mmol/100 g	FRAP	
Mint	116.4 mmol/100 g	FRAP	[6]
Cinnamon	77.0 mmol/100 g	FRAP	
Black garlic	30% inhibition	DPPH	[13]

Table 3. In vitro antioxidant activity of spices and herbs.

Finally, we cannot forget algae as source of phenolic compounds. Many authors have studied the potential antioxidant effects of edible marine algae, as well as their phenolic compounds,

http://dx.doi.org/10.5772/66885

some of them like phlorotannins, a type of tannins found in brown algae and bromophenols, exclusive to seaweed [14, 15].

3. Phenolic compounds and antimicrobial activity

Nowadays, regarding food, there is the tendency to consume more and more fresh and healthy products, and as similar to its original condition. Therefore, it has emerged the need to seek conservation alternatives, because it has been associated the consumption of chemical preservatives with poisoning. Many foods contain natural compounds with antimicrobial activity. In nature, these compounds can play the role of prolonging the life of food, even many of them have been studied for their potential as direct food antimicrobials. The antimicrobial agents of natural origin interest (vegetable derived) is increasing, so now it seeks a combination of two or more factors which interact additively or synergistically controlling the microbial population. In general, more and more plants or parts of these that contain natural antimicrobial are discovered, for example, which include phenolic compounds from bark, stems, leaves, flowers,... so not only we have more security, but better quality, because this type of antimicrobials are considered as potentially safe sources [23]. Herbs and plants antimicrobial activity is generally attributed to the phenolic compounds present in extracts or essential oils, and it has been observed that fat, protein, salt concentration, pH and temperature affect the antimicrobial activity of these compounds [24]. It is estimated that 1–10% of about 500,000 species of plants in the world have use as food. Most of food antimicrobials are only bacteriostatic (prevent the development of germs) or fungistatic instead of bactericides (destroy germs) or fungicides, so its effectiveness is limited. On the other hand, due to that some microorganisms cannot be inhibited or destroyed by conventional doses of antimicrobials used individually, it is preferable to use a combination of them, expanding its spectrum of action [23]. The problem of microbial food spoilage has obvious economic implications for manufacturers, distributors and consumers [25]. The food quality is affected by physical, chemical, biochemical and microbiological factors, and the control of these factors, in particular microbiological factor, is essential for food preservation. The use of food additives of natural origin involves the isolation, purification, stabilization and incorporation of these compounds to food with antimicrobial purposes, without this affecting adversely the sensory characteristics, nutritional and its health guarantee.

3.1. Phenolic compounds

Phenolic compounds such as caffeic acid, chlorogenic, *p*-coumaric and ferulic are present in parts of plants that are used as spices. The antimicrobial activity of these and other acids as hydroxycinnamic and cinnamic may retard microbial invasion as well as fruit and vegetable putrefaction. Gram-positive and Gram-negative bacteria molds and yeasts commonly found as deteriorative organisms are sensitive to hydroxycinnamic acid derivatives. Caffeic, ferulic and *p*-coumaric acids, for example, inhibit *Escherichia coli*, *Staphylococcus aureus* and *Bacillus cereus*. Other phenolic compounds, which have demonstrated antimicrobial activity, are tannins and tannic acid, the latter for example is inhibitory to *Listeria monocytogenes*, *E. coli*, *Salmonella enteritidis*, *S. aureus*, *E. faecalis* [25] and *Aeromonas hydrophila* [26].

Phenolic compounds such as flavonols, typically present in fruit and green tea, have antibacterial activity. Thereby, Puupponen et al. [27] showed that myricetin, which is used as pure chemical compound, inhibited the growth of lactic acid bacteria derived from the flora of the gastrointestinal tract of humans, but not affect the growth of *Salmonella*, whereas extracts prepared directly from strawberries, raspberries and others were strong inhibitors of *Salmonella* and *E. coli* [28].

3.2. Spices and herbs

Many spices and herbs exhibit antimicrobial activity, such as celery, coriander, laurel, basil, angelica, leeks, horseradish, mint, thyme, among others. The compounds in spices and herbs that have antimicrobial activity are simple and complex phenol derivatives. Generally, spices are more effective against gram-positive, that against gram-negative organisms:

- Cinnamon, cloves and mustard: great preservative power.
- Black/red pepper, ginger: weak inhibitors against a wide variety of microorganisms.
- Pepper, bay leaf, coriander, cumin, oregano, rosemary, sage and thyme: intermediate activity.
- Other: anise, mint, fennel, celery, dill, turmeric.

The conservative function is due to the essential oils of these spices and herbs, whose composition have phenols as thymol or carvacrol, as well as other compounds as eugenol or cinnamic aldehyde with antimicrobial power.

But there is a major drawback in its use and the problem is that it is necessary a high concentration to obtain a preservation effect, and therefore, there are alterations in flavor. Consequently, the use of herbs as antimicrobial agents is limited to food in which the change in taste is considered desired [29].

3.2.1. Oregano

There are a lot of studies about the antimicrobial activity of extracts of different types of oregano. Specifically, it has been evaluated the antimicrobial activity of the individual components as well as the essential oil. The carvacrol and thymol phenols have the highest levels of activity against Gram-negative microorganisms, such as *Salmonella typhimurium, E. coli, Klebsiella pneumoniae, Enterobacter cloacae* and *Yersinia enterocolitica*; thymol being the most active. Also against Gram-positive bacteria such as *Staphylococcus aureus, Staphylococcus epidermidis, L. monocytogenes* and *Bacillus subtilis* [30]. And against fungal species such *as Candida albicans, C. tropicalis, Torulopsis glabrata, Aspergillus niger, Rhodotorula* and *Geotrichum*.

http://dx.doi.org/10.5772/66885

3.2.2. *Cinnamon extract*

Cinnamic aldehyde is a phenolic compound of some species, including cinnamon. It is generally recognized as safe for use in foods, and it is used in many foods as a flavoring. This not only exhibits antibacterial activity but also inhibits the growth of molds, production of mycotoxins and it may reduce aflatoxin production by 99%.

3.3. Other extracts

Plant extracts from grape seeds, grapefruit seeds and green tea are important sources of polyphenolic compounds and phenolic acids with significant antibacterial and antioxidant activity [31]. These compounds impart an inhibitory effect against gram-positives.

3.4. Phenolic compounds and antimicrobial mode of action

Phenolic compounds mode of action has not yet been determined. However, it has been observed that these can inactivate essential enzymes, react with cell membrane or alter the function of the genetic material.

The active components of essential oils can vary in its composition because it can be affected by certain variables such as plant genotype, different extraction methods, geographical location as well as environmental and agronomic conditions. Hydroxycinnamic acids and esters, due to their propenoid side chain, are less polar than the corresponding hydroxybenzoic acids which, facilitates their transport across the cell membrane [32].

Antimicrobials attack mechanism within a cell is carried out in parts and/or important functions for cell survival. It can be carried out in the cell wall, cell membrane, protein synthesis and genetic elements; this can cause irreparable damage to a cell. Several natural antimicrobials are not yet known its mode of action, but as these act differently, combinations of these can lead to better results [33].

Part of polyphenols antimicrobial properties has been attributed to their chelating properties complexing metal ions that are essential for the bacterial growth. The cell walls of Gram-negative bacteria represent a great barrier for polyphenols to get into cell cytoplasm; only in some studies grape seed extracts have been reported to inhibit Gram-negative bacteria [34].

There are few studies focused on understanding the mechanism involved in inhibition of microbial by spices and essential oils. However, phenolic structure of many of the compounds with antimicrobial activity present in the spices and their essential oils, suggest that the mode of action should be similar to other phenolic compounds.

In many cases antimicrobials may have no effect until a critical concentration is exceeded. Thyme extracts were used at different concentrations to inhibit *Salmonella typhimurium* by Raibaudi [28]. These researchers found that there was a critical concentration in which the extract had antimicrobial effect, and at lower concentrations the phenolic compounds did not have antimicrobial activity. The authors indicated that the phenolic compounds can sensitize the cell membrane, and saturate the sites of action, therefore, the cell suffers a serious injury, causing the membrane collapse.

4. Phenol fortification of food products

Referring to meat industry, the meat products are vulnerable to lipid oxidation. One way of measuring the degree of lipid oxidation is the thiobarbituric acid reactive substances (TBARS) method. Although, initially, synthetic antioxidants have been used with the purpose of avoiding the lipid oxidation, the new tendencies are finding them in natural sources and applying into the meat. In order to prevent undesirable lipid oxidation changes, a 0.2% of bee pollen was effective in retard lipid oxidation in pork sausage during 30 days of storage at 4°C. It showed lower values of TBARS along the experiment than control [35] being the highest percentages of decrease in TBARS after 10 days of storage. Cocoa and grape seed extracts allowed to enrich in phenol Spanish dry fermented sausages without affecting the sensory profile [36] and the incorporation kordoi (*Averrhoa carambola*) fruit juice extract in pork nuggets allowed increasing the storage life of them from 21 to 35 days compared to the pork nugget without extract [37] and the TBARS values of enrichment of 4% juice and 6% of extract were lower during the 35 days compared to control. In addition to lead lo attenuation effect against lipid oxidation, although the only addition of green tea extract directly in hamburger allowed reduction of TBARS during 8 days of storage, the incorporation of green tea extracts in combination with chitosan in hamburgers achieved more resistant to lipid oxidation at the end of storage and to microbiological deterioration [38]. A common strategy of enrichment of phenol content in food is the olive leaves extracts. The treatment consisted of incorporation of olive leave extract in pork patties, whose TBARS values were significantly decreased by increasing amount of grape seed flour ranged from 0.5 to 5.0%. Consequently, it also delayed protein and lipid oxidation [39]. The addition of spice extracts in chicken meat not only was effective against microbial growth and lipid oxidation but CIE a* values and sensory color and odor were also improved referred to the use of butylated hydroxyl toluene during storage for 15 days at 4°C [40]. Over storage period, TBARS values were lower in the samples control with of 1.0 and 0.5% of different spices extracts in chicken meat. This kind of addition was more effective and provided TBARS values considerably lower during 20 days of storage than the chicken meat without spice extract fortification in storage temperature the range from 4 to 20°C [41]. A typical non meat product susceptible of oxidation is the margarines but it could reduce in relation with vitamin E-enriched margarine with using *Opuntia ficus-indica* peel extract [42].

Although pomegranate peel extract was also effective on retarding lipid oxidation and protein oxidation beef meatballs [43], another kind of application of pomegranate of peel extract is its capacity as melanosis inhibitor during the refrigerated storage of Pacific white shrimp in addition to retard the mesophilic, psychrophilic, lactic acid bacteria and enterobacteriacea counts [44]. Noticeable improvements of color of foodstuff such as strawberry and red radish can be achieved by intermolecular co-pigmentation phenolic mango peel extracts [45].

In relation with vegetables oils, phenolic extract can be used for improving their frying characteristical by means of enrichment in oregano whose phenols such as rosmarinic acid protected the endogenous antioxidants from degradation [46]. In this same line, a concentration of at least

400 mg/kg of polyphenols extracted from olive vegetation is enough to reduce oxidation of the tocopherols of refined oils in more efficient way than synthetic antioxidant [47] and the incorporation of 100, 200, 400 and 1200 mg/kg of determined groups of phenolic compounds allowed induction period determined by Rancimat test to increased from 4.15 (refined oil control) to 5.96, 6.90, 8.50 and 12.3 h, respectively. The incorporation of olive leaf extract in concentration of 120 and 240 mg per kg of oil improved the oxidative stability of frying olive oils as results of high retention of microconstituents [48]. In this study, the oxidative stability of fresh sunflower, olive and palm oil with addition of 240 mg per kg increased from 5.1, 13.3 and 34 from 7.7, 20.8 and 43.1 h, respectively, while the same oils submitted to fry ranges from 3.4, 9.8 and 31.0 to 5.9, 17.6 and 36.7, respectively. In an essay where natural bioactive compounds of olive leaves were profited, Delgado-Adámez et al. [49] found the oxidative stability of Arbequina olive oils increased by incorporation 100 mL of olive leaf extract referred to control, being the maxima oxidative stability (80 h) where these extracts where used in combination with lecithin as emulsionant. Furthermore, the incorporation of rosemary methanol extract in oil used for frying showed an enhanced stability retarding the oil oxidation throughout its use in frying due to phenolic compounds mainly carnosol and carnosic acid [50]. The olive oil enriched by phenolic compounds from thyme increased in more than 10 h of oxidative stability than control oil [51].

During Maillard reaction, which is necessary for the appearance and taste of foods, advanced glycation end-products can be generated and increase the risk for development of health disorders such as diabetes [52]. In this context, polyphenols fractions from decaffeinated tea and grape seed extract have been added in the elaboration of breads preventing the formation of the harmful advanced glycation products [53, 54]. In connection with other enzymatic reaction, rice bran extract phenols have the ability of inhibiting polyphenol oxidase and enzymatic browning activity effects on potato and apple [55]. In **Table 4** are summarized the principal quality improvement of phenolic compounds in food matrix.

Type of phenol extract added	Type of food matrix	Quality improvement
Bee pollen	Pork sausage	Retarding lipid oxidation in pork sausage during 30 days of storage at 4°C
Cocoa and grape seed extracts	Spanish dry fermented sausages	Enrichment in phenol without affecting the sensory profile
Kordoi fruit juice extract	Pork nuggets	Increasing the storage life of them from 21 days to 35 days
Green tea extracts in combination with chitosan	Hamburgers	Achievement more resistant to lipid oxidation at the end of storage and to microbiological deterioration
Olive leave extract	Pork patties	Delaying protein and lipid oxidation
Spice extracts	Chicken meat	Effectiveness against microbial growth and lipid oxidation. Improvement of sensory color and odor
Opuntia ficus-indica peel extracts	Margarines	Reduction of oxidation in relation with margarine with vitamin E
Pomegranate peel extract	Beef meatballs	Retarding lipid oxidation and protein oxidation

Type of phenol extract added	Type of food matrix	Quality improvement
	Pacific white shrimp	Capacity as melanosis inhibitor during the refrigerated storage. Retarding the mesophilic, psychrophilic, lactic acid bacteria and enterobacteriacea count
Mango peel extracts	Strawberry red radish	Improvements of color by intermolecular co-pigmentation
Oregano	Vegetable oils	Improvement frying characteristical. Protection the endogenous antioxidant from degradation
Olive vegetation	Refined oil	Reduction of oxidation of the tocopherols in more efficient way than synthetic antioxidant. Rancimat test to increased from 4.15 (refined oil control) to 12.3 h
Olive leaf extract	Sunflower oil Olive oil Palm oil	Improvement the oxidative stability both fresh and frying oil
	Arbequina olive oils	The oxidative stability increased
Rosemary methanol extract	Oil for frying	Enhancement stability retarding the oil oxidation
Decaffeinated tea and grape seed extract	Bread	Prevention the formation of the harmful advanced glycation products
Rice bran extract	Apple potato	Inhibition polyphenol oxidase and enzymatic browning activity effects

Table 4. Main quality improvement of phenolic compounds in food matrix.

5. Use of phenolic compounds in active food packaging and edible films

Bio-based and synthetic polymers are being functionalized with well-known antioxidants and antimicrobials such as phenolic compounds, showing excellent opportunities to prolong shelf life when used directly in contact with the food matrix or as part of combined strategies. However, the evaluation of the efficiency consists of a multidisciplinary approach and its effect in a food has to be studied case by case. This section provides an overview on the most recent scientific advances and a critical view of the benefits, limitations and future trends of the use of phenolic compounds in the active food packaging and edible films.

During distribution, the quality of the food product can be deteriorated biologically and chemically as well as physically. Traditional food packaging concepts are reaching their limits in prolonging shelf life. Therefore, novel packaging concepts, as active packaging, enable a further prolongation of shelf life. Active packaging can be defined as a t'ype of packaging that interacts with the packaging condition, extending shelf life and improving safety or sensory properties while maintaining food product quality [56]. Active food packaging has focused their attention on bio-based functional packaging materials incorporating natural active compounds and ingredients. [57] Different incorporation mechanisms are currently being used:

- Addition of emitting sachets: This technique has been applied for volatile compounds such as timol and carvacrol. No direct surface contact occurs, and volatile compounds are released into the headspace of the package.
- Incorporation of absorbent pads: pads are one of the most successful applications of active food packaging. The food product is placed on the absorbent pad, and pad soaks up fluid or juice exuded by the food product that would otherwise collect on the bottom of food packaging or tray. The unsanitary juices immobilized in pads might, however, originate undesirable odors, spoil the food quality or promote the propagation of foodborne pathogens. Phenolic compounds may be incorporated into the absorbent pad, adding functionality to packaging.
- Dispersion of phenolic compounds in the packaging polymer: Phenols can be incorporated by extrusion, heat-press or casting. The main disadvantage of extrusion is the use of high temperatures and shearing forces that can reduce biological activities (antioxidant and antimicrobial).
- Coating or dipping: Coatings and edible films serve as carriers of phenolic compounds and are in direct contact with the food surface. The advantages of this method are that the compounds are not exposed to excessive heat and can be applied at any stage of the food supply chain.

Independently of the technique used for incorporation, the phenols packaging systems are divided in two main categories: (1) those in which the phenolic compounds migrates from the package into the food, and (2) those in which the phenolic compounds remains immobilized in the package.

5.1. Scope of applications

Phenolic compounds can be incorporated into polymers or into carriers that may be extruded or coated into packaging materials. Applications of active packaging are numerous and growing. **Table 5** and **Table 6** provide a synopsis of current and future applications of the use of phenolic compounds in the active food packaging and edible films.

5.2. Recent trends and regulatory aspects

While in the United States, Japan and Australia, active packaging systems are already being successfully applied to extend shelf life or to monitor food quality and safety, in Europe, the development and application of active packaging systems are limited. This can be explained by the legislative restrictions, as there are no specific regulations on the use of active packaging in Europe [76]. In addition, fear of consumer resistance, lack of knowledge about effectiveness, economic and environmental impact of active packaging have to be taken into account.

Sources of phenolic compounds	Main results	References
Several phenol compounds: acids, essential oils components and dopamine.	Some pathogens were significantly reduced (*Staphylococcus aureus and Escherichia coli*)	[58]
Carvacrol	Carvacrol could therefore be used in active packaging formulations as its release from the polymer matrix can be controlled.	[59]
Aqueous green tea extract	Enhanced polyphenolic content and antioxidant activity of the films.	[60]
Tea polyphenols	Increased the antioxidant activity of the films.	[61]
Zataria multiflora Boiss and Mentha pulegium essential oils	Exhibit antimicrobial activity	[62]
Essential oil of oregano, rosemary, and garlic.	The results of this study suggested that the antimicrobial activity of some spice extracts were expressed in a WPI based edible film	[63]
Rosemary essential oil	Exhibit antimicrobial activity	[64]

Table 5. Examples of phenolic compounds for potential use in food packaging materials.

Sources of phenolic compounds	Type of food matrix	Main results	References
Barley husks	Salmon	Increasing the oxidative stability	[65]
Barley husks	Blue shark muscle	Exhibit antioxidant capacity	[66]
Brewery residual stream extract and commercial rosemary extract	Beef	Active packaging films enhanced oxidative stability of beef during refrigeration.	[67]
Catechin and quercetin	Different food simulants	Can improve food stability	[68]
Green tea extract	Pork sausages	Shelf life extension	[60]
Green tea extract	Several foods	Exhibit antioxidant capacity	[69]
Essential oil of cinnamon, oregano, and clove.	Different food simulants	Exhibit antimicrobial activity	[70]
Rosemary and oregano	Fresh lamb steaks	Extended fresh odor and color from 8 to 13 days compared to the control.	[71]
Grape seed extract	Pork loins	The active packaging in a significant shelf life extension.	[72]
Zataria multiflora Boiss essential oil and grape seed extract.	Mortadella sausage	The active packaging in a significant shelf life extension.	[73]
Grapefruit seed extract	Ground beef	Preserving beef quality	[74]
Grapefruit seed extract	Table grapes	Exhibits antifungal and antioxidative activity	[75]

Table 6. Relevant examples of phenolic compounds applied to active food packaging and edible films.

The legislation that applies to traditional packaging also use for active packaging, which requires that compounds are registered on positive lists and that the overall and specific migration limits are respected. This is more or less contradictory to the concept of some active packaging systems that require a sensor of some kind being in direct contact with food products and some substance may migrate from the sensor into foods [76]. These migrations could be intentional or unintentional, and the type, amount and possible health effects of the substance must be determined in order to regulate the use of them.

Meanwhile, the U.S. Food and Drug Admisnitration (USFDA) (1997) classifies essential oils and the majority of natural extracts as generally recognized as safe (GRAS). However, there are regulatory limitations on the accepted daily intake of essential oils or essential oil components, so before they can be used in food products, a daily intake survey should be available for USFDA. In Europe, essential oils fall under Regulation 1334/2008 on natural flavorings; and natural plant extracts have been considered under Directive 2002/46/EC on food supplements.

The food industry main concern about introducing active components to packaging seems to be that consumers consider the components dangerous. Before the food industry can decide on the best active packaging technique, studies are needed in markets to evaluate consumer attitudes towards these techniques. It is also important that the food producer, retailer, and the consumer be in tuned with the compounds used in active packaging. Attitudes must be willing to accept new technologies and those involved in each step of the food chain must be sure that the new system is safe and true for the user. Phenolic compound are often perceived favorably by consumers as healthy or natural foods.

Recent technological advances in active packaging are discussed, and food related applications are presented.

Furthermore, the benefits of active packaging need to be considered in a global approach to environmental impact assessment. The environmental effect of plastics-based active packaging will vary with the nature of the product/package combination. The additional ingredients need to be evaluated for their environmental impact. Active packaging is an emerging area of technology which can confer many preservation benefits on a wide range of foods. As more companies become aware of the economic advantages of using absorbent technology, and consumers accept this approach, the technology will likely emerge as the preservation technology of the twenty first century.

Acknowledgements

Sara Martillanes and Manuel Cabrera-Bañegil thank to the sponsorship of Comunidad Autonoma de Extremadura, to Consejería de Economía e Infraestructuras and the co-financing of the Fondo Social Europeo (FSE) for the grant to the formation of technologist in the year 2014. The publication of this chapter was funded by Government of Extremadura and FEDER (GR100006).

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