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Review

# Phenols recovered from olive mill wastewater as additives in meat products

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ABSTRACT

*Background:* The current trend in the food industries is the utilization of natural additives that exist inherently in foods and sound healthier to the consumers,

*Scope and approach:* This review explores the possibility of utilizing natural, phenol-rich extracts recovered from olive mill wastewater to fortify meat and meat products as well as to increase the preservation of the latest in the shelf. The utilization of natural antioxidants as additives in meat and meat products is denoted in comparison to the advantages of synthetic preservatives. To this prospect, the antioxidant capacity of olive phenols is discussed and compared with this of raw and pure natural antioxidants. The *in vitro* and *in situ* applications of olive phenols against lipid peroxidation, meat colour stability are reported together with their application as antimicrobial agents.

*Key findings and conclusion:* The implementation of olive phenols as additives in the meat sector has great potentiality due to the fact that they can provide multidimensional improvement of stored meat products, namely colour retaining, retardation of microbial growth, retardation of fats deterioration and ultimately extended shelf-life.

## 1. Introduction

Nowadays, consumers are more and more exigent when they buy food by demanding products with decent organoleptic characteristics, like attractive colour and pleasant odor. Nevertheless, oxidative processes of meat products during storage lead to diminution of food quality, e.g. rancid flavor and odors, colour and texture mutation as well as nutritive value reduction (Ventanas, Estevez, Delgado, & Ruiz, 2007). Microbial spoilage is one of the major factors affecting the organoleptic characteristics and shelf-life of high moisture foods like meat (Smith, Daifas, El-Khoury, Koukoutsis, & El-Khoury, 2004). On the other hand, lipid oxidation is one of the primary causes of quality losses in frozen stored meat products and contributes consequently to the reduction in their corresponding shelf-life (Akarpat, Turhan, & Ustun, 2008). Furthermore, colour mutation due to lipid oxidation is a major problem for food manufacturers, e.g. it causes an annual loss of 1 billion United States dollars to the meat industry (Hunt & Mancini, 2009).

The retardation of these negative effects is usually accomplished with the utilization of antioxidants as meat additives. Based on their function, the lipid antioxidants can be classified in two categories. The primary or chain breaking donate electrons to the lipid radicals and produce lipid derivatives that are less available to autoxidation process (Kiokias, Varzakas, & Oreopoulou, 2008). The secondary or synergistic antioxidants are basically chelating agents that retard lipid oxidation by tying up transition of metals (Roozen, 1987). These antioxidants are sometimes termed as synergistic due to their ability to promote the action of the primary antioxidants (Minnoti, 1993). Primary synthetic antioxidants with phenolic groups such as butylated hydroxyanisole and butylated hydroxytoluene have been used in meat products over the last 50 years (Rojas & Brewer, 2008). Despite the superior efficacy and high stability of synthetic antioxidants, there is an increasing concern about their safety. The necessity of improving the quality, safety and image of processed meat products has turned researchers to utilize natural antioxidants that exist inherently in foods and sound healthier to the consumers (Kiokias et al., 2008; Ramarathnam, Osawa, Ochi, & Kawakishi, 1995). Besides, environmental issues and circular economy has developed a trend in the food industry to seek for natural antioxidants in food processing by-products.

Dietary antioxidants of fruits or vegetables include ascorbate, tocopherols, carotenoids as well as bioactive plant phenols like flavonoids and phenolic acids (Boskou, 2006). Ascorbic acid (vitamin C) is mainly secondary antioxidant acting by different mechanisms that prevent the development of lipid and pigment peroxidation (Frankel, Huang, Aeschabach, & Prior, 1996; Gök, Kayaardi, & Obuz, 2009). Tocopherols comprise a subgroup of lipo-soluble chromanol homologs comprising vitamin E. They act as hydrogen donators, but they can also possess a

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synergistic effect as they are able to regenerate ascorbic acid in meat applications (Bast & Haenen, 2002; Djenane, Sánchez-Escalante, Beltran, & Roncales, 2002). Carotenoids involve a class of natural pigments, which act either as primary or secondary antioxidant (Edge, Truscoot, & McGarvey, 1997). Lycopene is a lipo-soluble carotenoid (similar to popular $\beta$-carotene) that acts by neutralizing free radicals. For instance, tomato lycopene has been utilized as additive in minced meat in order to increase storage stability and improve colour of the product (Osterlie & Lerfall, 2005). Catechin and caffeic acid are typical examples of plant phenols, namely flavonoids and phenolic acids, respectively. Olive fruit contains phenolic acids (*o* - and *p*-coumaric, cinnamic, caffeic, ferulic, gallic, sinapic, chlorogenic, protocatechuic, syringic, vanillic and elenolic) phenolic alcohols (tyrosol and hydroxytyrosol), secoiridoids and flavonoids (Galanakis & Kotsiou, 2017). Phenols act by hydrogen donating and sequentially quenching of radicals and have been utilized against lipid oxidation in meat products (Gramza & Korczak, 2005; Gülçin, 2006; Rey, Hopia, Kivkari, & Kahkonen, 2005; Yilmaz, 2006).

The fortification of meat products with natural antioxidants and extracts has been tested by several researchers. Djenane et al. (2002) investigated the ability of a-tocopherol, taurine and rosemary, in combination with vitamin C, to increase the oxidative stability of beef steaks packaged in modified atmosphere. Results demonstrated that surface application of antioxidant combinations resulted in an effective delay of oxidative deterioration of fresh beef steaks. Shelf life was extended beyond that of control, according to evaluation of sensory attributes. Rojas and Brewer (2008) studied the effect of grape seed extract (0.01 and 0.02%), oleoresin rosemary (0.02%) and water-soluble oregano extract (0.02%) on the oxidative and colour stability of raw beef and pork patties, vacuum packaged and stored frozen for 4 months. Based on the TBARS values, the extracts provided small degrees of protection against oxidation in both meat species, whereas they did not alter the sensory perception of oxidation, redness, yellowness or colour intensity. Bastida et al. (2009) evaluated the effect of adding condensed tannins in the form of non-purified or purified extracts obtained from Carob fruit to prevent lipid cooked pork meat systems from oxidising during chilling and frozen storage. The antioxidant activity of these extracts was compared with that of a-tocopherol showing lower levels of TBARS levels under chilled storage.

These early studies have revealed the opportunity of using natural additives and extracts instead of synthetic antioxidants and preservatives in order to increase the shelf-life of meat products. Nevertheless, this replacement is not so easy in practice for the following reasons:

i. Microbial spoilage and fats deterioration of meat products is very fast, causing off-flavors and rapid changes in the meat colour;
ii. Synthetic antioxidants and preservatives are in general more powerful and cheaper compared to natural antioxidants and extracts;
iii. Natural extracts have usually a taste and odor associated with the source of recovery and subsequently they change the organoleptic characteristics of the fortified meat products.

## 2. The prospect of utilizing phenols recovered from olive mill wastewater (OMW) for this purpose

Olive fruit and its processing by-products during olive oil production are well known to contain high concentrations of several phenolic classes, as well as other organics such as pectin, insoluble dietary fibre, proteins, sugars and nitrogenous compounds (Galanakis, Tornberg, & Gekas, 2010b; Galanakis, Tornberg, & Gekas, 2010d; Galanakis, Tornberg, & Gekas, 2010e; Roselló-Soto et al., 2015a).

Chemical and mineral composition of OMW and its physicochemical characteristics differ depending on the olive oil extraction as well as other factors, e.g. seasonal production. Table 1 presents the mean composition of OMW from different studies. The above compounds

**Table 1**
Composition of olive mill wastewater {(prepared using data of Galanakis (2017b)}.

| Parameter | Unit | Value |
|---|---|---|
| Density | g/mL | 1.01–1.10 |
| Water | g/100 g | 83–94 |
| Organic compounds | g/100 g | 4–18 |
| Inorganic compounds | g/100 g | 0.4–2.5 |
| Total solids | g/100 g | 3.2–30 |
| Fats and oils | g/100 g | 0.03–1.1 |
| Sugars | g/100 g | 1–4.7 |
| Carbohydrates | g/100 g | 2–8 |
| Pectin | g/100 g | 1–1.5 |
| Phenolic compounds | g/100 g | 0.6–4.0 |
| Nitrogen (N) | g/100 g | 0.58–2 |
| Potassium ($K^+$) | g/100 g | 0.3–0.9 |
| Phosphorus (P) | g/100 g | 0.06–0.32 |
| Calcium ($Ca^{2+}$) | g/100 g | 0.32–0.53 |
| Sodium ($Na^+$) | g/100 g | 0.04–0.48 |
| Magnesium ($Mg^{2+}$) | g/100 g | 0.06–0.22 |

have been recovered from relevant sources (olive cake, olive kernel, OMW etc) and used for the fortification of food products and the production of nutraceuticals. For instance, the insoluble dietary fibre of olive processing by-products has been targeted as a source of fermentable sugars in order to fortify bakery products (Felizón, Fernández-Bolaños, Heredia, & Guillén, 2000; Galanakis, 2015), whereas the soluble one (pectin) has been used as fat replacement in meatballs due to its gelling properties (Galanakis, Tornberg, & Gekas, 2010a; Galanakis, Tornberg, & Gekas, 2010c). Although these applications look interesting, the main focus of researchers has been directed to olive phenols due to their advanced antioxidant properties (Rahmanian, Jafari, & Galanakis, 2014) and the tremendous amounts of them lost through OMW during olive oil production, causing multiple environmental problems (Belaqziz, El-Abbassi, Lakhal, Agrafioti, & Galanakis, 2016; Regni et al., 2017; Souilem et al., 2017).

The recovery of phenols from olive mill waste and generally food processing by-products is typically conducted through conventional techniques (Galanakis, 2012), membranes (Galanakis, 2015; Galanakis, Kotanidis, Dianellou, & Gekas, 2015), solvent extractions (Heng et al., 2015; Tsakona, Galanakis, & Gekas, 2012), and more recently via emerging non-thermal technologies (Barba, Galanakis, Esteve, Frigola, & Vorobiev, 2015; Galanakis, 2012; Kovacevic et al., 2018; Roselló-Soto et al., 2015a) that promise minimal impact on sensorial and nutritional properties of the product (Zinoviadou et al., 2015). The prospect of recycling ingredients from olive mill waste is a story started few decades ago (Galanakis, 2017b). Today, all these efforts has led to the industrial recovery of phenols from OMW since at least 5 companies around the worlds have commercialized relevant methodologies (Galanakis & Kotsiou, 2017; Galanakis & Schieber, 2014) and sell phenols as natural preservatives and bioactive agents (Galanakis, 2017a). Applications include the fortification of different products such as vegetable oils (Galanakis, Tsatalas, & Galanakis, 2018b; Yangui, Abessi, & Abderrabba, 2015), table olives (Lalas et al., 2011), lard (De Leonardis, Macciola, Lembo, Aretini, & Ahindra, 2007), bakery products (Galanakis, Tsatalas, Charalambous, & Galanakis, 2018a), milk beverages (Servili et al., 2011b), meat products (Balzan et al., 2017; Chaves-López et al., 2015; Dejong & Lanari, 2009; Serra et al., 2018; Veneziani, Novelli, Esposto, Taticchi, & Servilli, 2017), cosmetics and sunscreens (Galanakis, Tsatalas, & Galanakis, 2018c; d). All these applications (especially those on food products) are based either on the antioxidant ability of phenols to reduce oil peroxidation during cooking, deep fat frying and storage or on their antimicrobial properties. Among the different applications, the fortification of meat products constitutes the greatest challenge for a number of reasons. Therefore, meat industry is a huge market, whereas phenols possess both antioxidant and antimicrobial properties that are often better that the rest