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REVIEW ARTICLE

Concise Reviews and Hypotheses in Food Science

Effect of edible coatings and films enriched with plant extracts and essential oils on the preservation of animal-derived foods

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Abstract: Edible coatings and films for food preservation are becoming more popular thanks to their environmentally friendly properties and active ingredient-carrying ability. Their application can be effective in contrasting quality decay by limiting oxidation and deterioration of foods. Many reviews analyze the different compounds with which films and coatings can be created, their characteristics, and the effect when applied to food. However, the possibility of adding plant extracts and essential oils in edible coatings and films to preserve processed animal-derived products has been not exhaustively explored. The aim of this review is to summarize how edible coatings and films enriched with plant extracts (EXs) and essential oils (EOs) influence the physico-chemical and sensory features as well as the shelf-life of cheese, and processed meat and fish. Different studies showed that various EXs and EOs limited both oxidation and microbial growth after processing and during food preservation. Moreover, encapsulation has been found to be a valid technology to improve the solubility and stability of EOs and EXs, limiting strong flavor, controlling the release of bioactive compounds, and maintaining their stability during storage. Overall, the incorporation of EXs and EOs in edible coating and film to preserve processed foods can offer benefits for improving the shelf-life, limiting food losses, and creating a food sustainable chain.

KEYWORDS
cheese, edible coatings and films, essential oil, fish, meat, plant extract, processed foods

1 | INTRODUCTION

Food preservation aims to inhibit and/or slow down spontaneous alternative processes. During production, processing, storage, and distribution, it is necessary to maintain stable environmental and chemical food storage parameters. Therefore, food must limit interaction with the external environment which could lead to deterioration and loss of initial characteristics (Huang et al., 2021). In particular, cheese, processed meat, and fish products present a high risk of contamination by microorganisms due to high moisture, optimal pH, and features that promote microbial growth (Donnelly, 2018; Sivamaruthi et al., 2021). In addition, lipid oxidation can change the con-

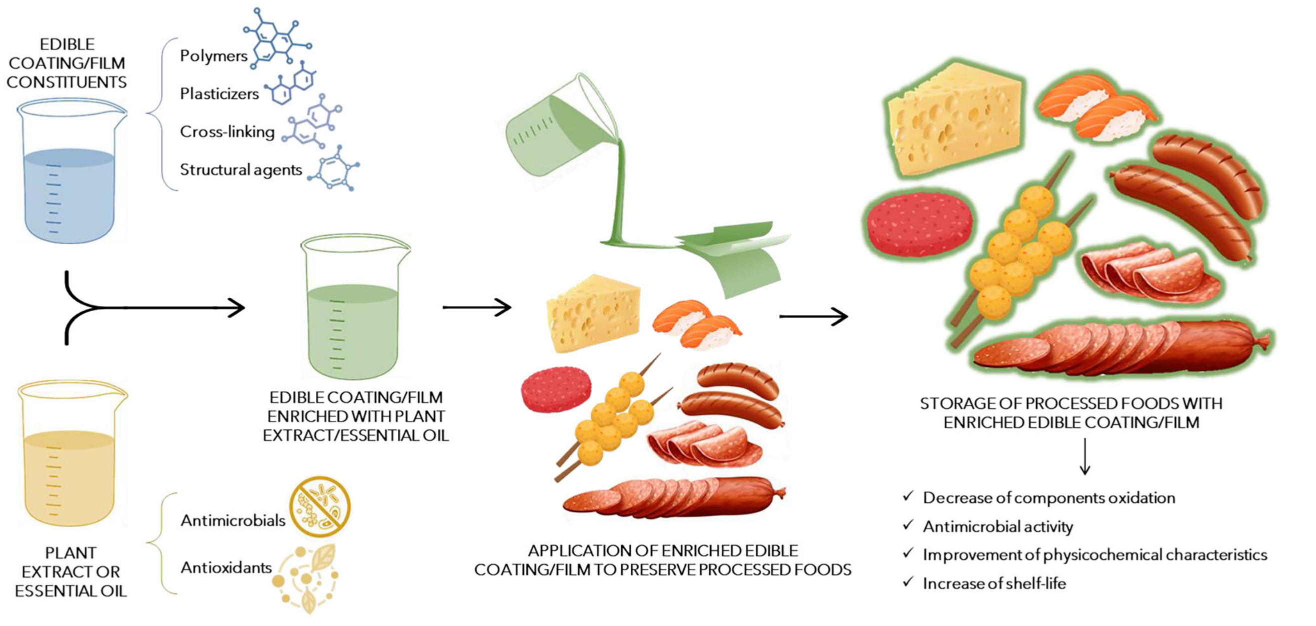

FIGURE 1 Application of plant extracts or essential oils in edible coating and film to preserve processed animal foods.

centration of certain chemical compounds in products, affecting nutritional and organoleptic characteristics (Wu et al., 2022).

However, over the years, various coating innovations have been developed to maintain the quality and safety of food products. One strategy to increase food shelf-life is applying edible coatings and films. These strategies are cost-effective and environmentally friendly. They are generally obtained from food waste and byproducts, thus enabling their reuse in the food chain (Chiralt et al., 2020). The possibility to consume edible coatings and films with cheese, meat, or fish, avoid the formation of waste. The characteristics of the possible constituents of edible coatings and films, their potential, and limitations in their food application are widely analyzed in the literature (Chhikara & Kumar, 2022; Paidari et al., 2021).

However, it also needs to be highlighted that over the years, the demand for biodegradable coatings and films with functional plant extracts (EXs), and/or essential oils (EOs) is becoming a viable alternative to conventional coatings and films. Biologically active agents obtained from plant matrices, such as antioxidants and antimicrobial molecules, reduce the risk of microbial proliferation, improving the shelf-life and quality of packaged products (Al-Tayyar et al., 2020). Different plant EXs/EOs derived from spices and herbs with antioxidant and antimicrobial activity, added in the formulation of edible coatings and films were tested for the preservation of cheese, processed meat, and fish. The edible material increased the microbiological quality, decreased lipid oxidation and texture change of packaged food, and increased shelf-life (Figure 1). On the other hand, there is no literature review on the application of EXs and EOs in edible coatings/films in the preservation of processed animal foods such as cheese, meat, and processed fish.

The objective of this review is to summarize the advantage in the application of edible coatings and films, and the bioactive features of plant-derived EXs and EOs. Particularly, scientific publications on the application of plant-based EXs and EOs in edible coatings and films for the preservation of cheeses and processed meat and fish products were analyzed. Moreover, the attention was focused on the antioxidant and antimicrobial activity of the EXs and EOs in edible coatings and films and its ability to increase the shelf-life of the products. In addition, the impact of the EXs and EOs into edible coatings and films on the physico-chemical and sensory characteristics of animal-derived foods was discussed.

2 | EDIBLE COATINGS

In response to the environmental crisis, new food preservation techniques, that limit the use of plastics and pollution with non-biodegradable products, have been studied in recent years. Edible coatings and films are environmentally sustainable strategies for food preservation (Sun et al., 2022). Their advantage is based on the biodegradability of the materials used, which can also be consumed with food. Furthermore, the materials are mainly derived from food waste and byproduct. This allows material that is not yet exhausted to be fed into the production cycle, thus following the concept of circular economy (Chiralt et al., 2020). Edible coatings and films for food preservation positively impacts the circular economy as, unlike conventional coatings, they are biodegradable, non-toxic, and effectively exhibit barrier properties. In addition, agro-food waste and byproducts enables the creation of a coating that provides functional bioactive molecules for food preservation (Gaspar & Braga, 2023).

Edible coatings and films are transparent edible films that can be removed by simply washing with water. This term includes all type of covering which can be consumed with food. Their thickness is generally less than 0.3 mm (Ribeiro et al., 2021). In the literature, there are authors who use the term film and edible coating indifferently. In other cases, it is considered useful to define a difference given the technique of application to the product. The edible films are first molded as solid sheets which are then applied in wrap form on the food. Differently, edible coatings are applied in liquid form on the food, usually by soaking the product in a solution consisting of a structural matrix (carbohydrates, proteins, lipids, or a multi-component mixture) (Maan et al., 2021).

During the production of films and edible coatings, the basic components are dispersed and dissolved in a solvent such as water, alcohol, or a mixture of other solvents. By adjusting the pH and/or heating the solutions, the dispersion of a specific polymer can be facilitated. During the process, plasticizing substances (glycerol, sorbitol, fatty acids, and monoglycerides), cross-linking, antimicrobial agents, structural agents, antioxidants, dyes, and flavorings can be added to intensify the final functional properties, increase the coatings and films' adaptability, reduce brittleness, and make it suitable for using.

Edible coatings can be applied using the dipping method where the food is dipped directly into the corresponding coating solution. After natural drying, a thin coating layer forms on the surface of the product. Another method is the spraying method, which can be used for solutions with low viscosity to be applied at low pressure (Suhag et al., 2020). The spreading method, on the other hand, consists of directly brushing the coating solution onto the product (Ju et al., 2019). On the other hand, film application is usually carried out by wrapping the film in contact with the product. The performance of edible coatings and films depends on the physical–chemical characteristics of materials like solubility, density, viscosity, and surface tension. Furthermore, the choice of material depends on the type of food (high-moisture or dry products), and the storage conditions (temperature and relative humidity).

Chitosan is among the most widely used polysaccharides of animal origin for edible coatings and films. This is obtained from the exoskeleton of crustaceans or the cell wall of fungi (Chhikara & Kumar, 2022). This has a good barrier property against O_2 and CO_2, is transparent, flexible, and lipid resistant. It also exhibits antimicrobial and antioxidant activity. Nevertheless, it has a high permeability to water vapor, due to high hydrophilic nature of chitosan (Peter et al., 2021). This could lead to a water loss of the packaged product. For this reason, chitosan is combined with other biomaterials to ameliorate properties of film/coating for food preservation (Iqbal et al., 2021). Combining chitosan with gelatinized maize starches can reduce water vapor transmission rates. While, the combination with protein molecules can improve mechanical properties (Cazón & Vázquez, 2020). Plant-derived polysaccharides include cellulose derivatives such as hydroxypropyl methylcellulose, methylcellulose, and carboxymethylcellulose, which form water-soluble polymers. This group of compounds exhibits good barrier properties, are fat and oil resistant, and protect coated foods from O_2; mechanical characteristics show a flexible nature (Mohamed et al., 2020).

In the plant derivate section there is starch, which has excellent barrier properties for water and O_2 (Panahirad et al., 2021) but show moderate mechanical properties which are overcome by combining it with other edible materials. On the other hand, alginate forms insoluble polymers when it binds to calcium ions and present excellent colloidal properties. It is obtained from seaweed, and forms a coating/film with low water permeability, delaying the oxidation of fats in coated foods, and maintaining their sensory characteristics (Chhikara & Kumar, 2022).

Among the protein sources that can be used to obtain coatings are animal proteins. In particular, whey proteins are obtained from casein and cheese production. They can be concentrated or isolated depending on the protein content (20%–80% and >90%, respectively). These proteins can form flexible, transparent, tasteless, and oxygen-impermeable films but are ineffective due to water vapor permeability (Costa et al., 2018). However, studies have shown that mixing whey proteins with water and glycerol resulted in a flexible and water-resistant material (Chen et al., 2019; Srour et al., 2016). Purified proteins from cereals can also be used for film/coating formation. Soy proteins show an effective oxygen barrier, antimicrobial activity, reduce moisture loss and lipid oxidation (Zhang et al., 2018). However, soy proteins applied alone have poor mechanical properties and high water solubility. Blending with other biodegradable polymers, such as gelatin and caseinate, is a promising method to improve the mechanical properties of the coating/film (Zhao et al., 2020).

Lipid-based edible coatings/films are another alternative for food preservation. These compounds can be of plant or animal origins. Lipids, being lipophilic, exhibit a high barrier capacity against moisture loss (Hassan et al., 2018). The lipids classes also include essential oil that exhibits an antioxidant and antimicrobial activity when added in coating/film formulation (Ju et al., 2019).

The application of one or more of the above-mentioned compounds allows coatings/films or composite coatings/films to limit food spoilage and increase shelf-life.

3 | PLANT-DERIVED EXTRACTS AND ESSENTIAL OILS

Plant EXs and EOs in coating formulations are widely used nowadays to delay food deterioration. Plant compounds are derived from spices and seeds (cinnamon, cumin, clove, turmeric, papaya seed, and cardamom), leaves and flowers (tea, kecombrang, kaffir lime, and kesum), herbs (oregano, rosemary, basil, coriander, thyme, and mint), but also from fruit and vegetable waste and byproducts (garlic, fennel, orange, and cucumber). These matrices of plant origin have a high amount of secondary metabolites, such as phenols, flavones, terpenes, ketones, aldehydes, and alcohols (Butnariu, 2021; Chiocchio et al., 2021). In traditional medicine, plants are described for their health properties like antioxidant, antimicrobial, antiseptic, anti-inflammatory, analgesic, stimulant, digestive, and lenitive effects (Guarrera & Savo, 2013). Subsequently, plant-derived extracts have been used as a source of bioactive compounds also in food industry.

Principal application of plant EXs/EOs in food formulation is for their antioxidant and antimicrobial power. Depending on quantity added to food, they can exhibit antioxidant activity and retard the growth of pathogenic microorganisms (Tongnuanchan & Benjakul, 2014). EXs and EOs act on the cell structure and vital activities of pathogens by limiting their growth. Gram-positive bacteria are more susceptible to the effects of EXs/EOs than gram-negative bacteria due to the less complex structure that protects the internal constituents of the cell (da Cunha et al., 2018). Bioactive compounds can modify cell membrane permeability or destroy membranes with subsequent release of cell contents. It can also act by modifying DNA and RNA synthesis. Moreover, the antioxidant activity, exhibited mainly by polyphenolic compounds in plant matrices, reduces free radical scavenging, limits lipid oxidation, and peroxide formation in food (Blasi & Cossignani, 2020).

3.1 | Herbs, leaves, and flowers

Herbs and leaves are the leafy green part of a plant that does not develop persistent woody tissue. Together with the flowers they account for the aerial part of the plants. The aromatic herbs present high diversity of volatile, aromatic, and low-molecular-weight compounds which can be extracted for pharmaceutical, cosmetic, and food applications (Kumar et al., 2018).

The oregano and thyme contain phenolic compounds such as carvacrol (53.4%), borneol (6.1%), linalool (4.8%), thymol (4.5%), sesquiterpene hydrocarbons (8.8%), and oxygenated sesquiterpenes (8.2%) as the major substances. They are widely used as food additives due to their antioxidant action and antimicrobial effect against gram-positive and gram-negative bacteria (Diego et al., 2015). In particular, carvacrol is able to disintegrate the outer membrane of gram-negative bacteria, releasing lipopolysaccharides and increasing the permeability of the cytoplasmic membrane to ATP. In gram-positive bacteria, it alters their cation permeability (Burt, 2004). The rosemary herb consists of eucalyptol, α-pinene, borneol, terpineol, myrcene, and camphene. They allow the destruction of the cell membrane of bacteria and an antioxidant action. Eucalyptol (1,8-cineole) is the major constituent (15%–50%), exhibiting anti-inflammatory activities, that occurs by suppression of lipopolysaccharide-induced proinflammatory cytokine production, and reduction of oxidative stress through radical scavenging activity and regulation of signaling pathways (Do Nascimento et al., 2020). Herbs include basil that show linalool (31.66%), methyl chavicol (17.37%), and methyl cinnamate (15.14%) as major constituents. Several studies on basil highlighted its beneficial effects, in particular, antifungal activity against different fungal species, such as *Candida albicans* and *Cryptococcus neoformans*, and a strong antioxidant activity (11.23 to 55.15 mg/mL) (Ahmed et al., 2019; Carrasco et al., 2012). Mint herb counts numerous bioactive compounds. Particularly, in EOs was found limonene (1%–7%), isomenthone (2%–8%), menthofuran (1%–10%), menthyl acetate (2%–11%), 1,8-cineole (eucalyptol) (5%–13%), menthone (15%–32%), and menthol (33%–60%). Due to the high phenols content, 335.4 mg GAE (Gallic Acid Equivalents)/100 g, mint performs an antioxidant action and an inhibition of *Salmonella typhimurium* and *Escherichia coli O157:H7* (Wani et al., 2022). Several studies have showed the bioactivity of laurel. Eucalyptol was the most abundant monoterpenoid (25%–60%) present in laurel, follow by a-pinene (2.5%–32%), sabinene (0.07%–13%), and linalool (0.1%–18%) (Anzano et al., 2022). These compounds enable the inhibition of the growth of *Enterobacteriaceae, Staphylococcaceae*, and *Pseudomonadaceae*. Particularly, linalool retards the overall development and propagation of different fungi through the respiratory restriction of their aerial mycelia (Anzano et al., 2022).

Tea is among the leaves most commonly used in medicine and food. It is very rich in flavonoids (20.63 mg/g), catechins (136.72 mg/g), and polyphenols compounds (217.10 mg/g) (Ma et al., 2022). They have been shown to suppress the growth of important pathogens such as *Staphylococcus aureus*, *E. coli, Listeria monocytogenes, S. typhimurium, Clostridium perfringens*, and *Pseudomonas aeruginosa* (Grzesik et al., 2018). Although less well known, the leaves and flowers of *Cornus officinalis*, kaffir lime, kecombrang, kesium, artemisia, *Moringa oleifera, Paulownia tomentosa*, pine needle, *Pimpinella saxifraga, Rubia cordifolia, Portulaca oleracea, Roselle calyx, Santolina chamaecyparissus*, and *Terminalia arjuna*, have bioactive constituents that exert antioxidant and antimicrobial activities (Table 1).

3.2 | Spices and seeds

The spices are derived from plants and present aromatic or pungent substances that are used to flavor foods. The harvest period, type of processing, drying, and storage condition can change bioactive compounds content. Several spice plants present EOs described by their antioxidant and antimicrobial activity, which depend on their chemical composition (Do Nascimento et al., 2020).

The terpenes, alcohols, phenols, and aldehydes are the major classes present in cumin. Particularly, cuminaldehyde, eugenol, and *b*-pinene showed a complete inhibition zone against different gram-negative and gram-positive bacteria including *Penicillium citrinum, Bacillus cereus, Bacillus subtilis, S. aureus*, and *P. aeruginosa*. Among the constituents there is carvacrol. Several studies have demonstrated its antioxidant potential (Mnif & Aifa, 2015). Clove (*Syzygium aromaticum*) is a spice that contains approximately 15%–20% of EO. It is characterized by high levels of eugenol (50%), followed by eugenyl acetate, β-caryophyllene, α-humulene, diethyl phthalate, caryophyllene oxide, cadinene, α-copaene, 4-(2-propenyl)-phenol, chavicol, and α-cubebene. Eugenol, the major constituent, showed an antimicrobial, anti-inflammatory, antioxidant, and anticancer activity. Instead, eugenyl acetate has a potent antioxidant activity; it showed 90.30% DPPH free radical scavenging at 35 μg/mL (Haro-González et al., 2021). The *Zingiberaceae* family includes cardamom and ginger. Cardamom seeds are rich sources of quercetin, kaempferol, and luteolins that neutralize free radicals by preventing oxidation of other components. The profiling of EO of cardamom exhibited the presence of 1,8-cineole (28.94%), α-terpinyl acetate (26.7%), α-terpineol (14.6%), sabinene (13.5%), nerol (5.0%), and α-pinene (2.4%). The application of 10 mg/mL of EO showed antibacterial activity against *S. aureus, E. coli, Salmonella typhi, Streptococcus mutans, Bacillus pulmilus*, and *L. monocytogenes* (Ashokkumar et al., 2020). Otherwise, the bioactivity of ginger is given by the presence of phenolic compounds (6-gingerol, 8-gingerol, 10-gingerol, quercetin, zingerone, gingerenone-A, and 6-dehydrogingerdione) and terpens (β-bisabolene, α-curcumene, zingiberene, α-farnesene, and β-sesquiphellandrene). Different studies showed a strong antioxidant and antimicrobial activity. Especially, gingerenone-A and 6-shogaol exhibited an in vitro inhibitory effect on *S. aureus* thanks to the inhibition of 6-hydroxymethyl-7,8-dihydropterin pyrophosphokinase in the pathogen (Mao et al., 2019). Other spices like curcuma, anise, and pimento showed bioactive compounds than displayed functional properties (Jarquín-Enríquez et al., 2021; Yu et al., 2021; Zhang et al., 2017).

3.3 | Agri-food byproducts

Fruit and vegetable industry produces a significant quantity of waste and byproducts, representing 10% to 35% of the gross mass (Majerska et al., 2019). The potential of byproducts refers to the presence of bioactive compounds to be added in food formulation (Difonzo et al., 2023).

Cucumber peel is a good source of dietary fiber and phytochemicals compounds such as polyphenols (8.51 mg/g), glycosides (32.23 mg/g), terpenoids (26.27 mg/g), and steroids (11.69 mg/g). Numerous studies showed antioxidant, anti-carcinogenic, anti-inflammatory, anti-hyperglycemic, diuretic, antimicrobial, and analgesic effects (Uthpala et al., 2020). Fennel is an important *Apiaceae* species from the Mediterranean area and is among the most widespread medicinal plant worldwide. In particular, fennel seeds are considered also as source of many health beneficial compounds including gallic, caffeic, and ellagic acid, quercetin, kaempferol, minerals, vitamins, and others which explain their applications for pharmaceutical and food industries. Fennel EO was obtained from seeds. The main volatile active compounds are *trans*-anethole (70.7%), and fenchone followed by anisketone and *p*-anisaldehyde. These bioactive compounds displayed an antioxidant activity (35.85–60.36 Trolox Equivalent μmol/g), and an antimicrobial activity particularly against *S. aureus* (Ahmad et al., 2018). Garlic is one of the most important vegetables throughout the world. Among the byproducts of this vegetable are the leaves that contain a large amount of sulfur compounds. These are responsible for the renowned medicinal properties of garlic, such as anticancer, antidiabetic, anti-inflammatory, antimicrobial, antioxidant, cardioprotective, and immunomodulatory activities. Further significant volatile compounds with highly bioactive properties are ajoenes, as well as allicin, 1,2-vinyldithiine, allysine, and S-allylcysteine, and sulfides, such as mono-, di-, tri- and tetra-sulfides of diallyl, methyl, and dipropyl, which are formed after the decomposition of thiosulfates. In nature, these compounds are used by plants in defensive mechanisms against parasites and pathogens.

TABLE 1 Plant products, their bioactive compounds and actions. List obtained by considering the main extracts and essential oils used in edible coatings and films analyzed in this collection.

Product	Bioactive compounds	Reference
Anise	*Trans*-anethole, terpenoids, polyphenols, coumarins, scopoletin, umbelliferon, terpene hydrocarbons	(Yu et al., 2021)
Artemisia	Monoterpenes, sesquiterpenes, hydrocarbons, polyphenols	(Nigam et al., 2019)
Basil	Phenolic acids, quercetin, anthocyanins, vitamins, minerals, linalool, methyl chavicol, methyl cinnamate, eugenol	(Do Nascimento et al., 2020)
Black cumin	Phenolic compounds, monoterpenoids, *p*-cymene	(Hassanien et al., 2015)
Boldo	Alkaloids, proanthocyanidins, flavonoids, tannins, coumarins, terpenoids	(Mariano et al., 2019)
Cardamom	Quercetin, kaempferol, luteolins,1,8-cineole, α-terpinyl acetate, α-terpineol, sabinene, nerol, α-pinene, flavonoids, tannins, phenolic compounds, tocopherols	(Ashokkumar et al., 2020)
Cinnamon	Cinnamaldehyde, cuminaldehyde, β-carotene, eugenol	(Do Nascimento et al., 2020)
Clove	Eugenol, eugenyl acetate, β-caryophyllene, α-humulene, diethyl phthalate, caryophyllene oxide, cadinene, α-copaene, 4-(2-propenyl)-phenol, chavicol, α-cubebene	(Haro-González et al., 2021)
Coriander	Sterols, unsaturated fatty acids, tocopherols, linalool, terpinene, geranyl acetate, phenolic acids, flavonoids	(Laribi et al., 2015)
Cornus officinalis	β-carotene, triterpenoid, phenols	(Park et al., 2022)
Cucumber peel	Polyphenols, glycosides, terpenoids, steroids, dietary fibers, minerals	(Uthpala et al., 2020)
Cumin	Cuminaldehyde, eugenol, *b*-pinene, terpenes, phenols, flavonoids	(Mnif & Aifa, 2015)
Curcuma	Terpenes, α- and β-turmerone	(Lanyue Zhang et al., 2017)
Fennel	Phenolic acids, quercetin, kaempferol, minerals, vitamins, trans-anethole, fenchone, anisketone, p-anisaldehyde	(Ahmad et al., 2018)
Garlic	Organosulfur (allicin), phenolic acids	(Martins et al., 2016)
Ginger	Phenols (gingerols, shogaols, paradols, quercetin, zingerone, gingerenone-A, 6-dehydrogingerdione), terpenes (β-bisabolene, α-curcumene, zingiberene, α-farnesene, β-sesquiphellandrene)	(Mao et al., 2019)
Green tea	Alkaloids, polyphenols, phenolic acids	(Xu et al., 2019)
Kaffir lime leaves	Limonene, citronellol, terpinen-4-ol, α-pinene, *p*-cimene, phenolic compounds, α-tocopherol, limonoids, dietary fiber, glycerolipids, coumarins	(Agouillal et al., 2017)
Kecombrang leaves and flowers	Polyphenols, alkaloids, flavonoids, steroids, saponins	(Naufalin et al., 2021)
Kesum leaves	Phenolic acids, caryophyllene, dodecanal, decanal, drimenol, α-caryophyllene, quercitrin, scutellarein-7-glucoside, tannins, catechins, flavonoids	(Ain et al., 2022)
Laurel	Flavonoids, organic acids, polyunsaturated fatty acids, tocopherols, 1,8-cineole, camphene, limonene, p-cymene, linalool, α-pinene, α-terpinene, α-terpineol	(Anzano et al., 2022)
Mint	Limonene, isomenthone, menthofuran, menthyl acetate, 1,8-cineole (eucalyptol), menthone, menthol	(Wani et al., 2022)

(Continues)

TABLE 1 (Continued)

Product	Bioactive compounds	Reference
Moringa oleifera	Vitamins, terpenoids, polyphenols, flavonoids, glucosinolates, alkaloids, glycosides, carotenoids	(Vergara-Jimenez et al., 2017)
Orange peel	Vitamin C, carotenoids, phenolic acids	(Wedamulla et al., 2022)
Oregano	*p*-Cymene, carvacrol acetate, borneol, thymol, linalool, sesquiterpene hydrocarbons, oxygenated sesquiterpenes, flavonoids, polyphenols	(Do Nascimento et al., 2020)
Papaya leaves and seeds	Alkaloids, sulfur compounds, flavonoids, triterpenes, organic acids, tannins	(Ananthanayagi et al., 2022)
Parijoto	Flavonoids, alkaloids, saponin, tannins, β-carotene	(Milanda et al., 2021)
Paulownia tomentosa	Syringin, flavonoids, phenols, thymol, phytol	(He et al., 2016)
Pimento	Eugenol, gallic acid, quercetin, rutin	(Jarquín-Enríquez et al., 2021)
Pimpinella saxifraga	Terpenoids, polyacetylene compounds, phenolic compounds, coumarins, tannins, flavonoids, phenolic acids, vitamins	(Slobodianiuk et al., 2021)
Pine needle	Quercetin, catechin, kaempferol, myricetin, resveratrol, glycoside, pinoresinol, α-pinene, β-pinene, β-phellandrene, α-terpineol, camphene	(Dziedziński et al., 2021)
Portulaca oleracea	α-Tocopherol, ascorbic acid, β-carotene, lutein, zeaxanthin, phenolic compounds, flavonoids, lignins, stilbenes, terpenoids, saponins, tannins	(Petropoulos et al., 2016)
Pu-erh	Polyphenols, catechins, gallic acid, flavonoids, caffeine, dietary polysaccharides	(Liu et al., 2021)
Roselle calyx	Phenolic acids, flavonoids, anthocyanins, organic acids	(Izquierdo-Vega et al., 2020)
Rosemary	Eucalyptol, β-pinene, α-pinene, borneol, γ-cadinene, α-terpineol, myrcene, camphene, phenols, triterpenes, triterpenic acids, flavonoids, phenolic acids	(Senanayake, 2018)
Rubia cordifolia	Alkaloids, saponins, tannins, phenols, glycosides, terpenes, carotenoids, quinones	(Humbare et al., 2022)
Sage	Phenolic acids, tannins, α and b-thujone, 1,8 cineole, camphor, flavones, phenylpropanoid glycosides, triterpenoids, diterpenes, tocopherols, carotenoids	(Živković et al., 2017)
Santolina chamaecyparissus	Flavonoids, phenolic compounds, terpenoids	(Aourach et al., 2021)
Terminalia arjuna	Tannins, glycosides, triterpenoid saponin, flavonoids, gallic acid, ellagic acid, oligomeric proanthocyanidines, phytosterols, minerals	(Gupta et al., 2018)
Thyme	*p*-Cymene, carvacrol acetate, borneol, thymol, linalool, sesquiterpene hydrocarbons, oxygenated sesquiterpenes, flavonoids, polyphenols	(Do Nascimento et al., 2020)
White tea	Caffeine, epigallocatechin, flavonoids, catechins, phenolic compounds, amino acids	(Ma et al., 2022)
Yerba mate	Polyphenolic acids, xanthines, flavonoids, minerals, vitamins	(Aleksandra et al., 2021)

Furthermore, it was proved that garlic oil can damage the membrane functions of both gram-positive and gram-negative bacteria like *B. cereus, E. coli, L. monocytogenes, S. typhimurium*, and *S. aureus* (Martins et al., 2016). The citrus processing industries generate a large amount of citrus waste, approximately 50%–60%. Orange peel is very rich in polyphenolic compounds that protect fruit against UV and IR rays of the sun, and microbial infections. Phenolic compounds in citrus peel include *p*-cinnamic, ferulic, synaptic, isoferulic, 5-hydroxyvaleric, vanillic, and 2-oxybenzoic acid. Flavonoid compounds perform antioxidant, anti-carcinogenic, and anti-inflammatory activities and induce lipid antiperoxidative effects. Orange peel has also been identified as an excellent source of pectin, a fiber with high phenols as a natural preservative in foods for the capacity to control lipid oxidation (Wedamulla et al., 2022). Also, parijoto and papaya leaves and seeds, present alkaloids, flavonoids, polyphenols, quinones, saponins, and tannins that exhibit antimicrobial activity against *Bacillus stearothermophilus, L. monocytogenes, Pseudomonas spp.*, and *E. coli*, and antioxidant, anticancer, anti-inflammatory, anti-hypertensive, hepatoprotective, histaminergic, diuretic, and immunomodulatory properties (Ananthanayagi et al., 2022; Milanda et al., 2021).

4 | APPLICATION OF EDIBLE COATINGS

The potential of the plant-based EXs and EOs refers to the presence of bioactive compounds and their beneficial effect if added to food. Their quantity differs according to the type of EX or EO, the treatments, and the type of application. Several studies have shown the ability of edible coatings to increase the shelf-life of cheese, and processed meat and fish (Dehghan et al., 2021; Pluta-Kubica et al., 2020, 2021). This is due to the antioxidant activity exerted by the added EX/EO and the ability to inhibit the growth of pathogenic microorganisms (Gediko˘glu, 2022; Karunamay et al., 2020; Ríos-De-benito et al., 2021). In addition, a change in physico-chemical, sensory and texture characteristics was evidenced when products were stored with edible coating (Bashir et al., 2022; López-Córdoba, 2021).

The following chapters of this review will analyze the applications of the various edible coatings enriched with plant-based EXs/EOs in cheese, and processed fish and meat. The results regarding a change in antioxidant activity, antimicrobial activity, and an increase in shelf-life were discussed. Furthermore, the possible impact on the physico-chemical, and sensory characteristics of coated processed foods was highlighted. The main applications of edible coating with plant-based EXs/EOs in cheese, and processed fish and meat, their purpose, and results are summarized in Tables 2–4.

4.1 | Cheese

Cheese is dairy product that is very popular among consumers (Paszczyk, 2022). The easy spoilage of cheese, especially fresh cheese, is due to the high water content and high pH value, which allow easy microbial growth and weight loss of cheese if not stored properly (Iqbal et al., 2021). The weight loss of cheese during storage depends on the type of packaging used. It is necessary to store cheese with materials that have good permeability to water vapor, limiting the possibility of dehydration of the product. The resistance to oxygen and water is also useful in preventing the proliferation of bacteria and fungi that could grow quickly due to a matrix with optimal growth conditions. Many pathogens are able to develop during cheese storage (Khorshidian et al., 2018).

Edible coatings and films incorporating plant-based natural agents with antioxidant and antimicrobial potential have been investigated in the dairy sector for their ability to improve microbial safety and extend shelf-life of cheese by reducing oxygen and moisture transmission, limiting microbial contamination, and preserving technological features such as texture, color, and flavor. Considering the antioxidant activity, it limits the oxidation of lipids leading to the formation of hydroperoxides, which can result to the production of off-flavor. This phenomenon, followed by the release of fatty acids and increasing the microbial growth, can lead to qualitative decay and unacceptability (Wu et al., 2022). Several studies have demonstrated the high potential of edible coatings and films with EXs or EOs to preserve the quality of various cheeses.

Joseph-Leenose-Helen et al. (2022) showed that pine-needle EX in beeswax edible coating increased DPPH radical scavenging activity by about 7% in Kalari cheese (Joseph-Leenose-Helen et al., 2022). It is important to note that the antioxidant activity increased with the amount of EX, reflecting positively on the samples shelf-life. The power of pine-needle EX could be attributed to flavonoids, quercetin, catechin, resveratrol, and other bioactive compounds (Dziedziński et al., 2021). Mei et al. (2015) confirmed the antioxidant potential and compounds bioactivity adding pine-needle EOs (0.35% v/v) in chitosan-starch edible coating to preserve Bod Ljong cheese. In this case, the 2-thiobarbituric acid (TBA) assay values of the cheese were significantly lower during 25 days of storage in comparison to the uncoated cheese (0.55 mg malondialdehyde [MDA]/kg for coated cheese and 1.36 mg MDA/kg for uncoated cheese). In addition, a greater ability to counteract lipid oxidation was shown compared to *C. officinalis* EX and nisin applied in the same cheese formulation (Mei et al., 2015). Also, tea EX may be a natural antioxidant agent. Indeed, it has a high concentration of polyphenols, mainly catechins that may have antioxidant action when applied during food storage (Nain et al., 2022). Active edible furcellaran-whey protein coating with white tea EX exhibited antioxidant activity added at 20% w/w in the film formulation. This film was found to prolong the shelf-life of fresh soft cheese (Pluta-Kubica et al., 2020). The same trend was obtained with whey protein film enriched in 2.5% w/w of green tea EX to coat Latin-style fresh cheese. At TBA analysis, cheese samples packed with the active film had 3.2 and 3.7 mg MDA/kg sample, respectively,

TABLE 2 Influence of plant extracts and essential oils added in edible coatings and films on cheese characteristics.

Cheese type	Type	Formulation	Functional substance	Study and key finding	References
Latin-Style Fresh	Film	WP, GY	Green tea EX (2.5% w/w)	↓ Lipid oxidation, inhibition of mesophilic bacteria and *E. coli* growth.	(Robalo et al., 2022)
Quark	Film	Furcellaran, WP, GY	Green tea and Pu-erh EX (20% w/w)	↓ Water content, water activity. ↓ *S. aureus, Lactococcus* and TBC with green tea. ↑ pH, yeast. Negative influence on the organoleptic quality of cheese.	(Pluta-Kubica et al., 2021)
Eastern European curd	Coating	WP, GY, guar gum, tween, sunflower oil	Cinnamon EX (0.3% w/w)	Antimicrobial effect especially in vacuum-packaging condition. ↑ pH, lactic acid, water content, lactic acid bacteria, lightness, *a** and *b** value during storage. ↓ Protein content, hardness, TBC, yeast and mold. No difference in coliform, *Enterobacteria*, and *Staphylococcus* spp. Change in texture parameters. No negative effect on the cheese sensory evaluation.	(Mileriene et al., 2021)
Kashar	Coating	Natamycin, GY	Oregano and rosemary EOs (0.5%–1% w/w)	↓ Coliform, mold growth, proteolysis. ↑ Lactic acid bacteria (except with 0.5% of rosemary EO), pH, protein, shelf-life. High sensory score in cheese with oregano EO.	(Yangilar, 2017)
Minas frescal	Coating	SA, calcium chloride	Oregano (0.06% w/w) and rosemary (0.1% w/w) EOs	↓ Mass loss, ash, protein, lipids, microbial growth, *L* and *a** value. ↑ Moisture. High sensory score in cheese with oregano EO. Best performance for oregano EO.	(Pieretti et al., 2019)
Kashar	Coating	Sorbitol, WP, SA	Ginger EOs (1.5% v/v)	↑ Water and fat barrier. Bacteriostatic effect on *E. coli O157:H7* and a bactericidal effect on *S. aureus*.	(Kavas et al., 2016)
Kashar	Film	WP	Oregano and garlic EOs (2% w/v)	↑ Antimicrobial activity against *E. coli O157:H7, S. Enteritidis, L. monocytogenes, S. aureus, Penicillium spp*. ↓ Antimicrobial effect for garlic EO. ↑ Shelf-life of coating cheese.	(Seydim et al., 2020)
Fresh soft	Coating	Furcellaran, GY, WP	Yerba Mate and White tea EX (20% w/w)	↓ Water content, pH, yeast, mold and coliform bacteria. Small negative effect on the appearance and smell. Positively influenced the consistency of the cheese.	(Pluta-Kubica et al., 2020)
Gouda	Coating	WP	Black cumin EO (0.5% w/w)	↓ Growth of *Listeria, Enterobacter, Pseudomonas, E. coli*, lactic acid bacteria, lipid oxidation, peroxide value, pH. ↑ Odor and color score at sensory evaluation, free fatty acid, and shelf-life.	(Saravani et al., 2019)
Manchego	Coating	CH, tween 20 and 80, GY, L(β)-lactic acid	*Santolina chamaecyparissus* byproduct EX (1% w/v)	Antifungal and antioxidant capacities. ↓ Gas exchange.	(Elguea-culebras et al., 2019)

(Continues)

TABLE 2 (Continued)

Cheese type	Type	Formulation	Functional substance	Study and key finding	References
Semi-hard goat's cheese	Film	CH, acetic acid	Rosemary and oregano EO (1:0.5)	↓ Weight loss, free fatty acids. Double coated with oregano were the best evaluated in terms of aroma and flavor. Antifungal effect from oregano.	(Embuena et al., 2017)
Ricotta	Film	Gelatin, GY	*Moringa oleifera* EX (20 µg/mL)	↓ Weight loss, lipid peroxidation, gel strength, cohesiveness, springiness, chewiness, b^* value, psychrophilic bacteria, mesophilic bacteria, yeasts and molds growth. ↑ pH, lightness, texture during storage.	(Mezhoudi et al., 2022)
Coalho	Coating	Polysorbate 80	*Caesalpinia pulcherrima* galactomannan (1%, 2% w/v) *Cymbopogon citratus* EO (0.2%, 0.5% v/v)	↓ Weight loss, moisture, pH, totals coliform, aerobic mesophilic microorganisms, hardness, gumminess, chewiness. ↑ Adhesiveness. No difference for sensory analysis.	(Lima et al., 2021)
Kalari	Coating	Beeswax	Pine-needle EX (2:1, 1:1, 2:3 beeswax:EX)	DPPH, metal chelating, α-amylase inhibition and antibacterial potential of the coatings increased with the increase in EX concentration. ↑ color, texture, LAB counts, whereas the mold counts showed a significant inhibition. ↓ Taste, texture, flavor and ↑ appearance in sensory evaluation.	(Joseph-Leenose-Helen et al., 2022)
Karish	Coating	CH, acetic acid	Thyme EO free and liposomes (1%, 2% v/v)	↓ Total aerobic bacteria, total psychrotrophic bacteria and total yeast and mold counts. ↑ Moisture, titratable acidity, shelf life from 2 to 4 weeks.	(Al-moghazy et al., 2021)
Prato	Film	CH, gelatin	Boldo EX (1% v/v)	↑ Moisture content, b^* value, fat content. ↓ Lipid oxidation, total aerobic, coliform and psychrotrophic, lightness.	(Bonilla & Sobral, 2019)
Cream	Coating	Achira starch, GY, microcrystalline cellulose, tween 40	Garlic and oregano EO (4% w/w)	Antimicrobial effect. ↓ Weight loss. ↑ Score for sensorial attribute. Oregano EO maintains the desired hardness and color for cheese.	(Molina-Hernández, 2020)
UF	Coating	Gelatin, wheat starch, GY	Cucumber peel EX (3% w/w), cumin EO (0.5% w/w)	↓ Total viable count, psychotropic bacteria, and yeast-mold population, lipid oxidation, weight loss, hardness, TBA value, titratable acidity. ↑ pH, moisture, lipid, chemical stability, sensory acceptance.	(Esparvarini et al., 2022)
Low-fat	Coating	SA, mandarin fiber, tween 80	Oregano EO (1.5%, 2%, 2.5% w/w)	↓ Microbial growth, whiteness, texture parameters. ↑ Shelf-life, appearance stability, b^* value.	(Artiga-Artigas et al., 2017)

(Continues)

TABLE 2 (Continued)

Cheese type	Type	Formulation	Functional substance	Study and key finding	References
Ricotta	Film	Gelatin, GY	Orange peel pectin (90:10, 70:30, 50:50, v:v gelatin:pectin)	↑ Antimicrobial activity. Improvement of the physicochemical and textural properties.	(Jridi et al., 2020)
Bod ljong	Coating	CH, starch, GY, acetic acid, nisin	*Cornus officinalis* fruit EX (1% w/w), pine needle EO (0.35% v/v)	↓ Water loss, lipid oxidation. ↑ Antimicrobial activity, color and sensory stability.	(Mei et al., 2015)
Soft	Film	WP, GY	Rosemary and sage EXs (2% w/w)	↑ Total phenolic and flavonoid content in edible film. Protection from spoilage and pathogenic bacteria.	(Kontogianni et al., 2022)
Kareish	Coating	CH, acetic acid, gelatin, GY	Papaya leaves and thyme EX (2% w/w)	↓ Microbial growth, TBA. ↑ Antioxidant, shelf-life, desirable sensory attributes.	(Hassan et al., 2022)
Ras	Film	CH, acetic acid, guar gum	*Roselle calyx* EX (1%, 3%, 5% w/w)	Antioxidant and antimicrobial effect. ↑ Moisture, pH during storage, sensory and shelf-life. ↓ Dry matter, protein.	(El-Sayed et al., 2020)
Lor	Coating	WP, sorbitol	Mint EO (1%, 2%, 3%, 4% v/v)	↑ Antimicrobial effect, shelf-life, water, oxygen and fat barrier. ↓ Weight losses. 4% has a bactericidal effect.	(Kavas et al., 2015)
Panela	Coating	Sodium caseinate, CH, GY, mesoporous silica nanoparticles	Oregano EO 2% (w/w)	Inhibition of gram-positive and gram-negative bacteria. ↓ Acidification and moisture loss. ↑ pH.	(Ríos-De-benito et al., 2021)
Çökelek	Coating	Sorbitol, WP, SA, tween 20	Curcuma EO (1%, 2% v/v)	Good water barrier. ↓ *S. aureus, E. coli O157:H7*, yeast and mold.	(Kavas & Kavas, 2017b)
Çökelek	Coating	Sorbitol, egg WP, SA, tween 20	Basil EO (2% v/v)	↑ Antimicrobial activity, shelf-life. Bacteriostatic effect on *E. coli O157:H7* and a bactericidal effect on *S. aureus, L. monocytogenes*, yeast, and mold.	(Kavas & Kavas, 2017a)
Kashar	Coating	Egg WP, sorbitol, tween 20	Orange EO (2% v/v)	↓ Outer and inner cheese hardness, weight loss, pH, *E. coli O157:H7, L. monocytogenes, and S. aureus* growth.	(Kavas & Kavas, 2016)
Kashar	Coating and film	Egg WP, sorbitol, tween 20	Lavender EO (1%, 2% v/v)	Good water barrier. ↑ Acidity. ↓ weight loss, *S. aureus* and *E. coli O157: H7*.	(Gokhan Kavas et al., 2018)
Homemade	Coating	SA, GY, tween 80	Mint, artemisia, basil, rosemary EO (tween:EO 1:0.5 v/v)	↓ Weight loss, hardness, microbial growth, lipid oxidation. Protein oxidation ↓ with artemisia and mint and ↑ with rosemary and basil. Best sensory score with basil.	(Mahcene et al., 2021)

(Continues)

TABLE 2 (Continued)

Cheese type	Type	Formulation	Functional substance	Study and key finding	References
Lighvan	Coating	SA, collagen, GY	Cumin EO (4%, 6%, 8% w/w)	↓ Lightness, water loss, hardness. ↑ a^* and b^* color value, moisture, thickness, water solubility, water vapor permeability, antioxidant activity. No negative effect on organoleptic acceptance.	(Ahmadimaram & Mostaghim, 2021)
Paneer	Film	Carboxymethyl cellulose, starch, GY	Oregano and clove EO (0.5% w/w)	Best performance of oregano EO and ↑ microbiological, physic-chemical stability and shelf-life (+5–6 days).	(Karunamay et al., 2020)
Queso Blanco	Film	WP, GY	Oregano EO (3% w/w)	↓ Lipid oxidation, yeast and mold counts, lightness and a^* color parameters. ↑ b^* color parameters.	(Gurdian et al., 2017)
Iranian	Film	Soy protein isolate, GY	Cardamom EO (1, 5, 10%, 20% w/w)	↓ Total count bacteria, coliform, *E. coli*. ↑ Odor and flavor, color, sensory acceptance.	(Hajirostamloo et al., 2022)
Béja Sicilian	Coating	SA, GY	*Pimpinella saxifraga* EO (1%, 2%, 3% w/w)	↓ Weight loss, lipid peroxidation, pH, mesophilic bacteria, lactic bacteria. ↑ Lightness, a^* and b^* value.	(Ksouda et al., 2019)

Abbreviations: ↑, increase; ↓, decrease; CH, chitosan; EO, essential oil; EX, extract; GY, glycerol; SA, sodium alginate; TBC, total bacteria count; WP, whey protein.

while those packed with the control film had 4.2 and 4.4 mg MDA/kg sample, respectively (Robalo et al., 2022). Considering lipid oxidation, Bonilla et al. (2019) tested 1% v/v boldo EX in gelatin-chitosan edible film obtaining a significant reduction in peroxide number (1.80 meq/kg of fat in functional cheese and 4.15 meq/kg in the control sample) in coated Prato cheese (Bonilla & Sobral, 2019). While, green tea EX added in whey protein edible coating at 2.5% w/w to preserve fresh goat cheese showed a reduction in TBA assay (3.2–3.7 mg MDA/kg in functional samples and 4.2–4.4 mg MDA/kg in control sample) (Robalo et al., 2022). The application of black cumin EO also intensified the barrier properties of whey protein edible coating by inhibiting lipid oxidation of gouda cheese (Saravani et al., 2019). *M. oleifera* EX in ricotta cheese and cucumber peel EX and cumin EO in ultrafiltered cheese were also shown to be effective in counteracting lipid oxidation (Esparvarini et al., 2022; Mezhoudi et al., 2022). Also oregano EO are able to limit oxidation during storage. This is confirmed by Gurdian et al. (2017) that adding 3% w/w in edible film to preserve Queso cheese significantly limits lipid oxidation during 60 days of storage. Contrasting results have been found by Machene et al., that investigated the effect of different EOs on the protein oxidation of cheese. The sulfhydryl group (SH) and the disulfide bonds (S—S) are important for maintaining the structure and functions of native proteins. In particular, they highlighted a decrease in protein oxidation when artemisia and mint EOs were applied. Instead, rosemary and basil EOs increased the protein oxidation of cheese at 10 days of storage (0.87 compared to the uncoated sample 0.67 MM) (Mahcene et al., 2021).

Considering the antimicrobial effect showed by EXs and EOs, the addition of 2.5% w/w of Portuguese green tea EX in whey-based protein film for preservation of Latin-style fresh cheese decreased the growth of mesophilic microorganisms compared with the film without EX (2.9 × 10^6 and 1.1 × 10^7 CFU/g, respectively). Same trend was noted for *E. coli* counts (Robalo et al., 2022). However, Pluta-Kubica et al. (2020, 2021) applied 20% w/w of white and green tea EX in furcellaran-whey protein film for the preservation of fresh soft rennet-curd cheese and acid-curd cheese. In both cheeses, there was no change in total bacterial count (TBC). The main microorganisms highlighted with TBC were found to be lactic acid bacteria. Thus, this indicates that edible film does not limit the growth of non-degrading microorganisms. In contrast, yeasts decreased with the application of functional film in fresh soft rennet-curd cheese and increased in acid-curd cheese. This highlights that acid-curd cheese is a more favorable matrix for yeast development than presamic cheese. Thus, the tea EX concentrations applied in the acid-curd cheese study were not sufficient to improve

TABLE 3 Influence of plant extracts and essential oils added in edible coatings and films on processed meat characteristics.

Processed meat type	Type	Formulation	Functional substance	Study and key finding	References
Ready-to-eat Carbonado chicken	Coating	CH, gelatin, corn germ oil, tween 80	Rosemary EX (2% w/w)	↑ Of 6 days of meat shelf-life with nanoemulsion-based coating. ↓ TBC, mold and yeast counts, TBA values and pH.	(Huang et al., 2020)
Ready-to-eat spiced chicken meat	Coating	Carboxymethyl cellulose	Garlic EX (50% w/v)	↓ Microorganisms growth, protein and lipid oxidation. Good appearance and taste.	(Diao et al., 2020)
Chevon sausages	Film	Maltodextrin, SA, GY	*Terminalia arjuna* EX (0.5%, 1% w/w)	↓ pH, TBA, total plate counts, psychrophilc, yeast and mold count, free fatty acids, lipid oxidation. ↑ Moisture, sensory score.	(Kalem et al., 2018)
Hamburger patties	Film	CH, sodium tripolyphosphate	Green tea EXs (0.5% w/w)	↓ Lipid oxidation, pH, moisture, lightness, *a** and *b** value, and total mesophilic aerobic counts, coliform bacteria, yeast and mold.	(Özvural et al., 2016)
Cooked meatballs	Film	WP, GY	Laurel and sage EX (2, 4% v/v)	↑ Total polyphenol content, antioxidant activity, *a** and *b** value with all EX. ↓ Lightness, peroxide value, conjugated diene, para-anisidine and TBA in meat. To improve the acceptability and sensory properties of the meatballs.	(Akcan & Est, 2017)
Ready-to-cook pork chops	Coating	CH, tween 80	Nanoencapsulated *Paulownia tomentosa* EO (1:1 w/w)	↓ pH, microbial growth and TBA. ↑ lipid oxidation stability. Good sensory properties.	(Zhang et al., 2019)
Ready-to-eat chicken patties	Coating	Gelatin, CH, tween 80	Cinnamon EO (0.5% w/w) and rosemary EX (1% w/w)	↓ pH, TVB, total volatile basic nitrogen, TBA and moisture loss. ↑ Shelf-life (+4 days).	(Qiu et al., 2022)
Sliced bolognas	Coating	Pectin, GY, tween 80	Thyme and thymbra EO and EXs (0.5, 1% w/v)	EO ↓ *S. typhimurium*, total aerobic bacteria, lactic acid bacteria, yeast and mold. ↑ lipid oxidation, shelf-life (+6 days). EX not provide antioxidant activity.	(Gediko˘glu, 2022)
Portuguese sausages (paínhos and alheiras)	Coating	WP, GY	Oregano EO (1% w/w)	↑ Shelf life (20 and 15 days for paínhos and alheiras, respectively). ↓ Total microbial load. ↑ pH and color. Good texture and sensory properties.	(Catarino et al., 2017)
Pork meat patties	Coating	CH, tween 80, GY	Fennel EO	↑ Antimicrobial effect, elasticity, chewiness and shelf-life (+4 days). ↓ lipid and protein oxidation, sulfides hardness.	(Sun et al., 2021)

(Continues)

TABLE 3 (Continued)

Processed meat type	Type	Formulation	Functional substance	Study and key finding	References
Chicken patties	Coating	CH	Clove EO (0.5% w/w)	↑ Lightness, b^* value, antioxidant activity, antimicrobial and shelf life (+20 days). ↓ pH, protein and lipid oxidation, a^* value, chroma, browning value, tyrosine, *Staphylococcus aureus*.	(Shukla et al., 2020)
Chicken burger	Film	CH, GY, tween 80	Anise EO (0.5%, 1%, 1.5%, 2% v/v)	↓ Lipid oxidation, water loss, TBA. At 1.5 and 2% ↓ microbial growth and ↑ sensory evaluation.	(Mahdavi et al., 2018)
Lamb patties	Coating	SA	Thyme and oregano EO (0.1%, 0.05% w/w)	↓ Weight losses, pH, lipid oxidation, lightness. ↑ a^* and b^* value, polyphenols and antioxidant activity in oregano EO. ↓ Flavor acceptability with thyme.	(Vital et al., 2021)
Chicken sausages	Film	CH, sorbitol	Parijoto fruit EX (0%, 2.5%, 5%, and 10% w/w)	↓ Microbiological and oxidative damages, TBA, smell, taste and texture parameters.	(Fatmawati & Susilowati, 2021)
Bologna-type sausage	Coating	WP, GY, wax	Thyme, rosemary, basil, pimento and coriander EO (4% w/v)	↑ Inactivation of *L. innocua* with pimento EO. ↑ Lightness and ↓ a^* value in all samples. Coatings containing thyme EO were the most sensory coating types.	(Kalkan & Ergİnkaya, 2020)
Cooked cured ham	Film	CH, GY, tween 80	*Thymus moroderi* and *Thymus piperella* EO (1%, 2% v/v)	Generally ↓ pH during storage and compared to the control. ↓ Aerobic mesophilic bacteria, lactic acid bacteria and lipid oxidation. ↑ Lightness, stability of sausages, shelf-life.	(Ruiz-Navajas, 2015)
Cooked ham	Film	CH, GY	Thyme EO (0.5%, 1%, 2%)	↓ pH to increase EO, microbial growth, exudate in the package. Change in color and sensory parameters (↓ ham odor).	(Quesada & Sendra, 2016)
Beef sausages	Coating	Durian starch, CH, GY	Kesum leaves EX (0.2%, 0.4%, 0.6%, 0.8%, 1%, 1.2%)	↓ Protein oxidation, total plate count. ↑ Shelf life.	(Lestari et al., 2022)
Chicken nuggets	Coating	SA, glycerin	Green tea EX (1% w/v)	↓ TBA, pH, peroxide, water loss. ↑ Sensory attribute, shelf-life (+5 days under refrigerated and +15 days in frozen condition).	(Kristam et al., 2016)
Chicken nuggets	Film	GY, SA, maltodextrin	*Rubia cordifolia* EX (0.5%, 0.75%, 1% v/v)	↑ Phenolic and flavonoid content, moisture, sensory acceptability. ↓ TBA, free fatty acids, pH, microbial growth (psychrophilic, anaerobic, yeast and mold count).	(Sharma et al., 2021)
Sausages	Film	CH, sorbitol	*Portulaca oleracea* EX (2.5%, 5%, 10% v/v)	↓ Microbial growth, oxidative damage.	(Qoeroti et al., 2021)

(Continues)

TABLE 3 (Continued)

Processed meat type	Type	Formulation	Functional substance	Study and key finding	References
Besto beef sausages	Coating	Tapioca flour, GY	Kaffir lime leaves EO (0.2%, 1.4% v/v)	↑ pH compared to control during storage. Modification of color parameter during storage. ↓ TBA, microbial growth. Best 0.2%.	(Utami et al., 2018)
Chicken patties	Film	Carrageenan, GY	Oregano (0.1% v/v) and thyme (0.15% v/v) EO	↓ TBA, pH, microbial growth (psychrophilic, *Staphylococcus aureus* and total plate count) during storage. ↑ Shelf-life (+5 days), sensory profile.	(Soni et al., 2018)
Beef sausages	Film	CH, WP, tween 80, GY	Garlic EO (2% v/v)	↓ TBA, peroxide, microbial growth. ↑ Sensory parameter.	(Esmaeili et al., 2020)

Abbreviations: ↑, increase; ↓, decrease; CH, chitosan; EO, essential oil; EX, extract; GY, glycerol; SA, sodium alginate; TBC, total bacteria count; WP, whey protein.

the microbiological quality of the cheeses (Pluta-Kubica et al., 2020, 2021). Among the most commonly used EOs in edible coating and film formulation we have oregano and rosemary EOs. Yangilar (2017) showed that the addition of 0.5% v/w oregano EO in edible coating for storage of Kashar cheese increased total aerobic mesophilic bacteria counts during 90 days of storage. A concentration of 1% v/w significantly reduced their growth. In the same study, it was shown that between rosemary and oregano EO, rosemary EO most inhibited coliform growth (Yangilar, 2017). EOs of oregano is able to reduce the growth of *E. coli O157:H7* by 1.48 Log and *S. aureus* by 2.15 Log during storage when applied in whey protein edible films for storage of Kashar cheese (Seydim et al., 2020). Furthermore, the presence of carvacrol in the EOs of oregano and rosemary exhibited high antifungal action for the genera *Penicillium* and *Mucor*. These results were highlighted by Embuena et al. (2017) in the preservation of goat cheese with edible chitosan film (Embuena et al., 2017). Kavas et al. showed the antimicrobial action of different EOs in edible coating to preserve Çökelek and Kashar cheeses. Particularly, ginger, curcuma, orange, and lavender EOs (1%–2% w/w) limited *E. coli O157:H7*, *L. monocytogenes*, and *S. aureus* growth (Kavas et al., 2016, 2017b, 2018). Otherwise, Mileriene et al. (2021) included 0.3% w/w of cinnamon EX in whey protein coating to preserve curd. In particular, the coating was applied alone or in combination with vacuum packaging. The results showed a strong antimicrobial effect of edible coating, especially in vacuum-packaging condition (Mileriene et al., 2021). Considering the antifungal power, Elguea-culebras et al. focused their study on improvement of antifungal activity by adding *S. chamaecyparissus* byproduct EX (1% w/v) in chitosan coating to preserve Manchego cheese. The results highlighted an increase in antifungal activity compared to the film without the EX and additionally, a reduction of gas exchange (Elguea-culebras et al., 2019).

The antioxidant and antimicrobial actions have a positive effect on the shelf-life of the cheeses. Several studies have obtained satisfactory results about the application of EXs/EOs in edible coatings/films for foods to extend shelf-life. In particular, in the majority of the studies, an increase in shelf-life was indicated as a result, but only a few studies quantified, by numbers of days, the increase in the shelf-life of the cheeses analyzed. Thyme EO added in edible coatings showed a 2 weeks increase in shelf-life when applied for the storage of Karish cheese (Al-moghazy et al., 2021). Instead, Karunamay et al. (2020) showed a 5–6 day increase in the shelf-life of Paneer cheese when coated with a film enriched with 0.5% (w/w) oregano and clove EOs (Karunamay et al., 2020).

Above the oxidation and microbial growth, the physicochemical parameters of cheese that are affected by edible

TABLE 4 Influence of plant extracts and essential oils added in edible coatings and films on processed fish characteristics.

Processed fish type	Type	Formulation	Functional substance	Study and key finding	References
Fish sausages	Coating	Gelatin	*Portulaca olearacea* EX (1.5% w/v)	↓ Lipid oxidation, pH. ↑ Protein content, ash, sensory parameters, antimicrobial and shelf-life.	(Dehghan et al., 2021)
Keropok lekor sausages	Coating	Starch, gelatin	Papaya seed EX (5%, 7% w/w)	↑ pH, moisture, lightness, *a** and *b** value, shelf-life (also with 5%). ↓ Lipid oxidation, microbial growth. Positive effect on fish color.	(Kadir & Mazlan, 2020)
Carp burger	Film	SA-GY, gelatin-GY, CH-GY	Sage EO (0.5% v/v)	Chitosan film best antioxidant activity and polyphenols content. ↓ Bacterial growth, lipid and protein oxidation, free fatty acids. Maintenance of quality parameters.	(Ehsani et al., 2019)
Salmon nigiri	Coating	Furcellaran, gelatin, GY	Green tea or pu-erh EX (20% v/v)	Not increase of shelf life, not statistical ↓ of microbial growth. ↓ pH, protein oxidation. ↑ Lightness, *a** and *b** value of salmon, ↓ lightness and *a** value and ↑ *b** of rice.	(Kulawik et al., 2019)
Gourami sausages	Coating	Carboxymethylcellulose, GY	Kecombrang leaves EX (1%, 2%, 3%, 4% v/v)	Best 4%. ↓ Total mold, yeast and bacteria count.	(Latifasari et al., 2019)
Catfish sausage	Film	Carrageenan, GY	Garlic EO (0.2%, 0.4%, 0.6%)	↓ TBA value, pH, protein oxidation. ↑ Aw.	(Dewi & Purnamayati, 2019)
Gourami sausage	Coating	Carboxymethylcellulose, GY	Kecombrang flower EX (1, 2, 3, 4%)	↓ Mold, *E. coli, P. aeruginosa, S. aureus and B. cereus.*	(Putri et al., 2019)

Abbreviations: ↑, increase; ↓, decrease; CH, chitosan; EO, essential oil; EX, extract; GY, glycerol; SA, sodium alginate; TBC, total bacteria count; WP, whey protein.

coating/film preservation with EXs/EOs include color. The phenolic compounds of EXs/EOs can cause light scattering and refraction, which leads to the production of darker films. This phenomenon was highlighted by Pluta-Kubica et al. (2020) that, coating fresh soft rennet-curd cheese with furcellaran/whey protein films with 20% w/w yerba mate and white tea EXs obtained lower brightness and higher yellow and green values than the control sample (Pluta-Kubica et al., 2020). Similar trend was obtained by Pieretti et al. (2019) that applied oregano and rosemary EOs in sodium alginate coating to preserve Minas frescal cheese (Pieretti et al., 2019). Opposite results were shown by Mezhoudi et al. (2022), that obtained higher brightness and lower yellow values by coating ricotta cheese with edible film from triggerfish gelatin and *M. oleifera* EX (Mezhoudi et al., 2022). In contrast, applying boldo EX in gelatin-chitosan edible film in Prato cheese kept brightness and red unchanged, with a significant increase in yellow (Bonilla & Sobral, 2019). Instead, Ahmadimaram et al. (2021) and Ksouda et al. (2019) have shown a correlation between color parameters and the amount of added extract. In particular, a higher concentration of *P. saxifraga* EO (1%, 2%, and 3% w/w) in sodium alginate coating caused an increase in lightness and yellowness and lower redness value in Béja Sicilian cheese (Ksouda et al., 2019). The higher amount of cumin EO added in alginate coating (4%, 6%, 8% w/w) induced a reduction in lightness and yellowness values and major redness values in Lighvan cheese (Ahmadimaram & Mostaghim, 2021).

The structural characteristics of products during storage are constantly subject to changes. Pine-needle EX in been wax edible coating for Himalayan cheese resulted in improved cheese texture. The hardness value of coated cheese increased significantly, but at the same time the hardness value was significantly lower than that of fresh cheese after 14 days. This showed the preservative effect of the coating on moisture retention. The coated cheese was also more cohesive during storage (Joseph-Leenose-Helen et al., 2022). Cucumber peel EX and cumin, basil, rosemary, artemisia, and mint EOs showed a similar trend limiting the moisture loss and hardness reduction of ultrafiltered and homemade cheeses (Ahmadimaram & Mostaghim, 2021; Esparvarini et al., 2022; Mahcene et al., 2021). The edible coating can improve the barrier properties of the film against water vapor permeability resulting in increased moisture content. This was confirmed by El-Sayed et al. (2020) which resulted in the maintenance of body and texture of Ras cheese during 4 months of ripening storage when coated with chitosan-*R. calyx* EX coating (El-Sayed et al., 2020). Orange peel pectin also showed a reduction in weight loss when added in the coating formulation during ricotta cheese storage. Indeed, at 7 days of storage, control cheese had 9.25% of weight loss while experimental cheese resulted in 0.47% of this parameter.

An important aspect in obtaining and applying new edible coatings and films is the sensory appreciation of the product. This is an essential aspect to consider, and a limitation when negative results are obtained from panel during the sensory analysis of an experimental product. Excessive oxidation can cause an unpleasant flavor, and additionally, accelerate protein breakdown and promote the deterioration of the product. In addition, EXs/EOs can bring sensory notes to the packaged product by changing its characteristics as perceived by the taster. In this regard, the publications analyzed showed conflicting results. The application of pine-needle EX in edible coating to preserve Himalayan cheese showed significantly higher scores for appearance and texture, especially when increasing the amount of EX. In contrast, flavor and taste showed lower values, probably due to the typical smell of pine needles (Joseph-Leenose-Helen et al., 2022). Similarly, cucumber peel EX and cumin EO incorporated in gelatin-starch coating resulting an increase of all attributes of sensory analysis (Esparvarini et al., 2022). It was shown, however, that in some cases, although the addition of the EX in edible coating was functional, it led to a reduction in the sensory acceptability of the product. This trend was showed with the application of green tea and Pu-erh EX in furcellaran-sodium alginate coating to preserve Quark cheese (Pluta-Kubica et al., 2021). Instead, other authors did not obtain significant differences to sensory analysis scores by adding *Cymbopogon citratus* EO to preserve Coalho cheese (Lima et al. 2021) and by adding cinnamon EX to preserve curd Mileriene et al. (2021).

4.2 | Processed meat and fish

Physico-chemical alteration of processed meat and fish during storage is a major cause of quality decay. Meat contains pro-oxidants such as myoglobin and hemoglobin that can promote oxidation of unsaturated lipids resulting in quality deterioration, subsequent discoloration, due to oxidation of heme proteins, and formation of unpleasant odor, for the production of volatile compounds (Richards, 2010). Similarly, fish spoilage includes biotechnological mechanisms that include enzymatic autolysis (proteolysis and lipolysis), chemical oxidation of unsaturated fatty acids, and microbial action, mainly psychrotolerant species, in the production of biogenic amines (Hussain et al., 2021). Indeed, edible coatings and films must exhibit good characteristics that limit quality decay of meat and fish. The addition of plant EXs/EOs in coating formulation for food preservation has proven to be efficient in counteracting degradation of food constituents.

As far as processed meat, the 0.5% w/w of green tea EX in chitosan edible coating was studied to coat hamburger patties. The results showed a three-fold lower lipid oxidation reduction in coated patties compared to the control sample (2.50 mg MDA/kg treatment for the control sample and 0.84 mg MDA/kg for coated patties, TBA assay) (Özvural et al., 2016). On the other hand, Kristam et al. (2016) added 1% w/v of green tea EX in alginate coating to preserve chicken nuggets achieving a reduction in TBA values and peroxide number, increasing the product shelf-life by 5 days when stored in refrigerated condition and by 15 days in frozen storage. Similar trend was highlighted by adding garlic, *T. arjuna* EXs, and oregano EO in coating to preserve ready-to-eat spiced chicken meat, Chevon sausages, and Portuguese sausages, respectively (Catarino et al., 2017; Diao et al., 2020; Kalem et al., 2018). In particular, their application limited protein and lipid oxidation without negatively affecting the sensory properties. Indeed, the addition of EXs or EO enhanced appearance and taste compared to the control samples (Diao et al., 2020; Kalem et al., 2018). Particularly, for the Portuguese sausages this was due to a reduction in color drift of the sausages when they were not coated, making the product more attractive. In addition, in the two sausages analyzed, *paínhos* and *alheiras*, the EO of oregano added to the coating increased shelf-life by 20 and 15 days, respectively (Catarino et al., 2017).

The application of green tea EX (20% w/w) in furcellaran-gelatin coating to preserve salmon nigiri significantly inhibited oxidation, resulting in a reduction of TBA at day 8 in the coated nigiri (0.81 vs. 0.47 mg MDA/kg in control sample and coated nigiri, respectively). However, the green tea EX significantly increased the growth of thermotolerant coliform bacteria (Kulawik et al., 2019).

Akcan et al. (2017) showed that enriching edible film with laurel or sage EXs at 2% and 4% v/v reduced the formation of conjugated dienes during frozen storage of cooked meatballs (Akcan & Est, 2017).

An alternative to the traditional application of EXs in edible coatings is nanoemulsion-based edible coatings. Nanoemulsion-based edible coating of rosemary EX as a new antimicrobial material effectively releases active compounds on the surface of products. This new technology was tested on ready-to-eat carbonado chicken and patties. Nanoemulsion-based edible coatings was more efficient in reducing TBC, mold, and yeast counts and stronger antimicrobial activity against *E. coli*, *B. subtilis*, and *S. aureus* than coarse emulsion. This reflected positively on the shelf-life which was increased by 4 and 6 days for carbonado chicken and patties, respectively (Huang et al., 2020; Qiu et al., 2022). Among the nanotechniques, we find the nanoencapsulation. The direct incorporation of EOs into edible coating for food preservation displays disadvantages like intense aroma, low water solubility, and high volatility. Encapsulation is a valid technology to improve the solubility and stability of EO, limiting strong flavor, control the release of bioactive compounds, and maintain their stability during food storage. In this regard, nanoencapsulation of *P. tomentosa* EO in chitosan coating showed a higher lipid oxidation stability of ready-to-cook pork chops, limiting a sensory decay during 15 days of storage (Zhang et al., 2019).

Ruiz-Navajas (2015) studied the antimicrobial effect of EO obtained from two endemic Spanish thyme species (*Thymus piperella* and *Thymus moroderi*) on different spoilage bacteria. EO was added in concentrations of 1% and 2% w/w in chitosan edible films for the preservation of cooked cured ham. They reported that *T. piperella* had a greater effect in inhibiting the growth of aerobic mesophilic bacteria than *T. moroderi*. This is probably due to the higher concentration of carvacrol in *T. piperella* (Ruiz-Navajas, 2015). The concentration of the EX added in edible coating for product preservation may be important for the antimicrobial activity exhibited. Kecombrang leaves and flowers EX applied in edible coating for preservation of gourami sausages showed antimicrobial activity for *E. coli, P. aeruginosa, S. aureus*, and *B. cereus*. In particular, a higher efficiency was shown by increasing the concentration of the added EX (Latifasari et al., 2019; Putri et al., 2019).

The antimicrobial activity against gram-positive bacteria such as *S. aureus, Listeria innocua*, and *B.cereus* has been highlighted by adding kecombrang flower EX, oregano, pimento, clove, and thyme EOs in coating for the preservation of sausages and patties (Kalkan & ErgİnKaya, 2020; Putri et al., 2019; Shukla et al., 2020; Soni et al., 2018). In particular, the antimicrobial action of oregano and thyme EO (0.1% v/v) in edible film increased shelf-life by 5 days when applied to chicken patties. Similarly, the action of clove EO in chitosan (0.5% w/w) coating increased the shelf-life of chicken patties by 20 days. The ability of thyme and thymbra EX to limit the growth of gram-negative organisms like *S. typhimurium* has been highlighted on the preservation of sliced bolognas, with an increase of 6 days of storage (Gedikoˇglu, 2022).

Despite the strong technological potential of the application of EX and EO in edible coatings to preserve processed meat and fish, one of the main obstacles still to be overcome is the negative impact on sensory characteristics. This was confirmed by Vital et al. (2021) that achieved lower flavor acceptability by using thyme EO to preserve lamb patties. Instead, parijoto fruit EX reduced smell, taste, and texture values when applied in chitosan coating to preserve chicken sausages (Fatmawati & Susilowati, 2021).

5 | CONCLUSION

This review highlighted the technological potential of several plant-based EXs and EOs applied in edible coatings and films for the preservation of cheese and processed meat and fish products. The application of most EXs and EOs showed effectiveness in contrasting quality decay by reducing oxidation of the constituents of various products. In addition, the antimicrobial activity by limiting the spoilage of the products, was highlighted. Furthermore, in some cases the physico-chemical characteristics of the preserved products were improved and the shelf-life increased. Thus, these preliminary results confirm the possibility of conducting further studies on the application of different EXs and EOs in edible coatings and films to preserve processed foods coatings. This approach would achieve the goal of increasing the shelf-life of products, then reduce food losses and pursue a circular and sustainable production system. Other studies are necessary to optimize the formulation of edible coatings and films to make them effective on the food preservation without compromising the main physical, chemical, and sensory features of foods.

AUTHOR CONTRIBUTIONS

Claudia Antonino: Writing—review and editing; writing—original draft. **Graziana Difonzo**: Conceptualization; writing—original draft; writing—review and editing. **Michele Faccia**: Writing—review and editing. **Francesco Caponio**: Writing—review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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REFERENCES

Agouillal, F., Taher, M. Z., Moghrani, H., Nasrallah, N., & El Enshasy, H. (2017). A review of genetic taxonomy, biomolecules chemistry and bioactivities of *Citrus hystrix* DC. *Biosciences, Biotechnology Research Asia*, *14*(1), 285–305. https://doi.org/10.13005/bbra/2446

Ahmad, B. A., Talou, T., Saad, Z., Hijazi, A., Cerny, M., Kanaan, H., Chokr, A., & Merah, O. (2018). Fennel oil and by-products seed characterization and their potential applications. *Industrial Crops and Products*, *111*, 92–98. https://doi.org/10.1016/j.indcrop.2017.10.008

Ahmadimaram, F., & Mostaghim, T. (2021). Evaluation of alginate/collagen edible coatings with betanin and cumin to improve the shelf life of Lighvan cheese. *Journal of Food Biosciences and Technology*, *11*(2), 69–84. https://jfbt.srbiau.ac.ir/article_17644.html

Ahmed, A. F., Attia, F. A. K., Liu, Z., Li, C., Wei, J., & Kang, W. (2019). Antioxidant activity and total phenolic content of essential oils and extracts of sweet basil (*Ocimum basilicum* L.) plants. *Food Science and Human Wellness*, *8*(3), 299–305. https://doi.org/10.1016/j.fshw.2019.07.004

Ain, N., Kiraman, S., & Yusof, H. (2022). A mini review on the methods for the extraction, isolation, and determination of *P. odorata*'s bioactive compounds. *Healthscope*, *5*(2), 38–44.

Akcan, T., & Est, M. (2017). Antioxidant protection of cooked meatballs during frozen storage by whey protein edible fi lms with phytochemicals from *Laurus nobilis* L. and *Salvia officinalis*. *LWT*, *77*, 323–331. https://doi.org/10.1016/j.lwt.2016.11.051

Al-moghazy, M., El-sayed, H. S., Salama, H. H., & Nada, A. A. (2021). Food bioscience edible packaging coating of encapsulated thyme essential oil in liposomal chitosan emulsions to improve the shelf life of Karish cheese. *Food Bioscience*, *43*, 101230. https://doi.org/10.1016/j.fbio.2021.101230

Al-Tayyar, N. A., Youssef, A. M., & Al-Hindi, R. R. (2020). Edible coatings and antimicrobial nanoemulsions for enhancing shelf life and reducing foodborne pathogens of fruits and vegetables: A review. *Sustainable Materials and Technologies*, *26*, e00215. https://doi.org/10.1016/j.susmat.2020.e00215

Ananthanayagi, N., Navamathavan, R., & Nirmala, R. (2022). Pharmacological activities and bioactive compounds of papaya (*Carica papaya* L.): A mini topical review. *International Journal of Green Pharmacy*, *16*(1), 35.

Anzano, A., de Falco, B., Grauso, L., Motti, R., & Lanzotti, V. (2022). Laurel, *Laurus nobilis* L.: A review of its botany, traditional uses, phytochemistry and pharmacology. *Phytochemistry Reviews*, *21*, 565–625. https://doi.org/10.1007/s11101-021-09791-z

Aourach, M., González-De-peredo, A. V., Vázquez-Espinosa, M., Essalmani, H., Palma, M., & Barbero, G. F. (2021). Optimization and comparison of ultrasound and microwave-assisted extraction of phenolic compounds from cotton-lavender (*Santolina chamaecyparissus* L.). *Agronomy*, *11*(1), 84. https://doi.org/10.3390/agronomy11010084

Artiga-Artigas, M., Acevedo-Fani, A., & Martín-belloso, O. (2017). Improving the shelf life of low-fat cut cheese using nanoemulsion-based edible coatings containing oregano essential oil and mandarin fiber. *Food Control*, *76*, 1–12. https://doi.org/10.1016/j.foodcont.2017.01.001

Ashokkumar, K., Murugan, M., Dhanya, M. K., & Warkentin, T. D. (2020). Botany, traditional uses, phytochemistry and biological activities of cardamom [Elettaria cardamomum (L.) Maton]—A critical review. *Journal of Ethnopharmacology*, *246*, 112244. https://doi.org/10.1016/j.jep.2019.112244

Bashir, S., Arshad, M. S., Khalid, W., Nayik, G. A., Al Obaid, S., Ansari, M. J., Moreno, A., & Karabagias, I. K. (2022). Effect of antimicrobial and antioxidant rich pomegranate peel based edible coatings on quality and functional properties of chicken nuggets. *Molecules*, *27*(14), 4500. https://doi.org/10.3390/molecules27144500

Blasi, F., & Cossignani, L. (2020). An overview of natural extracts with antioxidant activity for the improvement of the oxidative stability and shelf life of edible oils. *Processes*, *8*(8), 956. https://doi.org/10.3390/PR8080956

Bonilla, J., & Sobral, P. J. A. (2019). Gelatin-chitosan edible film activated with Boldo extract for improving microbiological and antioxidant stability of sliced Prato cheese. *International Journal *of Food Science and Technology*, *54*, 1617–1624. https://doi.org/10.1111/ijfs.14032

Burt, S. (2004). Essential oils: Their antibacterial properties and potential applications in foods—A review. *International Journal of Food Microbiology*, *94*(3), 223–253. https://doi.org/10.1016/j.ijfoodmicro.2004.03.022

Butnariu, M. (2021). Plants as source of essential oils and perfumery applications. In S. K. Upadhyay & S. P. Singh (Eds.), *Bioprospecting of plant biodiversity for industrial molecules* (pp. 261–292). John Wiley & Sons Ltd. https://doi.org/10.1002/9781119718017.ch13

Carrasco, H., Raimondi, M., Svetaz, L., Di Liberto, M., Rodriguez, M. V., Espinoza, L., Madrid, A., & Zacchino, S. (2012). Antifungal activity of eugenol analogues. Influence of different substituents and studies on mechanism of action. *Molecules*, *17*(1), 1002–1024. https://doi.org/10.3390/molecules17011002

Catarino, M. D., Alves-Silva, J. M., Fernandes, R. P., Jos, M., Salgueiro, L. R., Henriques, M. F., & Cardoso, S. M. (2017). Development and performance of whey protein active coatings with *Origanum virens* essential oils in the quality and shelf life improvement of processed meat products. *Food Control*, *80*, 273–280. https://doi.org/10.1016/j.foodcont.2017.03.054

Cazón, P., & Vázquez, M. (2020). Mechanical and barrier properties of chitosan combined with other components as food packaging film. *Environmental Chemistry Letters*, *18*(2), 257–267. https://doi.org/10.1007/s10311-019-00936-3

Chen, H., Wang, J., Cheng, Y., Wang, C., Liu, H., Bian, H., Pan, Y., Sun, J., & Han, W. (2019). Application of protein-based films and coatings for food packaging: A review. *Polymers*, *11*(12), 1–32. https://doi.org/10.3390/polym11122039

Chhikara, S., & Kumar, D. (2022). Edible coating and edible film as food packaging material: A review. *Journal of Packaging Technology and Research*, *6*(1), 1–10. https://doi.org/10.1007/s41783-021-00129-w

Chiocchio, I., Mandrone, M., Tomasi, P., Marincich, L., & Poli, F. (2021). Plant secondary metabolites: An opportunity for circular economy. *Molecules*, *26*(2), 495. https://doi.org/10.3390/molecules26020495

Chiralt, A., Menzel, C., Hernandez-García, E., Collazo, S., & Gonzalez-Martinez, C. (2020). Use of by-products in edible coatings and biodegradable packaging materials for food preservation. *Sustainability of the Food System*, *6*, 101–127. https://doi.org/10.1016/B978-0-12-818293-2.00006-9

Costa, M. J., Maciel, L. C., Teixeira, J. A., Vicente, A. A., & Cerqueira, M. A. (2018). Use of edible films and coatings in cheese preservation: Opportunities and challenges. *Food Research International*, *107*, 84–92. https://doi.org/10.1016/j.foodres.2018.02.013

da Cunha, J. A., Heinzmann, B. M., & Baldisserotto, B. (2018). The effects of essential oils and their major compounds on fish bacterial pathogens—A review. *Journal of Applied Microbiology*, *125*(2), 328–344. https://doi.org/10.1111/jam.13911

Dehghan, L., Zhaleh, T., Mohammad, K., & Azizi, H. (2021). Application of edible coating made of sturgeon gelatin and *Portulaca oleracea* extract for improving the shelf life of fish sausages. *Journal of Food Measurement and Characterization*, *15*(5), 4306–4313. https://doi.org/10.1007/s11694-021-01013-6

Dewi, E. N., & Purnamayati, L. (2019). Carrageenan and garlic essential oil edible film as protective coating on catfish sausage. *Omni-Akuatika*, *15*(2), 75. https://doi.org/10.20884/1.oa.2019.15.2.575

Diao, X., Huan, Y., & Chitrakar, B. (2020). Extending the shelf life of ready-to-eat spiced chicken meat : Garlic aqueous extracts-carboxymethyl chitosan ultrasonicated coating solution. *Food and Bioprocess Technology*, *13*, 786–796.

Diego, A., Melo, B., Amaral, A. F., Schaefer, G., Luciano, F. B., Andrade, C. D., Costa, L. B., & Rostagno, M. H. (2015). Antimicrobial effect against different bacterial strains and bacterial adaptation to essential oils used as feed additives. *The Canadian Journal of Veterinary Research*, *79*, 285–289.

Difonzo, G., Antonino, C., Squeo, G., Caponio, F., & Faccia, M. (2023). Application of agri-food by-products in cheesemaking. *Antioxidants*, *12*(3), 660. https://doi.org/10.3390/antiox12030660

Do Nascimento, L. D., de Moraes, A. A. B., da Costa, K. S., Galúcio, J. M. P., Taube, P. S., Costa, C. M. L., Cruz, J. N., de Aguiar Andrade, E. H., & de Faria, L. J. G. (2020). Bioactive natural compounds and antioxidant activity of essential oils from spice plants: New findings and potential applications. *Biomolecules*, *10*(7), 1–37. https://doi.org/10.3390/biom10070988

Donnelly, C. (2018). Review of controls for pathogen risks in Scottish artisan cheeses made from unpasteurized milk. *Food Standards Scotland*, *4*, 1–134. https://www.foodstandards.gov.scot/downloads/FSS_2017_015_-_Control_of_pathogens_in_unpasteurised_milk_cheese_-_Final_report_v_4.7_-_20th_November_2018_.pdf

Dziedziński, M., Kobus-Cisowska, J., & Stachowiak, B. (2021). Pinus species as prospective reserves of bioactive compounds with potential use in functional food—Current state of knowledge. *Plants*, *10*(7), 1306. https://doi.org/10.3390/plants10071306

Ehsani, A., Hashemi, M., Aminzare, M., & Raeisi, M. (2019). Comparative evaluation of edible films impregnated with sage essential oil or lactoperoxidase system : Impact on chemical and sensory quality of carp burgers. *Journal of Food Processing and Preservation*, *43*, 1–10. https://doi.org/10.1111/jfpp.14070

de Elguea-culebras, G. O., Bourbon, A. I., Costa, M. J., Muñoz-tebar, N., Carmona, M., Molina, A., Sánchez-vioque, R., Berruga, M. I., & Vicente, A. A. (2019). Optimization of a chitosan solution as potential carrier for the incorporation of *Santolina chamaecyparissus* L. solid by-product in an edible vegetal coating on 'Manchego' cheese. *Food Hydrocolloids*, *89*, 272–282. https://doi.org/10.1016/j.foodhyd.2018.10.054

El-Sayed, S. M., El-Sayed, H. S., Ibrahim, O. A., & Youssef, A. M. (2020). Rational design of chitosan/guar gum/zinc oxide bionanocomposites based on Roselle calyx extract for Ras cheese coating. *Carbohydrate Polymers*, *239*, 116234. https://doi.org/10.1016/j.carbpol.2020.116234

Embuena, A. I. C., Nácher, M. C., Boix, A. C., Pons, M. P. M., Llopis, M. B., Martínez, M. C. B., & Martínez, C. G. (2017). Quality of goat's milk cheese as affected by coating with edible chitosan-essential oil films. *International Journal of Dairy Technology*, *70*(1), 68–76. https://doi.org/10.1111/1471-0307.12306

Esmaeili, H., Cheraghi, N., Khanjari, A., Rezaeigolestani, M., Basti, A. A., Kamkar, A., & Aghaee, E. M. (2020). Incorporation of nanoencapsulated garlic essential oil into edible films: A novel approach for extending shelf life of vacuum-packed sausages. *Meat Science*, *166*, 108135. https://doi.org/10.1016/j.meatsci.2020.108135

Esparvarini, Z., Bazargani-Gilani, B., Pajohi-Alamoti, M., & Nourian, A. (2022). Gelatin-starch composite coating containing cucumber peel extract and cumin essential oil: Shelf life improvement of a cheese model. *Food Science and Nutrition*, *10*, 1–15. https://doi.org/10.1002/fsn3.2730

Fatmawati, D. R., & Susilowati, A. (2021). Use of edible film incorporated with parijoto fruit extract (*Medinilla speciosa* Blume) to inhibit microbiological and oxidative damages of sausages. *Applied Food Biotechnology*, *8*(4), 319–328.

Gaspar, M. C., & Braga, M. E. M. (2023). Edible films and coatings based on agrifood residues: A new trend in the food packaging research. *Current Opinion in Food Science*, *50*, 101006. https://doi.org/10.1016/j.cofs.2023.101006

Gedikoˇglu, A. (2022). The effect of *Thymus vulgaris* and *Thymbra spicata* essential oils and/or extracts in pectin edible coating on the preservation of sliced bolognas. *Meat Science*, *184*, 108697. https://doi.org/10.1016/j.meatsci.2021.108697

Grzesik, M., Naparło, K., Bartosz, G., & Sadowska-Bartosz, I. (2018). Antioxidant properties of catechins: Comparison with other antioxidants. *Food Chemistry*, *241*, 480–492. https://doi.org/10.1016/j.foodchem.2017.08.117

Guarrera, P. M., & Savo, V. (2013). Perceived health properties of wild and cultivated food plants in local and popular traditions of Italy: A review. *Journal of Ethnopharmacology*, *146*(3), 659–680. https://doi.org/10.1016/j.jep.2013.01.036

Gupta, S., Bishnoi, J. P., Kumar, N., Kumar, H., & Nidheesh, T. (2018). *Terminalia arjuna (Roxb.) Wight & Arn.*: Competent source of bioactive components in functional food and drugs. *The Pharma Innovation Journal*, *7*(3), 223–231. www.thepharmajournal.com

Gurdian, C., Chouljenko, A., Solval, K. M., Boeneke, C., King, J. M., & Sathivel, S. (2017). Application of edible films containing oregano (*Origanum vulgare*) essential oil on Queso Blanco cheese prepared with flaxseed (*Linum usitatissimum*) oil. *Journal of Food Science*, *82*(6), 1395–1401. https://doi.org/10.1111/1750-3841.13733

Hajirostamloo, B., Molaveisi, M., Asl, P. J., & Rahman, M. M. (2022). Novel soy protein isolate film containing cardamom essential oil microcapsules: Study of physicochemical properties and its application in Iranian white cheese packaging. *Journal of Food Measurement and Characterization*, *17*, 324–336. https://doi.org/10.1007/s11694-022-01603-y

Haro-González, J. N., Castillo-Herrera, G. A., Martínez-Velázquez, M., & Espinosa-Andrews, H. (2021). Clove essential oil (*Syzygium aromaticum* L. myrtaceae): Extraction, chemical composition, food applications, and essential bioactivity for human health. *Molecules*, *26*(21), 6387. https://doi.org/10.3390/molecules26216387

Hassan, A. H. A., Korany, A. M., Zeinhom, M. M. A., Mohamed, D. S., & Abdel-Atty, N. S. (2022). Effect of chitosan-gelatin coating fortified with papaya leaves and thyme extract on quality and shelf life of chicken breast fillet and Kareish cheese during chilled storage. *International Journal of Food Microbiology*, *371*, 109667. https://doi.org/10.1016/j.ijfoodmicro.2022.109667

Hassan, B., Chatha, S. A. S., Hussain, A. I., Zia, K. M., & Akhtar, N. (2018). Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review. *International Journal of Biological Macromolecules*, *109*, 1095–1107. https://doi.org/10.1016/j.ijbiomac.2017.11.097

Hassanien, M. F. R., Assiri, A. M. A., Alzohairy, A. M., & Oraby, H. F. (2015). Health-promoting value and food applications of black cumin essential oil: An overview. *Journal of Food Science and Technology*, *52*(10), 6136–6142. https://doi.org/10.1007/s13197-015-1785-4

He, T., Vaidya, B., Perry, Z., Parajuli, P., & Joshee, N. (2016). Paulownia as a medicinal tree: Traditional uses and current advances. *European Journal of Medicinal Plants*, *14*(1), 1–15. https://doi.org/10.9734/ejmp/2016/25170

Huang, J., Hu, Z., Hu, L., Li, G., Yao, Q., & Hu, Y. (2021). Pectin-based active packaging: A critical review on preparation, physical properties and novel application in food preservation. *Trends in Food Science and Technology*, *118*(PA), 167–178. https://doi.org/10.1016/j.tifs.2021.09.026

Huang, M., Wang, H., Xu, X., Lu, X., Song, X., & Zhou, G. (2020). Effects of nanoemulsion-based edible coatings with composite mixture of rosemary extract and ε-poly-L-lysine on the shelf life of ready-to-eat carbonado chicken. *Food Hydrocolloids*, *102*, 105576.

Humbare, R. B., Sarkar, J., Kulkarni, A. A., Juwale, M. G., Deshmukh, S. H., Amalnerkar, D., Chaskar, M., Albertini, M. C., Rocchi, M. B. L., Kamble, S. C., & Ramakrishna, S. (2022). Phytochemical characterization, antioxidant and anti-proliferative properties of *Rubia cordifolia* L. extracts prepared with improved extraction conditions. *Antioxidants*, *11*(5), 1–20. https://doi.org/10.3390/antiox11051006

Hussain, M. A., Sumon, T. A., Mazumder, S. K., Ali, M. M., Jang, W. J., Abualreesh, M. H., Sharifuzzaman, S. M., Brown, C. L., Lee, H. T., Lee, E. W., & Hasan, M. T. (2021). Essential oils and chitosan as alternatives to chemical preservatives for fish and fisheries products: A review. *Food Control*, *129*, 108244. https://doi.org/10.1016/j.foodcont.2021.108244

Iqbal, M. W., Riaz, T., Yasmin, I., Leghari, A. A., Amin, S., Bilal, M., & Qi, X. (2021). Chitosan-based materials as edible coating of cheese: A review. *Starch*, *73*(11–12), 2100088. https://doi.org/10.1002/star.202100088

Izquierdo-Vega, J., Arteaga-Badillo, D., Sánchez-Gutiérrez, M., Morales-González, J., Vargas-Mendoza, N., Gómez-Aldapa, C., Castro-Rosas, J., Delgado-Olivares, L., Madrigal-Bujaidar, E., & Madrigal-Santillán, E. (2020). Organic acids from Roselle (*Hibiscus sabdariffa* L.)-A brief review of its pharmacological effects. *Biomedicines*, *8*(5), 1–16. https://doi.org/10.3390/BIOMEDICINES8050100

Jarquín-Enríquez, L., Ibarra-Torres, P., Jiménez-Islas, H., & Flores-Martínez, N. L. (2021). *Pimenta dioica*: A review on its composition, phytochemistry, and applications in food technology. *International Food Research Journal*, *28*(5), 893–904. https://doi.org/10.47836/ifrj.28.5.02

Joseph-Leenose-Helen, J., Noor, N., Mushtaq, M., & Gani, A. (2022). Ultrasonics as a tool for development of pine-needle extract loaded bee wax edible packaging for value addition of Himalayan cheese. *Ultrasonics Sonochemistry*, *82*, 105914. https://doi.org/10.1016/j.ultsonch.2022.105914

Jridi, M., Abdelhedi, O., Salem, A., Kechaou, H., Nasri, M., & Menchari, Y. (2020). Physicochemical, antioxidant and antibacterial properties of fish gelatin-based edible films enriched with orange peel pectin : Wrapping application. *Food Hydrocolloids*, *103*, 105688. https://doi.org/10.1016/j.foodhyd.2020.105688

Ju, J., Xie, Y., Guo, Y., Cheng, Y., Qian, H., & Yao, W. (2019). Application of edible coating with essential oil in food preservation. *Critical Reviews in Food Science and Nutrition*, *59*(15), 2467–2480. https://doi.org/10.1080/10408398.2018.1456402

Kadir, A., & Mazlan, A. (2020). Effect of edible coating of sago starch-gelatine incorporated with papaya seed extract on the storage stability of Malaysian fish sausage (keropok lekor). *International Food Research Journal*, *27*, 618–624.

Kalem, I., Bhat, Z. F., Kumar, S., Noor, S., & Desai, A. (2018). The e ff ects of bioactive edible film containing *Terminalia arjuna* on the stability of some quality attributes of chevon sausages. *Meat Science*, *140*, 38–43. https://doi.org/10.1016/j.meatsci.2018.02.011

Kalkan, S., & Ergİnkaya, Z. (2020). Impact of whey protein isolate coatings containing different antimicrobial agents on sliced bologna-type sausage during refrigerated storage. *Food Science and Technology*, *2061*, 136–145.

Karunamay, S., Badhe, S., & Shukla, V. (2020). Effect of edible packaging film treated with essential oil of clove in extending the shelf life of paneer. *International Journal of Livestock Research*, *9*(0), 1. https://doi.org/10.5455/ijlr.20200422100708

Kavas, G., Kavas, N., & Kavas, G. (2018). Effect of the lavander essential oil fortified edible film on some properties of Kashar cheese during storage time. *IOSR Journal of Environmental Science*, *12*(11), 55–60. https://doi.org/10.9790/2402-1211015560

Kavas, G., Kavas, N., & Saygili, D. (2015). The effects of thyme and clove essential oil fortified edible films on the physical, chemical and microbiological characteristics of Kashar cheese. *Journal of Food Quality*, *38*(6), 405–412. https://doi.org/10.1111/jfq.12157

Kavas, N., & Kavas, G. (2016). Physical-chemical and antimicrobial properties of egg white protein powder films incorporated with orange essential oil on kashar cheese. *Food Science and Technology*, *36*(4), 672–678. https://doi.org/10.1590/1678-457X.12516

Kavas, N., & Kavas, G. (2017a). Use of egg white protein powder based films fortified with basil (*Ocimum basilicum* L.) essential oils in the storage of Çökelek cheese. *Journal of Scientific Research and Reports*, *15*(5), 1–10. https://doi.org/10.9734/jsrr/2017/35716

Kavas, N., & Kavas, G. (2017b). Use of turmeric (*Curcuma longa* L.) essential oil added to an egg white protein powder-based film in the storage of Çökelek cheese. *Journal of Food Chemistry and Nanotechnology*, *3*(3), 105–110. https://doi.org/10.17756/jfcn.2017-045

Kavas, N., Kavas, G., & Saygili, D. (2016). Use of ginger essential oil-fortified edible coatings in Kashar cheese and its effects on Escherichia coli O157 : H7 and Staphylococcus aureus. *CyTA—Journal of Food*, *14*(2), 317–323. https://doi.org/10.1080/19476337.2015.1109001

Khorshidian, N., Yousefi, M., Khanniri, E., & Mortazavian, A. M. (2018). Potential application of essential oils as antimicrobial preservatives in cheese. *Innovative Food Science and Emerging Technologies*, *45*, 62–72. https://doi.org/10.1016/j.ifset.2017.09.020

Kontogianni, V. G., Kasapidou, E., Mitlianga, P., Mataragas, M., Pappa, E., Kondyli, E., & Bosnea, L. (2022). Production, characteristics and application of whey protein films activated with rosemary and sage extract in preserving soft cheese. *LWT*, *155*, 112996. https://doi.org/10.1016/j.lwt.2021.112996

Kristam, P., Eswarapragada, N. M., Bandi, E. R., & Tumati, S. R. (2016). Evaluation of edible polymer coatings enriched with green tea extract on quality of chicken nuggets. *Veterinary World*, *9*(7), 685–692. https://doi.org/10.14202/vetworld.2016.685-692

Ksouda, G., Sellimi, S., Merlier, F., Falcimaigne-cordin, A., Thomasset, B., Nasri, M., & Hajji, M. (2019). Composition, antibacterial and antioxidant activities of *Pimpinella saxifraga* essential oil and application to cheese preservation as coating additive. *Food Chemistry*, *288*, 47–56. https://doi.org/10.1016/j.foodchem.2019.02.103

Kulawik, P., Jamróz, E., Zając, M., Guzik, P., & Tkaczewska, J. (2019). The effect of furcellaran-gelatin edible coatings with green and pu-erh tea extracts on the microbiological, physicochemical and sensory changes of salmon sushi stored at 4°C. *Food Control*, *100*, 83–91. https://doi.org/10.1016/j.foodcont.2019.01.004

Kumar, Y., Prakash, O., Tripathi, H., Tandon, S., Gupta, M. M., Rahman, L. U., Lal, R. K., Semwal, M., Darokar, M. P., & Khan, F. (2018). AromaDb: A database of medicinal and aromatic plant's aroma molecules with phytochemistry and therapeutic potentials. *Frontiers in Plant Science*, *9*, 1–11. https://doi.org/10.3389/fpls.2018.01081

Laribi, B., Kouki, K., M'Hamdi, M., & Bettaieb, T. (2015). Coriander (*Coriandrum sativum* L.) and its bioactive constituents. *Fitoterapia*, *103*, 9–26. https://doi.org/10.1016/j.fitote.2015.03.012

Latifasari, N., Naufalin, R., & Wicaksono, R. (2019). Edible coating application of Kecombrang leaves to reduce gourami sausage damage. *IOP Conference Series: Earth and Environmental Science*, *250*(1), 012055. https://doi.org/10.1088/1755-1315/250/1/012055

Lestari, R. B., Permadi, E., Mulyadi, A., Peternakan, P. S., Pertanian, F., Tanjungpura, U., Studi, P., Sumberdaya, M., Pertanian, F., Tanjungpura, U., & Nawawi, H. H. (2022). Application of edible coating of durian seed starch chitosan composites with kesum leaves extracts on microbiological quality and tvb-n of beef sausage. *Journal Llmu Dan Teknologi Ternak*, *17*(1), 56–63.

Lima, F., Andrade, P. L., Leda, T., Lemos, G. D., Esdras, D., Uchoa, D. A., Cirineu, M., Siqueira, A., Silvio, A., Chastinet, R., Nascimento, J., Maria, D., & Teixeira, A. (2021). Development and application of galactomannan and essential oil-based edible coatings applied to " coalho " cheese. *Journal of Food Processing and Preservation*, *45*, 1–12. https://doi.org/10.1111/jfpp.15091

Liu, J. Y., He, D., Xing, Y. F., Zeng, W., Ren, K., Zhang, C., Lu, Y., Yang, S., Ou, S. J., Wang, Y., & Xing, X. H. (2021). Effects of bioactive components of Pu-erh tea on gut microbiomes and health: A review. *Food Chemistry*, *353*, 129439. https://doi.org/10.1016/j.foodchem.2021.129439

López-Córdoba, A. (2021). Feasibility of using carvacrol/starch edible coatings to improve the quality of Paipa cheese. *Polymers*, *13*, 2516.

Ma, B., Wang, J., Zhou, B., Wang, Z., Huang, Y., Ma, C., & Li, X. (2022). Impact of harvest season on bioactive compounds, amino acids and in vitro antioxidant capacity of white tea through multivariate statistical analysis. *LWT*, *164*, 113655. https://doi.org/10.1016/j.lwt.2022.113655

Maan, A. A., Ahmed, Z. F. R., Khan, M. K. I., Riaz, A., & Nazir, A. (2021). Aloe vera gel, an excellent base material for edible films and coatings. *Trends in Food Science and Technology*, *116*, 329–341. https://doi.org/10.1016/j.tifs.2021.07.035

Mahcene, Z., Khelil, A., Hasni, S., Bozkurt, F., Goudjil, M. B., & Tornuk, F. (2021). Home-made cheese preservation using sodium alginate based on edible film incorporating essential oils. *Journal of Food Science and Technology*, *58*(6), 2406–2419. https://doi.org/10.1007/s13197-020-04753-3

Mahdavi, V., Hosseini, S. E., & Sharifan, A. (2018). Effect of edible chitosan film enriched with anise (*Pimpinella anisum* L.) essential oil on shelf life and quality of the chicken burger. *Food Science and Nutrition*, *6*, 269–279. https://doi.org/10.1002/fsn3.544

Majerska, J., Michalska, A., & Figiel, A. (2019). A review of new directions in managing fruit and vegetable processing by-products. *Trends in Food Science and Technology*, *88*, 207–219. https://doi.org/10.1016/j.tifs.2019.03.021

Mao, Q. Q., Xu, X. Y., Cao, S. Y., Gan, R. Y., Corke, H., Beta, T., & Li, H. B. (2019). Bioactive compounds and bioactivities of ginger (*Zingiber officinale* Roscoe). *Foods*, *8*(6), 1–21. https://doi.org/10.3390/foods8060185

Mariano, X. M., de Souza, W. F. M., Rocha, C. B., & Moreira, R. F. A. (2019). Bioactive volatile fraction of Chilean boldo (*Peumus boldus* Molina)–An overview. *Journal of Essential Oil Research*, *31*(6), 474–486. https://doi.org/10.1080/10412905.2019.1617797

Martins, N., Petropoulos, S., & Ferreira, I. C. F. R. (2016). Chemical composition and bioactive compounds of garlic (*Allium sativum* L.) as affected by pre- and post-harvest conditions: A review. *Food Chemistry*, *211*, 41–50. https://doi.org/10.1016/j.foodchem.2016.05.029

Mei, J., Guo, Q., Wu, Y., & Li, Y. (2015). Evaluation of chitosan-starch-based edible coating to improve the shelf life of Bod ljong cheese. *Journal of Food Protection*, *78*(7), 1327–1334. https://doi.org/10.4315/0362-028X.JFP-14-402

Mezhoudi, M., Salem, A., Abdelhedi, O., & Fakhfakh, N. (2022). Edible films from triggerfish gelatin and *Moringa oleifera* extract : Physical edible films from triggerfish gelatin and *Moringa oleifera* extract : Physical properties and application in wrapping ricotta cheese. *Journal of Food Measurement and Characterization*, *16*(5), 3987–3997. https://doi.org/10.1007/s11694-022-01472-5

Milanda, T., Barliana, M. I., Rosidah, R., & Kusuma, A. S. (2021). Antibacterial activities of Parijoto (*Medinilla speciosa* Blume) fruit extracts against clinical isolates of *Salmonella typhi* and *Shigella dysenteriae*. *Pharmacology and Clinical Pharmacy Research*, *6*(1), 25. https://doi.org/10.15416/pcpr.v6i1.31992

Mileriene, J., Serniene, L., Henriques, M., Gomes, D., Pereira, C., Kondrotiene, K., Kasetiene, N., Lauciene, L., & Sekmokiene, D. (2021). Effect of liquid whey protein concentrate-based edible coating enriched with cinnamon carbon dioxide extract on the quality and shelf life of Eastern European curd cheese. *Journal of Dairy Science*, *104*(2), 1504–1517. https://doi.org/10.3168/jds.2020-18732

Mnif, S., & Aifa, S. (2015). Cumin (*Cuminum cyminum* L.) from traditional uses to potential biomedical applications. *Chemistry and Biodiversity*, *12*(5), 733–742. https://doi.org/10.1002/cbdv.201400305

Mohamed, S. A. A., El-Sakhawy, M., & El-Sakhawy, M. A. M. (2020). Polysaccharides, protein and lipid-based natural edible films in food packaging: A review. *Carbohydrate Polymers*, *238*, 116178. https://doi.org/10.1016/j.carbpol.2020.116178

Molina-Hernández, J. B., Echeverri-Castro, A., Martínez-Correa, H. A., & Andrade-Mahecha, M. M. (2020). Edible coating based on achira starch containing garlic/oregano oils to extend the shelf life of double cream cheese. *Revista Facultad Nacional de Agronomía Medellín*, *73*(1), 9099–9108. https://doi.org/10.15446/rfnam.v73n1.75234

Nain, C. W., Mignolet, E., Herent, M. F., Quetin-Leclercq, J., Debier, C., Page, M. M., & Larondelle, Y. (2022). The catechins profile of green tea extracts affects the antioxidant activity and degradation of catechins in DHA-rich oil. *Antioxidants*, *11*(9), 1844. https://doi.org/10.3390/antiox11091844

Naufalin, R., Sutrisna, E., & Wicaksono, R. (2021). Antioxidant potential ingredient of kecombrang plants (*Etlingera elatior*). *IOP Conference Series: Earth and Environmental Science*, *653*(1), 012130. https://doi.org/10.1088/1755-1315/653/1/012130

Nigam, M., Atanassova, M., Mishra, A. P., Pezzani, R., Devkota, H. P., Plygun, S., Salehi, B., Setzer, W. N., & Sharifi-Rad, J. (2019). Bioactive compounds and health benefits of *Artemisia* species. *Natural Product Communications*, *14*(7), 1–17. https://doi.org/10.1177/1934578x19850354

Özvural, E. B., Huang, Q., & Chikindas, M. L. (2016). The comparison of quality and microbiological characteristic of hamburger patties enriched with green tea extract using three techniques: Direct addition, edible coating and encapsulation. *LWT*, *68*, 385–390. https://doi.org/10.1016/j.lwt.2015.12.036

Paidari, S., Zamindar, N., Tahergorabi, R., Kargar, M., Ezzati, S., shirani, N., & Musavi, S. H. (2021). Edible coating and films as promising packaging: A mini review. *Journal of Food Measurement and Characterization*, *15*(5), 4205–4214. https://doi.org/10.1007/s11694-021-00979-7

Panahirad, S., Dadpour, M., Peighambardoust, S. H., Soltanzadeh, M., Gullón, B., Alirezalu, K., & Lorenzo, J. M. (2021). Applications of carboxymethyl cellulose- and pectin-based active edible coatings in preservation of fruits and vegetables: A review. *Trends in Food Science and Technology*, *110*, 663–673. https://doi.org/10.1016/j.tifs.2021.02.025

Park, C. H., Sathasivam, R., Kim, T. J., Park, B. B., Kim, J. K., & Park, S. U. (2022). Metabolic profiling and secondary metabolite accumulation during fruit development of *Cornus officinalis Sieb*. et Zucc. *Industrial Crops and Products*, *189*, 115779. https://doi.org/10.1016/j.indcrop.2022.115779

Paszczyk, B. (2022). Cheese and butter as a source of health-promoting fatty acids in the human diet. *Animals*, *12*(23), 3424. https://doi.org/10.3390/ani12233424

Peter, S., Lyczko, N., Gopakumar, D., Maria, H. J., Nzihou, A., & Thomas, S. (2021). Chitin and chitosan based composites for energy and environmental applications: A review. *Waste and Biomass Valorization*, *12*(9), 4777–4804. https://doi.org/10.1007/s12649-020-01244-6

Petropoulos, S., Karkanis, A., Martins, N., & Ferreira, I. C. F. R. (2016). Phytochemical composition and bioactive compounds of common purslane (*Portulaca oleracea* L.) as affected by crop management practices. *Trends in Food Science & Technology*, *55*, 1–10. https://doi.org/10.1016/j.tifs.2016.06.010

Pieretti, G. G., Pinheiro, M. P., Regina, M., Martha, J., Mikcha, G., & Madrona, G. S. (2019). Effect of an edible alginate coating with essential oil to improve the quality of a Fresh cheese. *Acta Scientiarum Techonology*, *41*, e36402. https://doi.org/10.4025/actascitechnol.v41i1.36402

Pluta-Kubica, A., Jamróz, E., Juszczak, L., Krzyściak, P., & Zimowska, M. (2021). Characterization of furcellaran-whey protein isolate films with green tea or Pu-erh extracts and their application as packaging of an acid-curd cheese. *Food and Bioprocess Technology*, *14*(1), 78–92. https://doi.org/10.1007/s11947-020-02570-2

Pluta-Kubica, A., Jamróz, E., & Kawecka, A. (2020). Active edible furcellaran /whey protein fi lms with yerba mate and white tea extracts : Preparation, characterization and its application to fresh soft rennet-curd cheese. *International Journal of Biological Macromolecules*, *155*, 1307–1316. https://doi.org/10.1016/j.ijbiomac.2019.11.102

Putri, F. A., Naufalin, R., & Wicaksono, R. (2019). Antimicrobial edible coating application of Kecombrang flower concentrate to reduce microbial growth on gourami fish sausage. *IOP Conference Series: Earth and Environmental Science*, *250*(1), 012056. https://doi.org/10.1088/1755-1315/250/1/012056

Qiu, L., Zhang, M., Chitrakar, B., Adhikari, B., & Yang, C. (2022). Effects of nanoemulsion-based chicken bone gelatin-chitosan coatings with cinnamon essential oil and rosemary extract on the storage quality of ready-to-eat chicken patties. *Food Packaging and Shelf Life*, *34*, 100933. https://doi.org/10.1016/j.fpsl.2022.100933

Qoeroti, B., Pangastuti, A., & Susilowati, A. (2021). Application of edible film incorporated with *Portulaca oleracea* extract to inhibit microbiological and oxidative damage in sausages. *Biodiversitas*, *22*(8), 3556–3561. https://doi.org/10.13057/biodiv/d220856

Quesada, J., & Sendra, E. (2016). Antimicrobial active packaging including chitosan films with *Thymus vulgaris* L. Essential oil for ready-to-eat meat. *Foods*, *5*, 57. https://doi.org/10.3390/foods5030057

Ribeiro, A. M., Estevinho, B. N., & Rocha, F. (2021). Preparation and incorporation of functional ingredients in edible films and coatings. *Food and Bioprocess Technology*, *14*(2), 209–231. https://doi.org/10.1007/s11947-020-02528-4

Richards, M. P. (2010). Heme proteins and oxidation in fresh and processed meats. In *Oxidation in foods and beverages and antioxidant applications: Understanding mechanisms of oxidation and antioxidant activity*. Woodhead Publishing Limited. https://doi.org/10.1533/9780857090447.1.77

Ríos-De-benito, L. F., Escamilla-García, M., García-Almendárez, B., Amaro-Reyes, A., Di Pierro, P., & Regalado-González, C. (2021). Design of an active edible coating based on sodium caseinate, chitosan and oregano essential oil reinforced with silica particles and its application on panela cheese. *Coatings*, *11*(10), 1212. https://doi.org/10.3390/coatings11101212

Robalo, J., Lopes, M., Cardoso, O., Silva, A. S., & Ramos, F. (2022). Efficacy of whey protein film incorporated with Portuguese green rea (*Camellia sinensis* L.) extract for the preservation of Latin-style fresh cheese. *Foods*, *11*(8), 1158. https://doi.org/10.3390/foods11081158

Ruiz-Navajas, Y. (2015). Effect of chitosan edible films added with *Thymus moroderi* and *Thymus piperella* essential oil on shelf-life of cooked cured. *Journal of Food Science and Technology*, *52*, 6493–6501. https://doi.org/10.1007/s13197-015-1733-3

Saravani, M., Ehsani, A., & Ghasempour, Z. (2019). Gouda cheese spoilage prevention : Biodegradable coating induced by *Bunium persicum* essential oil and lactoperoxidase system. *Journal of Food Science and Nutrition*, *7*, 959–968. https://doi.org/10.1002/fsn3.888

Senanayake, S. P. J. N. (2018). Rosemary extract as a natural source of bioactive compounds. *Journal of Food Bioactives*, *2*, 51–57. https://doi.org/10.31665/jfb.2018.2140

Seydim, A. C., Sarikus-tutal, G., & Sogut, E. (2020). Effect of whey protein edible films containing plant essential oils on microbial inactivation of sliced Kasar cheese. *Food Packaging and Shelf Life*, *26*, 100567. https://doi.org/10.1016/j.fpsl.2020.100567

Sharma, R., Bhat, Z. F., Kumar, A., Kumar, S., Bhatti, M. A., & Jayawardena, R. (2021). Rubia cordifolia based novel edible film for improved lipid oxidative and microbial stability of meat products. *Journal of Food Processing and Preservation*, *45*(7), 1–11. https://doi.org/10.1111/jfpp.15654

Shukla, V., Kumar, S., Ravindra, M., Zende, J., Kant, R., Rohit, A., & Jaiswal, K. (2020). Effects of chitosan coating enriched with *Syzygium aromaticum* essential oil on quality and shelf-life of chicken patties. *Journal of Food Processing and Preservation*, *44*, 1–12. https://doi.org/10.1111/jfpp.14870

Sivamaruthi, B. S., Kesika, P., & Chaiyasut, C. (2021). A narrative review on biogenic amines in fermented fish and meat products. *Journal of Food Science and Technology*, *58*(5), 1623–1639. https://doi.org/10.1007/s13197-020-04686-x

Slobodianiuk, L., Budniak, L., Marchyshyn, S., Parashchuk, E., & Levytska, L. (2021). Experimental studies on expectorant effect of extract from *Pimpinella saxifraga* L. *Pharmacologyonline*, *1*, 404–410.

Soni, A., Gurunathan, K., Mendiratta, S. K., Talukder, S., Jaiswal, R. K., & Sharma, H. (2018). Effect of essential oils incorporated edible film on quality and storage stability of chicken patties at refrigeration temperature (4 ± 1°C). *Journal of Food Science and Technology*, *55*(9), 3538–3546. https://doi.org/10.1007/s13197-018-3279-7

Srour, N., Daroub, H., Toufeili, I., & Olabi, A. (2016). Developing a carob-based milk beverage using different varieties of carob pods and two roasting treatments and assessing their effect on quality characteristics. *Journal of the Science of Food and Agriculture*, *96*(9), 3047–3057. https://doi.org/10.1002/jsfa.7476

Suhag, R., Kumar, N., Petkoska, A. T., & Upadhyay, A. (2020). Film formation and deposition methods of edible coating on food products: A review. *Food Research International*, *136*, 109582. https://doi.org/10.1016/j.foodres.2020.109582

Sun, X., Wang, J., Dong, M., Zhang, H., Li, L., & Wang, L. (2022). Food spoilage, bioactive food fresh-keeping films and functional edible coatings: Research status, existing problems and development trend. *Trends in Food Science and Technology*, *119*, 122–132. https://doi.org/10.1016/j.tifs.2021.12.004

Sun, Y., Zhang, M., Bhandari, B., & Bai, B. (2021). Nanoemulsion-based edible coatings loaded with fennel essential oil/cinnamaldehyde: Characterization, antimicrobial property and advantages in pork meat patties application. *Food Control*, *127*, 108151. https://doi.org/10.1016/j.foodcont.2021.108151

Tongnuanchan, P., & Benjakul, S. (2014). Essential oils: Extraction, bioactivities, and their uses for food preservation. *Journal of Food Science*, *79*(7), 1–19. https://doi.org/10.1111/1750-3841.12492

Utami, R., Khasanah, L. U. K., & Solikhah, R. (2018). The effect of edible coating enriched with Kaffir lime leaf essential oil (*Citrus hystrix* DC) on beef sausage quality during frozen storage (−18°±2°C). *Materials Science and Engineering*, *333*(1), 012070. https://doi.org/10.1088/1757-899X/333/1/012070

Uthpala, T. G. G., Marapana, R. A. U. J., Lakmini, K. P. C., & Wettimuny, D. C. (2020). Nutritional bioactive compounds and health benefits of fresh and processed cucumber (*Cucumis Sativus* L.) value-added products from Cassava View project Antibiotic susceptibility testing View project Nutritional Bioactiv. *Sumerianz Journal of Biotechnology*, *3*(9), 2617–3123.

Vergara-Jimenez, M., Almatrafi, M. M., & Fernandez, M. L. (2017). Bioactive components in *Moringa oleifera* leaves protect against chronic disease. *Antioxidants*, *6*(4), 1–13. https://doi.org/10.3390/antiox6040091

Vital, A., Guerrero, A., Guarnido, P., Severino, I. C., Olleta, L., Blasco, M., Nunes, I., Maggi, F., & Campo, M. (2021). Effect of active-edible coating and essential oils on lamb patties oxidation during display. *Foods*, *10*(263), 1–15.

Wani, S. A., Naik, H., Wagay, J., Ganie, N. A., Mulla, M. Z., & Dar, B. N. (2022). Mentha: A review on its bioactive compounds and potential health benefits. *Quality Assurance and Safety of Crops & Foods*, *14*(4), 154–168. https://doi.org/10.15586/qas.v14i4.1129

Wedamulla, N. E., Fan, M., Choi, Y. J., & Kim, E. K. (2022). Citrus peel as a renewable bioresource: Transforming waste to food additives. *Journal of Functional Foods*, *95*, 105163. https://doi.org/10.1016/j.jff.2022.105163

Wu, H., Richards, M. P., & Undeland, I. (2022). Lipid oxidation and antioxidant delivery systems in muscle food. *Comprehensive Reviews in Food Science and Food Safety*, *21*(2), 1275–1299. https://doi.org/10.1111/1541-4337.12890

Xu, X. Y., Meng, J. M., Mao, Q. Q., Shang, A., Li, B. Y., Zhao, C. N., Tang, G. Y., Cao, S. Y., Wei, X. L., Gan, R. Y., Corke, H., & Li, H. B. (2019). Effects of tannase and ultrasound treatment on the bioactive compounds and antioxidant activity of green tea extract. *Antioxidants*, *8*(9), 362. https://doi.org/10.3390/antiox8090362

Yangilar, F. (2017). Effects of natamycin edible films fortified with essential oils on the safety and quality parameters of Kashar cheese. *Journal of Food Safety*, *37*, 1–11. https://doi.org/10.1111/jfs.12306

Yu, C. Y., Zhang, J. F., & Wang, T. (2021). Star anise essential oil:Chemical compounds, antifungal and antioxidant activities: A review. *Journal of Essential Oil Research*, *33*(1), 1–22. https://doi.org/10.1080/10412905.2020.1813213

Zhang, H., Li, X., & Kang, H. (2019). Chitosan coatings incorporated with free or nano-encapsulated *Paulownia tomentosa* essential oil to improve shelf-life of ready-to-cook pork chops. *LWT*, *116*, 108580. https://doi.org/10.1016/j.lwt.2019.108580

Zhang, L., Chen, F., Lai, S., Wang, H., & Yang, H. (2018). Impact of soybean protein isolate-chitosan edible coating on the softening of apricot fruit during storage. *LWT*, *96*, 604–611. https://doi.org/10.1016/j.lwt.2018.06.011

Zhang, L., Yang, Z., Huang, Z., Zhao, M., Li, P., Zhou, W., Zhang, K., Zheng, X., Lin, L., Tang, J., Fang, Y., & Du, Z. (2017). Variation in essential oil and bioactive compounds of *Curcuma kwangsiensis* collected from natural habitats. *Chemistry and Biodiversity*, *14*(7), e1700020. https://doi.org/10.1002/cbdv.201700020

Zhao, K., Wang, W., Teng, A., Zhang, K., Ma, Y., Duan, S., Li, S., & Guo, Y. (2020). Using cellulose nanofibers to reinforce polysaccharide films: Blending vs layer-by-layer casting. *Carbohydrate Polymers*, *227*, 115264. https://doi.org/10.1016/j.carbpol.2019.115264

Ziemlewska, A., Zagórska-Dziok, ... Nizioł-Łukaszewska, Z., Bujak, T., Zagórska-Dziok, M., Wójciak, M., & Sowa, I. (2021). Effect of fermentation time on the content of bioactive compounds with cosmetic and dermatological properties in Kombucha Yerba Mate extract. *Scientific Reports*, *11*(1), 1–15. https://doi.org/10.1038/s41598-021-98191-6

Živković, J., Ristić, M., Kschonsek, J., Westphal, A., Mihailović, M., Filipović, V., & Böhm, V. (2017). Comparison of chemical profile and antioxidant capacity of seeds and oils from *Salvia sclarea* and *Salvia officinalis*. *Chemistry and Biodiversity*, *14*(12), e1700344. https://doi.org/10.1002/cbdv.201700344

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