Natural Polyphenols for Food Preservation

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Food spoilage makes foods undesirable and unacceptable for human use. Preservative agents are generally classified into antimicrobial, antioxidant, and anti-browning agents. On the other hand, artificial preservatives (sorbate, sulfite, or nitrite) may cause serious health hazards such as hypersensitivity, asthma, neurological damage, hyperactivity, and cancer. Thus, consumers prefer natural food preservatives to synthetic ones, as they are considered safer. Polyphenols have potential uses as biopreservatives in the food industry, because their antimicrobial and antioxidant activities can increase the storage life of food products. The antioxidant capacity of polyphenols is mainly due to the inhibition of free radical formation. Moreover, the antimicrobial activity of plants and herbs is mainly attributed to the presence of phenolic compounds. Thus, incorporation of botanical extracts rich in polyphenols in perishable foods can be considered since no pure polyphenolic compounds are authorized as food preservatives.

food spoilage food preservation polyphenols

1. Introduction

Fresh foods (meat, seafood, and horticultural products) are prone to foodborne disease outbreaks caused by pathogenic microbes, limiting their storage life [1]. Food spoilage is a metabolic process that makes foods undesirable or unacceptable for human use, due to alterations in their sensory characteristics. In some cases, such spoiled food may be safe for use and not cause illness, but changes in texture, taste, smell, and appearance lead to its rejection for consumption [2]. Thus, food preservation has been necessary for human survival since prehistory. In the past, techniques used for the preservation of food relied on the inactivation of spoiling microbes through drying, heating, salting, or fermentation [3]. The most important approaches in preservation of food are the decrease of the presence and effects of water, the control of temperature, and the use of preservatives (sorbate, sulfite, or nitrite) and competitive microorganisms (lactic acid bacteria) [4]. In general, there are three types of preservatives: (1) antimicrobial agents, which prevent the growth of microorganisms that may cause serious illnesses (i.e., salmonellosis or botulism) and which are used in margarine and dressings, cheeses, bakery products, and dried fruit preparations; (2) antioxidants, which slow down the degree of oxidation and can be used in products containing unsaturated fatty acids that are more susceptible to oxidative reactions; (3) anti-browning agents, which are added to fruits and vegetables in order to prevent enzymatic browning [5]. The scientific literature has shown that artificial preservatives may, in certain cases, cause serious health hazards such as hypersensitivity, asthma, neurological damage, hyperactivity, and cancer [6].

In the modern era, many consumers prefer natural food preservatives over synthetic ones. The benefits of natural preservatives are endless, and these tend to be safer for use in comparison to synthetic preservatives [7]. Polyphenols are the largest group of plant secondary metabolites, containing benzene rings with hydroxyl moieties, and they can be divided into different chemical classes, including flavonoids, phenolic acids, lignans, tannins, and stilbenes. They are the most abundant phytochemicals found in dietary sources, possessing many pharmacological effects including antioxidant and antimicrobial activities [8][9]. The major sources of polyphenols include fruits or fruit juices (apple, grapefruit, orange, pineapple, and Prunus fruits), vegetables (broccoli, cabbage, carrot, cucumber, mint, spinach, tomato, and yellow onion), beverages (tea and coffee), and wine [10]. This group of compounds could play an essential role in the defense and protective mechanisms of botanicals [11]. They have potential use as biopreservatives in the food industry and have been extensively studied for the enhancement of the shelf life of perishable products. The use of phenolic compounds from natural sources is an interesting approach, as it allows the production of food without synthetic additives [12].

2. Natural Methods of Food Preservation

Food can be preserved using multiple techniques such as refrigeration and heating, although these techniques have certain drawbacks in the form of alteration of organoleptic features and nutrient loss. Natural preservatives are getting more attention in the food industry due to the drawbacks of artificial preservatives. Allyl isothiocyanate is a natural food preserving agent isolated from the essential oil of mustard and other species of the Brassicaceae family. It exhibits antimicrobial potential against food spoilage microbes. Due to its pungent taste, fast evaporation, and hydrophobic nature, its natural preservative potential is limited to certain applicable foodstuffs [13].

Essential oils are historically known for their aroma and microbicidal action. Apart from their property of modifying food flavor, they can also exhibit antimicrobial potential against foodborne pathogens, thus replacing chemical preservatives [14]. As natural food preservatives, essential oils can be used as natural food additives and as a bioactive component in packaging materials. Oregano essential oil is rich in thymol and carvacrol and is added to pork meat, resulting in inhibition of the growth of L. monocytogenes and an improvement in food flavor [15]. The food preserving capacity of citron oil (a kind of oil extracted from Citrus medica fruit) in a fruit-based salad was evaluated against Salmonella typhi and L. monocytogenes. The results indicate an outstanding antimicrobial potential against these species, confirming its use as a natural food preservation agent [16].

Peptides from animal sources have shown antimicrobial action against a wide range of pathogens associated with food components. Counts of multiple bacteria including Serratia liquefaciens, Lactobacillus plantarum, and Zygosaccharomyces bailii were successfully reduced in mayonnaise after the application of chitosan [17]. Alginates and carrageenan isolated from algae have shown an effective role in food preservation. These form nanocomposite films containing essential oils, which display antimicrobial action against spoilage microorganisms in food materials. Lactic acid bacteria favor controlled acidification, producing acids that in turn preserve important foodstuffs [18].

Some food components can also act as food preservative agents. Jellies, jams, and marmalades are composed of 70% sugar, which is itself not toxic to microbes, but rather absorbs water content from foodstuffs, thus restricting the growth of spoilage microorganisms [19]. Similarly, salt is used at a concentration of 20% in pickles. Salt triggers microbial cell plasmolysis through the induction of a high osmotic pressure. Dehydration of foodstuffs and the presence of chlorine ions are two further useful factors that salt provides in food preservation [20].

3. Food Fortification with Phenols as Preservative Agents

Meat products are more vulnerable to lipid oxidation, which is often measured using the thiobarbituric acid reactive substances (TBARS) method. While synthetic antioxidants were initially used to prevent oxidation of lipids, natural sources have been found that might serve same purpose in meat [12]. The use of olive leaf extracts is a common strategy for the enrichment of food with phenol contents. The incorporation of olive leaf extract (with total phenolic contents of 45.2 mg gallic acid equivalent (GAE) kg^{-1}) in cooked pork meat patties resulted in a significant delay in lipid oxidation and both primary (conjugated dienes and hydroperoxides) and secondary (malondialdehyde) oxidation products. Protein oxidation was also inhibited in a concentration-dependent manner by decreasing protein carbonyls and increasing protein sulfhydryls [21].

Bee pollen (0.2%) was found to be effective in retarding lipid peroxidation in pork sausage stored at 4 °C for 30 days, showing significantly lower values of TBARS compared to control [22]. The percentage decrease in TBARS values was highest in storage after 10 days. The storage life of pork nuggets increased from 21 to 35 days with the incorporation of Averrhoa carambola L. fruit juice extract, in comparison to pork nuggets without the extract. The TBARS values of pork nuggets were found to be lower with fruit juice extract (4% and 6%) during 35 days of storage [23]. The addition of green tea extract in hamburger showed a reduction in TBARS values during the 8-day storage period. The effect of tea was increased in a combination of green tea extract with chitosan, as the resistance to lipid oxidation and microbial deterioration was significantly increased [24].

In another study, pork sausages fortified with a chitosan-film incorporating green tea extract showed decreased changes in color, texture, thiobarbituric value, microbial growth, and sensory characteristics, when compared to control (chitosan alone or green tea extract without chitosan). Successful inhibition of microbial growth (yeasts and molds, and lactic acid bacteria) and lipid oxidation was observed in refrigerated pork sausages, suggesting that the incorporation of green tea extract into chitosan may enhance the antimicrobial and antioxidant properties of the film, and thus, maintain the prolonged shelf-life of the sausages [25].

The addition of different spice extracts (Syzygium aromaticum (L.) Merr. and L.M. Perry, Cinnamomum cassia (L.) J. Presl., Origanum vulgare L., and Brassica nigra (L.) K. Koch) with high total phenolic content to raw chicken meat demonstrated an effective prevention against microbial growth and lipid peroxidation. The total phenolic contents ranged from 14.09 to 24.65 GAE/g. Samples with Syzygium aromaticum, C. cassia, and Origanum vulgare extracts exhibited a greater reduction of bacterial counts (lactic acid bacteria and Enterobacteriaceae) and TBARS concentrations than control, with a positive increase in sensorial properties such as color and odor over a storage period of 4 °C for 15 days [26]. This kind of fortification of raw meat with vegetable extracts can be effective for preservation, while providing lower TBARS values during storage for 20 days at temperatures ranging from 4 to 20 °C [27].

In addition to its capacity to delay lipid and protein oxidation, pomegranate peel extract can also be used for its melanosis-inhibitory activity during storage of Pacific white shrimp in refrigerators, with a decrease in mesophilic, psychrophilic, lactic acid bacteria, and Enterobacteriaceae counts [28][29]. Natural phenols derived from barley husks slow down lipid hydrolysis and increase the oxidative stability of salmon fish, as determined by peroxide value, conjugated dienes, conjugated triene hydroperoxides, free fatty acids, totox values, thiobarbituric acid index, and p-anisidine values [30]. Barley husks are quite rich in phenolic acids (p-coumaric acid, trans-ferulic acid, and syringic acid), as revealed by LC-MS analysis [31]. Barley husks also slow down lipid hydrolysis and oxidation (reflected by significant decreases in lipid hydrolysis and TBARS values) in blue shark (packaged in a film) during storage at −20 °C for 6 months [32].

Several studies suggest that the packaging application of films incorporated with natural antioxidants improves food stability (from aqueous to fatty food products) throughout storage.

Barbosa-Pereira et al. developed active antioxidant films with natural antioxidants (brewery residual stream extract and commercial rosemary extract) using a coating technique, and these films increased the oxidative stability of beef during refrigeration, reducing lipid oxidation up to

80% in comparison with the control [33]. Incorporation of catechin and quercetin into ethylene–vinyl alcohol copolymer films successfully improved the antioxidant protection of packaged food, with the most significant results being observed with catechin [34]. Similar results were observed with green tea extract incorporated in ethylene–vinyl alcohol copolymer films [35].

Active films treated with oregano significantly protected lamb against oxidation and microbial spoilage, as seen in the improvement in metmyoglobin formation, TBARS values, instrumental color, psychrotrophic aerobic flora counts, and sensory discoloration [36]. When applied to the packaging of ground beef stored at 3 °C, multilayered polyethylene films with incorporated grapefruit seed extract demonstrated a reduction of growth rates of numerous microbes including Escherichia coli IFO 3301, Staphylococcus aureus IFO 3060, and Bacillus subtilis IFO 12113 [37]. They also slowed down the chemical changes in packaged beef during storage.

Chouchouli et al., reported that yogurt fortified with grape seed extracts (rich in polyphenols) contained more bioactive compounds, with higher antioxidant and antiradical activities [38][39]. Similarly, oat-bran-fortified raspberry probiotic dairy drinks exhibited increased antioxidant effects, owing to a higher phenolic content [40]. Strawberry polyphenol extract–fortified stirred dahi (a traditional fermented dairy product prepared by lactic acid fermentation of milk) resulted in a seven-fold increase in the antioxidant activity while pH, acidity, water-holding capacity, and viscosity remained comparable with the control [41]. The addition of grape pomace powders to semi-hard (Italian Toma-like) and hard cheeses (cheddar) resulted in increased total phenolic contents and radical scavenging activity, while no variation was observed in the microbial counts and physiochemical parameters [42]. Tseng and Zhao stored grape-pomace-fortified yogurt for 3 weeks at 4 °C and observed an increase in pH and decrease in viscosity without alterations in lactose concentrations [43]. In addition, grape pomace also reduced the peroxide values during storage with advantages in oxidative stability. Polyphenol-enriched dairy products developed by incorporating black carrot concentrate demonstrated enhanced antioxidant activities with increased total phenolic contents [44]. The storage study showed that yogurt can be stored for up to 5 days, ice cream for more than 60 days, and buttermilk for up to 10 days with excellent stability attributes.

The addition of dry rosemary to cottage cheese resulted in the highest antioxidant and antimicrobial effects due to high content of caffeic acid, rosmarinic acid, flavones, and phenolic diterpenes [45]. It was shown to limit the growth of foodborne pathogens including Staphylococcus aureus, Escherichia coli, Listeria monocytogenes, and Salmonella typhimurium during 3-day storage at 4 °C. Polyphenols contained in dry extracts from plants such as dill, parsley, garlic, and red sweet peppers were also tested in the same study and showed considerable antioxidant and antimicrobial activities, which was attributed to high polyphenolic contents in the final dried products. However, rosemary showed the highest antioxidant activity with a FRAP value of 17.1–26.4 mmol per 100 g, followed by dill, parsley, red sweet peppers, and garlic. Citrus aurantium L. flower extract containing total phenolic and flavonoid contents of 81 and 46 mg/g, respectively, was studied in yogurt stew during storage for 28 days at 4 °C [46]. The extract was shown to inhibit the growth of Pseudomonas aeruginosa, E. coli O157:H7, Bacillus cereus, and Staphylococcus aureus. The extract showed significant antioxidant potential where the IC_{50} value for DPPH assay was calculated as 41.6 µg/mL while the IC_{50} value for control (butylated hydroxytoluene) was 18.8 µg/mL. Similarly, a FRAP assay showed a reducing power of the extract of 18.47 mmol Fe^{2+}/mass. Anisidine value, peroxide value, protein carbonyls value, and conjugated diene value indicated that Citrus aurantium reduced protein and lipid oxidation products in yogurt stew during storage. Punica granatum L. rind extract demonstrated significant lipid oxidative stability and antimicrobial effects when added to cheese stored for 28 days at 4 °C, suggesting its potential use as a natural preservative in dairy products [47]. Punica granatum extract exhibit a significant decrease on TBARS (mg malonaldehyde/kg) and free fatty acid (% oleic acid) values. In addition, considerably lower values were observed for total plate count (log cfu/g), yeast and mold count (log cfu/g), and psychrophilic bacterial count (log cfu/g) in samples with added P. granatum extract. Organic cottage cheese flavored with Argentinean oregano essential oils (Cordobes, Compacto, Mendocino, and Criollo) was tested for the quality of storage and shelf-life at thermal storage for 30 days by Asensio and colleagues [48]. The samples flavored with thymol and Cordobes essential oil presented reduced conjugated dienes (15.53 and 15.94, respectively) as compared to 17.54 for the control sample. Samples flavored with Cordobes, Criollo, and Compacto essential oils exhibited reduced saturated/unsaturated fatty acid ratios than the control (1.62, 1.68, and 1.67, respectively). A significant low production of organic acids during storage was found in the samples flavored with Cordobes and Compacto essential oils.

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