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Effects of Plants Bioactive Compounds on Foods Microbial Spoilage and Lipid Oxidation

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Abstract Extracts of many types of plants that are utilized as flavoring and seasoning agents in foods, have been used therapeutically for centuries. Sulphur compounds, terpenes and terpene derivatives, phenols, esters, aldehydes, alcohols and glycosides have shown antimicrobial and antioxidant functions. So far many literatures about the potential use of bioactive phytochemicals in food and pharmacy industries have been published. Thus, this paper reviews some of the works done to evaluate antimicrobial and antioxidant characteristic of some herbal chemicals, carried out in the world.

Keywords Antimicrobial and Antioxidant Properties, Plants Bioactive Compounds, Foodstuff

1. Introduction

Fruits and vegetables, as active biological sources, contain phytochemicals with antimicrobial, antioxidant, antimutagenic and anticarcinogenic activities. Phytochemicals showing both antioxidant and antimicrobial properties can be used to preserve foodstuffs and increasing their shelf lives. Besides the antimicrobial effect of herbs and spices rich in phenolic compounds, they may preserve foods by reducing lipid oxidation as they are reported to have significant antioxidant activity [1]. Essential oils and plants extracts are known to possess multifunctional properties other than their classical roles as natural food additives. Many essential oils have been confirmed to possess the antioxidant, antibacterial, antifungal and anti-inflammatory activities [2]. Some of the essential oils and their major compounds, used in food systems so as to retard microbial spoilage, are shown in Table 1.

By increasing the consumer's demand for green food products with high safety, quality and nutritional values, it seems that using plants and materials of plant origin such as essential oils and extracts is a suitable way to meet this need. Natural aromatic plants and spices have been widely used in many food products, dairy and bakery products as flavoring and seasoning agents [3] for preservation and their medicinal value [4, 5]

Main constituents in spices such as sulphur compounds, terpenes and terpene derivatives, phenols, esters, aldehydes, alcohols and glycosides have shown antimicrobial functions [6-8]. The most important parameters affecting antimicrobial potential are the type and composition of the spice, amount used, type of microorganism, composition of the food, pH value, temperature of the environment, and proteins, lipids, salts, and phenolic substances in the food system [9].

Aromatic and medicinal plants essential oils as natural additives with potential benefits in food systems showed antibacterial, antifungal and antioxidant efficacies [10]. Antimicrobial properties of some essential oils at low concentrations are extremely higher than food grade organic acids. It has been shown that essential oils have larger efficacy and lower storage temperatures in foods with higher acidities [5]. Although antioxidative and antimicrobial effects of many essential oils have been verified *in vitro* systems; the same concentrations were not effective in some foodstuffs. For example, some processing procedures such as heating lead to lower efficacy of some essential oils in heated products due to their evaporation [3]. Volatile components of cinnamon leaf, clove, bay, lemongrass and thym essential oils were effective against *Eurotium amstelodami*, *E. herbariorum*, *E. repens*, *E. rubrum*, *Aspergillus flavus*, *A. niger* and *Penicillium corylophilum*. However, these essential oils weakly performed in case of sponge cake [11]. Gamma irradiation is widely applied in spices to inactivate microbial cells and to prolong their shelf life. Gamma irradiation had no adverse effects on antioxidant and antimicrobial activities and total phenolic content of cinnamon samples. Only at doses more than 10 kGy did the radical scavenging activity of the cinnamon extract increase. Jamshidi et al. (2012) recommended gamma irradiation at doses up to 25 kGy for cinnamon [12].

Table 1. Some of the essential oils and their major compounds used in foods systems to retard microbial spoilage

Natural additives	Effective components	Effective against	Known Applications	Potent applications	Food system	Reference
Annatto	9′- cis-norbixin and all transformed of norbixin	*Clostridium perfringens*, *Bacillus cereus*, *Staphylococcus aureus*,	Color additive, antioxidant in oil-in-water emulsions	Antimicrobial activity	Sausage samples	[15, 16]
Amaranthus spp. seeds	Cichoric acid (diamides), polysaccharides, alkamides (alkyl amides) and glycoproteins	*Penicillium brevicompactum*, *P. chermesinum* and *Eurotium herbarioum*	Astringent, hemostatic, nutritive, and alterative	Antifungal activity	Bread	[38]
Caraway	Carvone, limonene and (E)-anethole	Rice pests (*Sitophilus oryzae*, *Rhyzopertha dominica* and *Cryptolestes pusillus*)	Colds, colic, coughs, flatulence, indigestion, poor appetite, stomach cramps treatments, flavoring agent, soap and lotion production	Effective against pests	Rice	[56]
Cinnamon	Cinnamaldehyde	*Escherichia coli*, *Enterobacteriaceae*, *B. cereus*, coagulase-positive *Staphylococci*	Snakebites, freckles, the common cold, and kidney troubles treatments, flavoring agent and preservative	Antimicrobial activity	Kolompe	[40]
Coriander	Linalool, camphor, cyclohexanol acetate, limonene and α-pinene	Rice pests (*Sitophilus oryzae*, *Rhyzopertha dominica* and *Cryptolestes pusillus*), gram positive and gram negative bacteria, fungi	Anorexia, dyspepsia, flatulence, diarrhea, griping pain and vomiting treatment, flavoring agent perfumes cosmetics	Effective against pests, antioxidant and antifungal activities	Rice, cake	[56] [33, 35]
Lavandula angustifolia essential oil	Linalool, camplhore, 1, 8 cineol, inalol acetat, borneol and α-terpineol	*S. aureus*, *E. coli, coliforms,* molds and yeasts	Acne, allergies, burns (cell renewal), and cramps treatment, lotions bath oils	Antioxidant and antimicrobial agent	Butter milk, soybean oil	[44, 71]
Echinacea purpurea extract	Phenolic compounds such as chicoric acid, caffeic and chlorogenic	*E. coli*, Enterobacteriaceae, *B. cereus*, coagulase-positive *Staphylococci*	Immunostimulant, anticarcinogenic, common cold, influenza, respiratory and urinary treatment, ingredient in functional foods, supplements and certain candies	Antioxidant and antimicrobial activities	Kolompe,	[40, 63]
Eremophila alternifolia and *Eremophila duttonii*	Terpenes or sterols	*Listeria monocytogenes*	Colds and inflammation of the throat treatment	Antimicrobial activity	Full cream milk and skim milk	[46]
Mango seed kernel oil	Phenolic compounds	*Coliforms*		Antioxidant and antimicrobial activities	Sunflower oil, potato chips, pasteurized cow milk	[32, 33]
Tea seed oil	(-)-epigallocatechin-3-gallate (EGCG), α-tocopherol, and tocotrienols	*B. cereus* and *S. aureus*		Antioxidant and antimicrobial activity	Marine oil, common kilka (*Clupeonella cultriventris caspia*), cooked red meat, poultry and fish patties, rice cake	[22, 43, 51, 65, 66, 67, 68]

In many cases, bioactive compounds could be produced of inexpensive sources or totally agricultural wastes, which can provide economic and highly available sources from co-products during a typical processing procedure. Rajaei et al. (2010) studied antioxidant, antimicrobial and antimutagenicity activities of pistachio (*Ahmadaghaei* variety) green hull extract (crude and purified extracts). The results obtained by 2, 2′-Azinobis (3-ethylbenzothiazoline-6-sulfonate) diammonium salt (ABTS) assay, 2, 2′-diphenyl 1-picrylhydrazyl (DPPH) assay and β-carotene bleaching (BCB) method indicated that pistachio green hull aqueous extracts presents a strong antioxidant activity. Furthermore, inhibition of the growth of the different pathogenic bacteria ($Gram^+$) and antimutagenicity by pistachio green hull extract. The results of disc diffusion test showed that *Bacillus cereus* was the most susceptible one with minimum inhibitory concentration (MIC) of 1 and 0.5 mg mL^{-1} for the crude and purified extracts, respectively [13].

2. Food Applications

Although various plant extract compositions, trial methods and microorganisms under test make it difficult to compare data from different studies [11], due to development of the natural antioxidants used in food industries, here we emphasize the antimicrobial properties of some medicinal plants, focusing on their applications in different food types.

2.1. Meat Products and Fish

Meat, fish and poultry products are highly susceptible to spoilage. Since ancient times, different methods have been developed to preserve these products including: pickling, drying, salting, freezing and canning. However, in recent years, there is an upsurge of interest in natural bioactive compounds originated in traditional medicinal plants due to their low cost and abundant sources and verification of their antioxidant and antimicrobial activities against common pathogens. Therefore, many researchers focused on antimicrobial and antioxidant activities of natural compounds in spices commonly used in meat, fish and poultry products. Cinnamon essential oil is extracted from bark and leaves of *Cinnamomum verum*. The presence of cinnamaldehyde and eugenol in cinnamon essential oil is found to be key antioxidant and antimicrobial chemical compounds. It showed antimicrobial activity against *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Enterococcus faecalis*, *Micrococcus luteus*, *Escherichia coli* and *Candida albicans* as common meat spoilage and pathogenic microorganisms [14]. Annatto, a food coloring and flavoring agent used in meat and fish products, is extracted from pericarp of the achiote (*Bixa orellana* L.). Evaluation of the inhibitory effect of annatto extract on growth ability and spore germination of *Clostridium perfringens*, *B. cereus*, *S. aureus* and *E. coli* in chemical medium and in sausage sample, showed antibacterial potential of this extract against *C. perfringens*, *B. cereus* and *S. aureus*. However, no activity was detected against *E. coli*. In addition annatto was capable to inhibit spore germination and outgrowth of *C. perfringens* and *B. cereus*. In sausage samples with nitrite alone or in combination with nitrite at 20 ºC, no germination of spores were observed [15]. Concerning the effective part in creating antimicrobial effect, literature shows that 9′-cis-norbixin and all transformed of norbixin are capable to create this characteristic [16].

Antimicrobial activities of garlic oil and nine constituents of essential oils (allyl isothiocyanate, carvacrol, cinnamaldehyde, citral, cuminnaldehyde, eugenol, isoeugenol, linalool and thymol) were evaluated against 16 bacterial strains isolated from common carp (*Cyprinus carpio*), by paper disc diffusion method. The most effective compounds against this microflora were thymol, carvcarol and cinnamaldehyde followed by isoeugenol, eugenol, garlic oil, and citral, while cuminnaldehyde, linalool and allyl isothiocyanate exhibited lower efficacy. An equal mixture of carvacrol and thymol solution, before storage at 5°C and 10°C, reduced the total count by about 100-fold in carp fillets and reduced the volatile base nitrogen. A concentration of 1% of carvacrol-thymol mixture solution inhibited bacterial growth and extended the shelf life of the dipped fillets by 8 and 4 days at low temperature over 5°C and 10°C storage, respectively [17].

Growth of *Photobacterium phosphoreum* has been inhibited by oregano oil in liquid medium and in naturally contaminated vacuum packed cod fillets at 2ºC and an increase in shelf life by 10-14 days has been successfully achieved [18]. Synergistic effect of modified atmosphere packaging with essential oils against spoilage bacteria has been used to extend shelf life of food products. Similarly, Chouliara et al. (2007) reported that combination of modified atmosphere packaging and oregano essential oil could remarkedly reduce microbial population by 1-5 log cfu/g in fresh chicken meat [19]. Antimicrobial properties of turmeric extract and shallot extract was examined both individually and in combination (1:1) on the quality of vacuum-packaged rainbow trout during refrigerated storage. Combined treatment of both turmeric and shallot extracts provided a hurdle technology for protecting the rainbow trout from the risk of pathogenic microorganism [20].

The most abundant water-soluble antioxidant vitamin that can react with superoxide radicals, hydrogen peroxide, hydroxyl radicals and single oxygen through Hydrogen Atom Transfer and remove reactive oxygen species is ascorbic acid [21]. Ojagh et al. (2011) examined the antioxidant effects of β-carotene in con centration of 100, 200, and 300 ppm combined with ascorbic acid (0.1, 0.2 and 0.3 g, respectively as a synergist agent) and green tea polyphenols in concentration of 200, 400 and 600 ppm on the quality of common kilka (*Clupeonella cultriventris caspia*)

during the storage with ice powder. According to the results, the β-carotene 100 and green tea polyphenols 200 samples produced the best preservation condition, while they did not have any significant difference in their qualitative characteristics (color, odor, texture, taste and flavor as well as off-flavor) [22]. Also, addition of concentrations greater than 300 mg kg^{-1} of tea catechins considerably reduced oxidation rate in patties [23].

Karpińska et al. (2001) reported that application of 1.5% of sage alone was more effective on turkey meat dish storage stability than the 1% mixture of spices (sage, red pepper, black pepper, garlic and marjoram). The quality of products with 1.5% sage was good after a-four-day storage in refrigerator [24].

Black cumin (*Nigella sativa*) is a medicinal seed, native to South and Southwest of Asia. Its antifungal and antibacterial effects have been studied by many researchers. Treatment with ethanolic extract of *N. sativa* reduced aerobic plate count, yeast, and coliforms in marinated raw trout (*Oncorhynchus mykiss*) [1].

Listeria monocytogenes is a gram-positive, psychrotrophic and facultative anaerobic bacterium, which causes the infection Listeriosis. Meats and fish products are known as food sources that have sometimes led to Listeriosis outbreaks. Application of oregano and cranberry extracts (75:25) against *L. monocytogenes in vitro* and in beef and fish showed good inhibitory effect. Combination of these phytochemicals with lactic acid was also found more effective when beef and fish slices were stored at 4°C [25]. *Micromelum minutum* and *Artocarpus heterophyllus* could effectively suppress *L. monocytogenes* in cooked pork at the storage temperature of 4°C for up to 7 days [26].

Rosemary has been extensively investigated for its antioxidant potent [27]. A mixture of aqueous extract of rosemary, sage and thyme was successfully used in marinated turkey thigh to prevent rancidity during storage [28]. Combination of Scutellaria, honeysuckle, forsythia and cinnamon and mixture of cinnamon, rosemary and clove oil reduced microbial counts from 1.81 to 2.32-log as compared to control in vacuum packaged fresh pork during 28 days storage [1].

Antimicrobial, antiradical and antioxidant activities of pomegranate peel extract have been shown. It possessed good antimicrobial activity against *S. aureus* and *B. cereus* at concentration of 0.01%. Addition of this extract to chicken meat products enhanced their shelf life by 2–3 weeks during chilled storage [29].

2.2. Bakery Products

Major microbial spoilage in bakery products is mold growth resulting in economic losses. Therefore, numerous techniques have been implemented to prevent or control the growth of spoilage microorganisms and enhance shelf life of food products. Various types of spices are used in bakery industries mainly to improve taste and flavor. Recently, a large number of these ingredients have demonstrated antimicrobial and antioxidant activities. Kordsardoui et al. (2011) studied antifungal properties of *Zataria multiflora Boiss* essential oil (ZMEO) in cake. This plant is one of the important species of Labiatae family, which is widely used as nutritional flavoring. According to this study, application of ZMEO at concentrations of 500, 1000 and 1500 ppm reduced mold counts significantly during cake batter production [30]. According to Zangiabadi et al. (2012) total phenolic contents of ZMEO was 322 mg ml^{-1} by Folin-Ciocalteu [31].

Recently, many studies proved that mango seed kernels possess antioxidant activity due to their different phenolic compounds [32]. Bakery products prepared with mango dietary fiber concentrate of unripe fruit, possessed most of its antiradical efficiency [33].

Coriander is the common name of *Coriandrum sativum* also known as Chinese parsley. Coriander essential oil (CEO) has been found to exhibit antioxidant and antimicrobial effects. It has been revealed that CEO at 0.05, 0.10 and 0.15% prevented the primary and secondary oxidation products formation, and at 0.15% level, it inhibited fungal growth in cake. Chemical composition of CEO mainly consists of camphor (44.99%), cyclohexanol acetate (cis-2-tert butyl-) (14.45%), limonene (7.17%), α-pinene (6.37%). Antioxidant effects of this essential oil may be due to its trepene and terpenoid components [34]. Another study demonstrated antimicrobial activity of CEO against five species of *Candida albicans* [35]. Also, it is reported that coriander essential oil has pronounced antibacterial activity against both Gram positive (*S. aureus* and *Bacillus* spp.) and Gram negative (*E. coli*, *Salmonella typhi*, *K. pneumonia* and *Proteus mirabilis*) bacteria. In addition, this extract showed anthelmintic activities against *Haemonchus contortus* [34]. Several researchers have described the antifungal activity of limonene, a terpenoid hydrocarbon isolated from coriander, against *Aspergillus niger*. According to Darughe et al. (2012) this essential oil could be used as natural antioxidant and antifungal in foodstuffs especially those lipid containing [34].

Echinacea purpurea L. extract was found to be effective in controlling growing molds and lipid oxidation during 60 days storage at 25°C. According to antimycotic evaluation, 1000 ppm of the extract showed greater antioxidant activity than 200 ppm BHA, and at concentrations of 1500 and 2000 ppm had an excellent antifungal effect on cake [36]. Noorolahi et al. (2013) also reported that 0.5 and 0.75% of *E. purpurea* extract showed very well preventing power on aerobic microorganism, yeast and molds [40].

Most important spoilage molds in cakes and bakery products are *Rhizopus stolonifer*, *Penicillium expansum*, *P. stoloniferum*, *A. niger*, *Monilia sitophila* and species of *Mucor* and *Geotrichum*. Lean and Mohamed (1999) indicated that turmeric showed antioxidant and antimycotic activities in butter cake [37]. In another study by Rizzello et al. (2009), common spoilage microorganisms in bread were inhibited by water-soluble extract of *Amaranthus* spp. seeds and it was indicated that may be also exerted as sensory

improving agent in wheat and gluten-free breads [38].

Rice bran is the byproduct of rice milling process. It is a rich source of important phytochemicals resulting in its significant antioxidant property. Among all phytochemicals, oryzanol, tocopherols and tocotrienols are considered the most powerful ones. Bhanger et al. (2008) reported that 500, 1000 and 2000 ppm of methanolic extracts of rice bran could successfully increase induction period from 7.5 hours to 14.73-31.22 hours in cookies [39].

Chamomile essential oil as a natural antioxidant and antimicrobial agent can increase shelf life of food products. Fungicidal effect of 0.15% of chamomile essential oil during 75 days of storage of cake was observed by Khaki et al. (2012) and it was reported that with increasing the concentration of chamomile essential oil, inhibitory activity would increase, and also, after 75 days, growth of molds was observed in all samples [41]. In another study, they investigated neroli essential oil in cake. Application of 0.05, 0.1 and 0.15% of this essence had a positive effect against *E. coli*, *coliforms*, *S. aureus*, Enterobacteriaceae, molds and yeasts [42].

Reddy et al. (2005) used three plant foods amla (*Emblica officianalis*), drumstick leaves (*Moringa oleifera*) and raisins (*Vitis vinifera*) as natural antioxidant sources in biscuits. Extracts from drumstick leaves and amla had more influence on controlling lipid oxidation during storage. Plant extracts from the three plant foods had pronounced antioxidative effect on biscuits after 6 weeks compared with the effect of BHA [4].

As described by Lee et al. (2009), 1 or 3% green tea or rosemary leaf powders added to rice cakes did not significantly reduce total aerobic counts. But levels of *B. cereus* and *S. aureus* were significantly reduced in rice cakes stored for 3 days at room temperature (22 ºC). Individual leaf powders of green tea and rosemary at 3% level had the strongest inhibitory effect, followed by 1% green tea and 1% rosemary leaf powder, respectively [43].

2.3. Dairy Products

The effect of *Lavandula angustifolia* essence on some microbial parameters of butter milk preservation was studied. This essence was successfully used as natural antimicrobial against *S. aureus*, *E. coli*, *coliforms*, molds and yeasts [44]. Investigation of mango seed kernel extract on pasteurized cow milk indicated that it had the potent to reduce total bacterial count and inhibited the growth of *coliforms* resulting in longer shelf life [1]. Oregano and thyme showed less antimicrobial effect against *L. monocytogenes* compared to *Pseudomonas fluorescens* on milk model media [45]. According to a study by Owen and Palombo (2007), the presence of fat in full cream milk could significantly reduce the antibacterial activity of whole plant extracts of *Eremophila alternifolia* and *E. duttonii* against *L. monocytogenes* compared to skim milk [46].

Ziziphora clinopodioides (with folk name of Kakuti-e Kuhi) is one of four species of *Ziziphora L.* It is widely grown in Iran and used as flavoring agent and in traditional medicine. Antioxidant and antimicrobial properties of the essential oil have been shown. A 4000 μg L^{-1} level of *Ziziphora clinopodioides* extract noticeably reduced the growth of yogurt starter culture [47]. Study on effect of mint extract in a native Iranian dairy drink containing probiotic bacteria, biodoogh, indicated a concentration dependent effect on the viability of probiotic strains [48].

2.4. Fruit and Vegetable Juices

Investigation of *E. coli* O157:H7 inoculated in apple juice indicated that carvacrol, oregano oil, geraniol, eugenol, cinnamon leaf oil, citral, clove bud oil, lemongrass oil, cinnamon bark oil, and lemon oil had the most effective compounds and Melissa oil, carvacrol, oregano oil, terpeineol, geraniol, lemon oil, citral, lemongrass oil, cinnamon leaf oil and linalool had good antimicrobial potent against *Salmonella enterica* [49].

Storage temperature is one of the most important parameters affecting antioxidant and antimicrobial activities of bioactive components. Increasing the temperature from 45 to 50ºC could significantly enhance mint extract efficacy in tomato juice [50].

Antimicrobial activity of koruk (*Vitis vinifera*) juice against two *Salmonella typhimurium* strains was determined in inoculated cucumber and parsley samples. Although koruk juice led to an instant reduction in initial total count, treatment for 15, 30 and 60 minutes did not differ significantly regarding reduction in total count [51].

Hippophae rhamnoides (known as sea buckthorn), owned by Elaeagnaceae family, is reputed to be an antioxidant-rich source. Ascorbic acid was reported to be the major antioxidant compound in sea buckthorn juice. The phenolic composition of sea buckthorn berry-like fruit juice was investigated. Flavonols were found to be the predominating polyphenols while phenolic acids and catechins represent minor components [52].

2.5. Sauces

Satureja hortensis L. belongs to Lamiaceae family and is well known in Iranian traditional medicine. The formulated mayonnaise prepared by the mixture of linseed and soybean oil and amended with ZMEO and *Satureja hortensis* L. essential oil (SHEO), showed that these natural antioxidants in mayonnaise formulation can ameliorate the quality of product as functional food due to advancing the public health [53].

“Tarkhun” and “Babune Shirazi” are the Persian names for *Artemisia dracunculus* L. and *Matricaria chamomilla* L., respectively, belonging to the family Asteraceae and are commonly used as condiment for sauces. The essential oil of Tarkhun is said to be a neuromuscular antispasmodic, anti-inflammatory, and used in aerophagy, spasmodic colitis, and as antibacterial and antifungal agent. *M. chamomilla* L. essential oil has been used commonly in medicine as an

anti-inflammatory, antispasmodic, anti-intestinal bloating, anti-pectic ulcer, anti-bacterial and anti-fungal [54].

Garlic has been used as a food additive and medicinal plant for thousands years. Scientific literature on garlic suggests different potentially beneficial effects on human health due to its related compounds. Study on antimicrobial effect of garlic against *S. enterica* serovar *enteritidis* showed 1% garlic decreased the viable cells in mayonnaise contaminated with 105 cfu g^{-1} *S. enterica* serovar *enteritidis* by a factor of 10 [55].

2.6. Cereals

The usefulness of bioactive compounds included essential oils as insecticides has been reported and traditionally implemented to protect grains against pests during storage by some countries. Lopez et al. (2008) investigated efficacy of essential oils of coriander, caraway and basil against stored rice pests (*Sitophilus oryzae*, *Rhyzopertha dominica* and *Cryptolestes pusillus*). The major effective compound in coriander oil was linalool at 1617 ppm against the three pests. Camphor-rich fractions significantly affected *R. dominica* and *C. pusillus* at concentrations greater than 400 ppm. Caraway extract included carvone, limonene and (E)-anethole as major constituents. Carvone and (E)-anethole were highly effective against *S. oryzae* and *R. dominica*, respectively, whereas only adults of *C. pusillus* were negatively affected by vapors of limonene [56].

2.7. Fruits and Vegetables

It is supposed that essential oils in vegetable dishes have better antimicrobial activity due to their low fat content [57]. Carvacrol and cinnamaldehyde exhibited higher potent in reducing the population of the natural flora on kiwifruit dipped in 0.15 μl ml^{-1}, than on honeydew melon. This difference probably emerged from the difference in pH between the fruits; the pH of kiwifruit was 3.2–3.6 and of the melon 5.4–5.5, i.e., essential oils and their constituents perform better in higher acidities [57].

Essential oil components that have been tested on vegetables appear effective against the natural flora and food-borne pathogens at levels of 0.1–10 μl g^{-1} in washing water. Cinnamaldehyde and thymol are effective against six *Salmonella* serotypes on alfalfa seeds (application in hot air at 50°C as fumigation). Efficacy of these natural antibacterial compounds decreased with increasing the temperature to 70°C. As indicated once, it may be due to evaporation of the effective compounds. Oregano oil showed inhibitory effect against *E. coli* O157:H7 at concentrations of 7–21 μl g^{-1} in eggplant salad [57]. Spice hydrosols have been used due to their low cost and easiness of application especially in beverage industries for a long time. Thyme hydrosols produced a reduction of more than 1 log cfu g^{-1} of *E. coli* O157:H7 and *S. typhimurium* number on inoculated apples and carrots. Overall, thyme hydrosol was more effective against *S. typhimurium* compared to *E. coli* O157:H7 on carrot samples with maximum reduction of 1.48 log cfu g^{-1} in *S. typhimurium* population [58].

2.8. Food Packaging

Basil (*Ocimum basilicum* L.) is a popular culinary herb, and its essential oils have been used as aroma additives in food, pharmaceuticals, and cosmetics [59]. Antimicrobial efficacy of Basil essential oils and their major components against a wide range of Gram-negative and Gram-positive bacteria, yeast, and mold has been proved. Suppakul et al. (2003) evaluated its potential in active food packaging [60]. Edible films on milk protein-base containing oregano, pimento, or oregano/pimento showed antibacterial properties against *E. coli* O157:H7 and *Pseudomonas* sp. on meat surfaces [61].

Nielsen and Rios (2000) investigated a mixture of spices and herbs as an alternative to active packaging for bread. The essential oils of mustard were the most effective followed by cinnamon, garlic and clove. However, oregano oleoresin and vanilla essential oil had weak activity and no inhibitory potent against most important spoilage fungi of bread, respectively [62].

2.9. Oil Systems

There are a lot of studies which proved the efficacy of essential oils in oil systems. Table 2 shows some of these investigations conducted medical plants application in different crude oils.

Hyssopus officinalis L. and *Echinacea purpurea* L. could be appropriate natural alternatives to synthetic antioxidants in soybean oil system. According to three $DPPH^{\bullet}$, $ABTS^{\bullet+}$ and beta carotene bleaching tests, the antioxidant activity of *Hyssopus officinalis* L. was greater than of *Echinacea purpurea* L. extract in soybean oil [63]. Oxidation rate of soybean oil reduced by *Artemisia dracunculus* L. and *Matricaria chamomilla* L. essential oils under accelerated conditions at 60°C (oven test) [54]. Likewise, dill (*Anethum graveolens Boiss*) with the vernacular name of shebet in Iran was found effective in inhibition of oxidation in crude soybean oil at 0.6 mg ml^{-1} concentration, suggesting that it could provide a good alternative to synthetic antioxidants [64].

According to investigations, the antioxidant activity of tea seed oil is mainly due to (-)-epigallocatechin-3-gallate (EGCG), α-tocopherol, and tocotrienols [65] and even, its antioxidant properties increased during the roasting process [21]. According to Wanasundara and Shahidi (1996) antioxidative activity of tea catechins is similar to or better than that of synthetic antioxidants [66]. Decholrophylized green tea extract was found to have antioxidative activity in marine oils; however, green tea extracts exhibited a prooxidant effect [67]. Fazel et al. (2009) applied tea and sesame seed oils as two natural antioxidants to a fish oil model system and compared them by radical scavenging activity. The results revealed that radical scavenging activity

of sesame seed oil was higher than that of tea seed oil (IC_{50}=37 mg and 45 mg, respectively). However, after 6 days at 60□C, the radical scavenging activity values of tea and sesame seed oils were the same [68].

Essential oil of *Zataria multiflora Boiss* containing carvacrol (26.08%) and thymol (17.23%) as main phenolic components showed good antioxidant activity in soybean oil [5]. However, in another study, ZMEO (1000 ppm) and SHEO (200 ppm) showed less antioxidant effect compared to BHA (200 ppm) as a synthetic antioxidant [69]. On the other hand, SHEO inhibited oxidation in safflower oil [70]. Linalool, camphore, 1, 8-cineol, inalol acetat, borneol and α-terpineol are six major bioactive components in *Lavandula angustifolia* essential oil reported to have antiradical activities in crude soybean oil [71]. Similarly, *Malva sylvestris* L. essence has shown antioxidant potential with maximum antiradical activity related to the 10 mg/ml of this essence [72]. Studies showed 400 ppm methanol extract and 5% mango seed kernel oil increased stability of sunflower oil both in ambient and in frying temperature against oxidation. Also, this mixture could increase oxidative stability and quality characteristic of potato chips [32].

Table 2. Some medical plants applications in different crude oil

Family	Latin name	Persian/Local name	Assays for determining antioxidant activity	Trial oil	Reference
Apiaceae	*Anethum graveolens Boiss*	Shebet	$DPPH^{\bullet}$ and beta carotene bleaching	Soybean oil	[64]
Asteraceae	*Echinacea purpurea* L.	Purple coneflower (Sarkhargol)	$DPPH^{\bullet}$, $ABTS^{\bullet+}$ and beta carotene bleaching	Soybean oil	[63]
Asteraceae	*Matricaria chamomilla* L.	Babune Shirazi	$DPPH^{\bullet}$ and beta carotene bleaching	Soybean oil	[54]
Labiatae	*Hyssopus officinalis* L.	Zoofa	$DPPH^{\bullet}$, $ABTS^{\bullet+}$ and beta carotene bleaching	Soybean oil	[63]
Labmiaceae	*Lavandula angustifolia*	Ostokhodus	$DPPH^{\bullet}$, $ABTS^{\bullet+}$ and beta carotene bleaching	Soybean oil	[71]
Labmiaceae (Labiatae; minths)	*Satureja hortensis* L.	Marze	Specific absorbance at 232 and 270 nm (conjugated dienens and trienes) $DPPH^{\bullet}$, $ABTS^{\bullet+}$, ferric thiocyanate and beta carotene bleaching Conjugated dienens and peroxide value	Soybean oil Safflower oil Linseed oil	[69] [70] [53]
Labiatae	*Zataria multiflora Boiss*	Avishan	Specific absorbance at 232 and 270 nm (conjugated dienens and trienes), peroxide value $DPPH^{\bullet}$ and beta carotene bleaching Conjugated dienens and peroxide value	Soybean oil Soybean oil Linseed oil	[5] [53]
Malvaceae	*Malva sylvestris* L.	Panirak	$DPPH^{\bullet}$, $ABTS^{\bullet+}$ and beta carotene bleaching	Soybean oil	[72]

3. Conclusion

Natural antioxidants and antimicrobials can improve shelf life of food products, and due to absence of synthetic agents, these compounds are safe without any side effects on human health. Antimicrobial activity of plant extracts is frequently due to the essential oil fraction or to sulfur-containing compounds in the aqueous phase. The composition, structure and functional groups in oils play an important role in determining their antimicrobial activity. Results of different studies indicate that herbal bioactive compounds can act as good replacers of synthetic antioxidant and preservatives.

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