# Potential of Medicinal Plants as Antimicrobial and Antioxidant Agents in Food Industry: A Hypothesis

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**Abstract:** Many food preservation strategies can be used for the control of microbial spoilage and oxidation; however, these quality problems are not yet controlled adequately. Although synthetic antimicrobial and antioxidant agents are approved in many countries, the use of natural safe and effective preservatives is a demand of food consumers and producers. This paper proposes medicinal plants, traditionally used to treat health disorders and prevent diseases, as a source of bioactive compounds having food additive properties. Medicinal plants are rich in terpenes and phenolic compounds that present antimicrobial and antioxidant properties; in addition, the literature revealed that these bioactive compounds extracted from other plants have been effective in food systems. In this context, the present hypothesis paper states that bioactive molecules extracted from medicinal plants can be used as antimicrobial and antioxidant additives in the food industry.

**Keywords:** food safety, natural products, phenolic compounds, terpenes

## Introduction

The search of new safe substances for food preservation is being performed around the world (Magnuson and others 2013). Synthetic food additives are passing a difficult season in addition to the great deal of time and money that is required to develop and approve new synthetic preservatives, especially in view of the public pressure against them (Tajkarimi and others 2010). The excessive use of synthetic preservatives, some of which are suspected because of their toxicity, increased pressure on food manufacturers to either completely remove these agents or to adopt natural alternatives for the maintenance or extension of a product's shelf life (Seneviratne and Kotuwegedara 2009). Such obstacles provide new opportunities for those seeking natural alternatives for new food preservatives.

Many plant occurring bioactive compounds can be considered as good alternatives to synthetic antimicrobial and antioxidant food additives (Cowan 1999; Silva-Espinoza and others 2013). These compounds are mostly derived from plants and their antimicrobial and antioxidant *in vitro* testing have resulted in many publications in the last decade (Nakatani 2000; Yanishlieva and others 2006; Krishnaiah and others 2011; Martins and others 2013). The antimicrobial and antioxidant properties of bioactive compounds are mainly due to their redox properties, ability to chelate metals, and quenching reactive species of singlet oxygen (Krishnaiah and others 2011). However, the selection of the plant sources to extract these compounds must be guided for the safe use of food additives. A possible alternative could be medicinal plants that have been used for thousands of years to treat health disorders and prevent diseases.

Medicinal plant parts (roots, leaves, branches/stems, barks, flowers, and fruits) are commonly rich in terpenes (carvacrol, citral, linalool, and geraniol) and phenolics (flavonoids and phenolic acids), and these compounds have been effective as food additives (Cai and others 2004). For example, lemongrass is a medicinal plant utilized as stomachic, antispasmodic, carminative, and antihypertensive agent (Naik and others 2010); in addition, it is a source of terpenes like citral that has shown antimicrobial activity against food pathogen and deteriorative bacteria, and antioxidant effect avoiding lipid peroxidation in food matrices (Ahmad and others 2012; Masniyom and others 2012). Other medicinal plants that could be used to sustain the idea of generating extracts with potential as food additives are: *Chenopodium ambrosioides* rich in terpenes (used to control menses disorders, fibroids, uterine hemorrhage, and parasitic diseases); *Euphorbia stenoclada* rich in phenolics (used to control skin diseases, gonorrhoea, migraine, intestinal parasites and wart cures); *Geranium mexicanum* rich in terpenes and phenolics (used as remedy against tonsillitis, cough, whooping cough, urticaria, dysentery and diarrhea); *Gnaphalium oxyphyllum* rich in phenolics (used to treat gripe, fever, asthma, bronchitis, and cough); *Helianthemum glomeratum* rich in flavonoids (used to treat bloody and mucoid diarrheas and for the relief of abdominal pain); *Larrea tridentata* rich in phenolic compounds (used to treat respiratory infections as tuberculosis); *Marrubium vulgare* rich in terpenes and phenolics (used mainly as an expectorant); *Peumus boldus* rich in phenolics and alkaloids (regulator of the hepatic function, colagogue, antispasmodic, digestive stimulant, and nervous sedative); *Eysenhardtia polystachya* rich in flavonoids (used to treat kidney and bladder infections, diuretic, antispasmodic and febrifuge). Previous studies have demonstrated that other plant extracts rich in similar bioactive compounds are effective in food systems. With this in mind, the present hypothesis paper describes the premises to sustain that "antimicrobial and antioxidant agents having potentialities in the food industries can be obtain from

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medicinal plants." This manuscript also contemplates the sensorial and toxicological shortcomings to achieve this goal.

## Premise I. Need of Natural Additives for Food Preservation

Most of the food systems are highly perishable products attributed to their intrinsic characteristics and environmental conditions. Quality and safety of foodstuffs are compromised by the loss of nutrients, sensorial attributes, and microbial growth. Their composition rich in substrates for microbial and enzymatic reactions cause these problems (Ayala-Zavala and others 2008). Food safety is an important international issue that is compromised by the presence of pathogenic bacteria (Godfray and others 2010). Food poisoning is associated with organisms such as *Staphylococcus aureus*, *Salmonella spp.*, *Bacillus cereus*, *Clostridium botulinum*, *Clostridium perfringens*, *Listeria monocytogenes*, *Campylobacter jejuni*, *E. coli* O157:H7, and *Toxoplasma gondii* (CDC 2011). Produce, seafood, poultry, and beef are mostly linked to foodborne illness outbreaks and are reported to be responsible for 53% of all the cases and 48% of illnesses (CSPI 2013). With food safety and pathogens, the path forward is clear: Increase monitoring and enforcement, develop and apply good hygiene and disinfection, and communicate risks broadly to the consuming public. Besides microbial growth, oxidation is another problem in numerous food products.

Lipids are the most susceptible food molecules to oxidative processes; however, proteins and carbohydrates can also be affected. Food oxidation not only results a rancid taste and an alteration in color, flavor or texture; in addition, it can result in deterioration of the nutritional qualities and even compromise safety (McClements and Decker 2006), for example, the vegetable oils are exposed to oxidizing environment during food processing and get oxidized (Brewer 2013). Oxidative deterioration can also occur in refrigerated, frozen, cooked, cured, freeze-dried, and irradiated meat products; and natural antioxidants can be used to retard this process (Pukalskas and others 2011). Food safety assurance and oxidation control are challenging situations even for modern preservatives techniques. Additionally, consumers demand safe and quality food preserved with natural additives (Brewer 2013). In this context, the search for effective natural substances to avoid food quality decay and assure safety is a major challenge to the food scientist.

## Premise II. Antibiotic and Antioxidant Activity of Medicinal Plants

As described before the use of natural compounds to avoid food quality deterioration and assure microbial safety has been of interest for consumers, producers, and scientists, in this context, medicinal plants should be considered as an alternative source to generate food additives. This potential is justified in the similarity in composition of these plants with other plant extracts that have successfully been applied to maintain food quality and assure microbial safety, in addition to the ancestral human uses of most of these plants.

### *Cymbopogon citratus* (D.C.) Stapf. (Lemongrass)

*C. citratus* is an Indian native plant widely used in the kitchen for food and beverage preparation; infusions or decoctions of its dried leaves have also been used against various diseases as stomachic, antihypertensive, carminative, antispasmodic, relaxant, and antidepressant agent (Figueirinha and others 2008). The essential oil of *C. citratus* is composed mainly by geranial, neral, and myrcene, and these are of major importance for the flavor and fragrance industries (Kasali and others 2001). Infusion extract from *C. citratus* exhibited strong activity against DPPH radical (Figueirinha and others 2008). In another study, *C. citratus* extract tested at 2 concentrations (33 and 50 $\mu$g/mL) were effective reducing the DPPH radical (40% and 68%) and superoxide anion production (15% to 32%), and at 500 $\mu$g/mL of these extracts the oxidation of erythrocytes membranes were kept in range of 19% to 71% (Cheel and others 2005). Similarly, the tannin and flavonoid fractions from essential oil-free infusion of *C. citratus* were effective in preventing the production of reactive oxygen species. DPPH inhibition ($IC_{50}$) concentrations of *Cymbopogon schoenanthus* L. ranged from 6.8 to 26.4 mg/mL, depending on the extraction solvent and sampled region (Khadri and others 2010). The same extracts showed good antimicrobial activity against *Streptococcus sobrinus* at low concentration (MIC = 4 mg/mL).

*C. citratus* can be used as a phytochemical agent incorporated into polymer coatings (Seabrook 2005). *C. citratus* oil was effective to inactivate *Salmonella enterica* on romaine, iceberg lettuces, and baby spinach (Moore-Neibel and others 2012). The essential oil and its majors components (citral and geraniol) were most effective for inhibiting *Streptococcus agalactiae and B. cereus* than *S. aureus and E. coli*; in addition, these compounds showed antibiofilm activity against *S. aureus* (Aiemsaard and others 2011). The same study concluded that the antibacterial activity depended on the concentration, compositions, and cell target sites. The state in the art of the composition and uses of *C. citratus* exemplified clearly the statement that a medicinal plant can be used to generate extracts effective as food additives, more details will be describe in the next premise.

### *Euphorbia stenoclada* Baill. (Silver thicket)

Stem infusion from *E. stenoclada* is traditionally used to heal respiratory disorders (Chaabi and others 2007). Two flavonoids, quercetin and quercitrin, were identified in extracts of this plant and indicates that phenolic compounds could be their bioactive constituents. The antiproliferative activity of these compounds were attributable to their molecular structure (free hydroxyls groups, methylation, glycosylation) (Chaabi and others 2007). The antioxidant effects of quercetin were comparable to that of catechin in AAPH-initiated peroxidation of liposomal suspension (Terao and others 1994). Quercetin is also effective to control lipid peroxidation in phospholipids (Terao and others 1994). Guinea pigs treated either with quercetin (142.9 mg/kg) or quercetrin (214.3 mg/kg) were resistant to *Shigella* sp. infection (Vijaya and Ananthan 1996). Quercetin is also a potent antibacterial agents against, *S. epidermidis*, *S. aureus*, *Bacillus subtilis*, *E. coli*, and *Micrococcus luteus* (Rauha and others 2000). The activity of quercetin has been at least partially attributed to the inhibition of DNA gyrase (Cushnie and Lamb 2005). This information revealed that the antioxidant and antimicrobial activity of *E. stenoclada* could be attributed partially to phenolic compounds.

### *Geranium mexicanum* Kunt (Geranium)

The genus *Geranium* is formed by almost 400 species in tropical mountains and temperate areas throughout the world (Alanís and others 2005). Some geranium species are used in traditional medicine as antidiabetic, hemostatic, antihemorrhoidal, antidiarrheic and in treatment of tonsillitis, cough, whooping cough, urticaria, dysentery, kidney pain, and gastrointestinal ailments (Calzada and others 2005). In previous studies, different types of compounds such as tannins (Calzada and others 2001; Calzada and others 2005), flavonoids (Şöhretoğlu and others 2009), lignans (Liu and others 2006) as well as essential oils (Toshkova and others 2004), have been isolated from *Geranium* species. The extracts from *G. mexicanum* (<8 mg/mL) possessed strong antibacterial activity against *Salmonella* spp., *Shigella* spp., and *E. coli* (Alanís and others 2005). Epicatechin and 2 flavan-3-ols were the active compound of *G. mexicanum* inducing the reduction of *Giardia lamblia* and *Entamoeba histolytica* (Calzada and others 2005). Results revealed that (–)-epicatechin therapy lowers lipid peroxidation in streptozotocin-induced diabetic rat tissues (Quine and Raghu 2005). Some studies have shown that (–)-epicatechin is a good hydroxyl radical scavenger, since it contains benzene ring and such aromatic compounds are known to have very high rate constants for reactivity with the hydroxyl radical (Rice-Evans 1999; Aruoma 2003).

### *Helianthemum glomeratum* Lag (Clustered frostweed)

*H. glomeratum* is an endemic Mexican herb with medicinal properties (analgesic in stomach pain, antidiarrheic, antiparasitic, and antidysenteric drug) (Calzada and Alanís 2007). The antidiarrheal and antiamoebic effect of this plant is attributed to tiliroside, quercitrin, kaempferol, epigallocatechin, and isoquercitrin (Calzada and others 1995; Calzada and Alanís 2007). In addition, these compounds could be effective as antioxidant, antibiotic, antiviral, antiallergenic, antigiardial, antiamoebic, antiinflammatory, and protective against cancer and heart diseases (Barbosa and others 2007). There is a patent proposing extracts of *H. glomeratum* as a dietary supplement for regulating the appetite and weight loss (Teisen-Simony and Saaby-Nielsen 2009). As shown in the literature, *H. glomeratum* is a rich source of phenolic compounds; these could be used as additives in the food industry.

### *Gnaphalium oxyphyllum* DC. (Gordolobo)

*Gnaphalium* spp. are plants widely used in traditional medicine for the relief of swellings, stomach diseases, wounds, lumbago, antimalarial, prostatism, neuritis, diuretic, angina ache, antipyretic, and for the lowering of blood pressure (Hocking 1997; Taddei-Bringas and others 1999; Rojas and others 2001; Campos-Bedolla and others 2005). Constituents have been isolated as diterpenoids, flavonoids, acetylenic compounds, and carotenoids (Meragelman and others 2003). Other isolated constituents from this plant are ent-Kaur-16-en-19-oic acid, ent-3-hydroxykaur-16-en-19-oic acid, zoapatlin, 13-epi-sclareol, 13-epi-cyclosclareol, luteolin, 3-methoxyquercetin, 5-hydroxy-3,7- dimethoxyflavone, $\beta$-sitosterol and stigmasterol (Villagómez-Ibarra and others 2001). Extracts from this plant have proved to be effective as antibacterial agents. The hexane extracts of flowers or leaves from *G. oxyphyllum var. oxyphyllum*, *G. liebmannii var. monticola* and *G. viscosum* showed higher inhibition against both *S. aureus* and *B. cereus*, except the *G. viscosum* leaf extract, which only inhibited *B. cereus* (Villagómez-Ibarra and others 2001). The *G. oxyphyllum* flower extract, characterized by the highest content of ent-kaur-16-en19-oic acid, showed a broader spectrum of activity, extended to *S.* Typhimurium and *E. coli*. Also, the methanol extract of *G. oxyphyllum* flowers, in which luteolin and 3-methoxyquercetin were found, significantly inhibited *S. aureus* and *B. cereus. G. oxyphyllum* was effective to inhibit pathogens bacterial as *S. aureus*, *E. coli*, *Enterococcus faecalis*, *Candida albicans*, *Streptococcus pyogenes*, and *Streptococcus pneumoniae* (Rojas and others 2001). No reports of the antioxidant activity of this plant were found, however, its phenolic composition is an indicative of this potential property.

### *Chenopodium ambrosioides* L (Wormseed)

*C. ambrosioides* is known in different countries as American wormseed, mastruz, goosefoot, paico, or epazote. Aqueous leaves extracts and essential oil of this plant are used traditionally as dietary condiments and in traditional medicine against menses disorders, fibroids, uterine hemorrhage, parasitic diseases, and inhibits the Ehrlich tumor growth (Ososki and others 2002; Nascimento and others 2006; Cruz and others 2007). The essential oil from *C. ambrosioides* leaves at 100 $\mu$g/mL showed fungicide activity against *Aspergillus niger*, *A. flavus*, *A. fumigatus*, *Fusarium oxysporum*, *Botryodiplodia theobromae*, *Sclerotium rolfsii*, *Cladosporium cladosporioides*, *Macrophomina phaseolina*, *Pythium debaryanum*, and *Helminthosporium oryzae* (Kumar and others 2007). Essential oil from *C. ambrosioides* has a significant *in vitro* and *in vivo* effect on macrophages and mice infected with *Leishmania amazonensis*, inhibiting the progression of the infection (Patrício and others 2008). The constituents of *C. ambrosioides* (flavonoids, terpenes, and steroids) have shown antioxidant properties and its oil showed scavenging activity against ABTS radical (Kumar and others 2007).

### *Larrea tridentata* (DC.) Coville (Creosote bush)

*L. tridentata* grows in Sonora and Chihuahua deserts (Mexico), and Mojave (United States); extracts from its stems and leaves are useful to treat tuberculosis, menstrual pains, diabetes, and various cancers (Lambert and others 2005). Composition studies indicated that flavonoids, triterpenes, and lignans (nordihydroguaiaretic acid, NDGA) are the main constituents of this plant having efficacy to inhibit reactive oxygen species and proliferation of human promyelocytic leukemia cells (Abou-Gazar and others 2004; Jitsuno and Mimaki 2010). *L. tridentata* extracts were effective reducing Fe by FRAP assay and inhibit the free radical DPPH; this antioxidant activity might be explained by the high content of phenolic and NDGA (Martins and others 2010). Three lignans (4-epi-larreatricin; dihydroguaiaretic acid; 3′-demethoxy-6-Oethylisoguaiacin) and 4 flavonoids (5,4′-dihydroxy-3,7,8-trimethoxyflavone; 5,4′-dihydroxy-3,7,8,3′-tetramethoxyflavone; 5,8,4′-trihydroxy-3,7-dimethoxyflavone; 5,4′-dihydroxy-7-methoxyflavone) from *L. tridentata* were effective to inhibit the growth of *S. aureus*, *Mycobacterium tuberculosis*, *Enterobacter cloacae*, *E. faecalis, and E. coli* (Martins and others 2013). *L. tridentata* extracts have antifungal activity *in vitro* against at least 17 fungal pathogens of economic importance; likewise, extracts and ground plant material incorporated into the soil as powder inhibited 6 fungi that affect agricultural crops (Gamboa-Alvarado and others 2003; Lira-Saldívar 2003). Flavonoid constituents from *L. tridentata* were effective against viruses that cause polio, AIDS, and herpes (Graham and others 2000).

### *Marrubium vulgare* L. (Horehound)

*M. vulgare* is a herb commonly known as "horehound" or "Marrubia," this plant possesses aromatic, tonic, diuretic, stimulant, diaphoretic, expectorant, hypoglycemic, antidiabetics, stomachic, and antiparasites properties (Román and others 1992; Moreno-Salazar and others 2008). The aqueous extracts from *M. vulgare* elicit a high degree of antioxidant activity (VanderJagt and others 2002); however, the ethyl acetate fraction was effective in reducing DPPH radical (50%) at a low concentration (11.67 ± 1.51 Wg/mL) (Matkowski and others 2008). *M. vulgare* leaves composition consisted of vitexin, vicenin II, luteolin 7-glucoside, apigenin 7-(6"-p-coumaroyl) glucoside, apigenin, chrysoeriol, and luteolin (Nawwar and others 1989). The presence of these flavonoid compounds could be responsible for the antioxidant activity of this plant. *M. vulgare* essential oil presented antibacterial activity against Gram positive bacteria (*S. epidermidis*, *S. aureus*, *Micrococcus luteus*, *E. faecalis*, *E. cloacae*, *S. aureus*, *B. subtilis*, and *B. cereus)* showing inhibition zones ranging from 6.6 to 25.2 mm and MICs from 1120 to 2600 $\mu$g/mL, while Gram negative bacteria (*P. aeruginosa*, *K. pneumoniae*, *E. coli*, and *Salmonella* sp.) exhibited a higher resistance (Zied and others 2011). In addition, this oil was effective against *B. cinerea*; however, *A. niger*, *Penicillium digitatum*, and *Fusarium solani* were less sensitive (Zied and others 2011). Extracts from this plant are used by Ricola® (Laufen, Switzerland), which is one of the manufacturers of sweets candies made from *M. vulgare* in conjunction with other medicinal plants (*Pimpinella saxifrage*, *Veronica officinalis*, *Althaea officinalis*, *Alchemilla vulgaris*, *Sambucus nigra Elderberry*, *Malva sylvestris*, *Mentha piperita*, *Salvia officinalis*, *Achillea millefolium*, *Primula veris*, *Plantago lanceolata*, and *Thymus vulgaris*) and exports around 30 different types of candy and herbal teas to over 50 countries. Horehound also serves as raw material for herbal extracts and beverage industries as a substitute for hop in beer-breweries and can be used as an ingredient of cough pastilles (Weel and others 1999).

Even when the antimicrobial and antioxidant activities of medicinal plants have been studied with details, however, several research gaps were noticed: (i) the effect of the solvent polarity in composition and antimicrobial and antioxidant efficacy of the extracts should be contemplated; (ii) the antimicrobial effect of the evaluated plants extracts is not generally directed to antibiofilm antibacterial tests, omitting that most of the bacterial problems is caused by this organization of microbial growth; (iii) despite the antioxidant and antimicrobial composition and uses of medicinal plants in human health, the research about their potential use as food additives is few compared with other plants with similar composition as spices, herbs, fruit, and vegetable tissues.

## Premise III. The Composition of Medicinal Plants is an Indicative of the Potential Uses as Antimicrobial and Antioxidant Agents

As mentioned before, the clearest example of the uses of medicinal plants as food additives is lemongrass. This plant has shown efficacy to inhibit food pathogen and deteriorative bacteria, anticarcinogenic effects, and presents a fresh, juicy, citrus-like aroma and taste (Table 1). Lemongrass and their major component (citral) showed complete inhibition of fungal growth on tomatoes inoculated with *B. cinerea* and *Alternaria alternata* (Plotto and others 2002). A 4 log reduction of *E. coli* O157:H7 on fresh cut apples was achieved incorporating lemongrass essential oil (0.7%) and citral (0.5%) into alginate coatings (Raybaudi-Massilia and others 2009). Lemongrass oils and their active compound citral have also shown promising antimicrobial and quality effects on fresh-cut melon (Raybaudi-Massilia and others 2009). In the last studies, this compound was used at low concentrations compared to the lethal dose in rats ($LD_{50}$ = 4960 mg/kg). In addition, this oil is listed as a substance generally recognized as safe (21CFR182.20) (FDA 2013b). The combination of *C. citratus* and *C. zeylanicum* essential oils (0.1 $\mu$L/mL), applied on strawberry fruits inoculated with *E. coli*, reduced 5 log to 5 d of freeze storage (Duan and Zhao 2009). The oil of this plant was used as antibacterial treatment against *Salmonella* Newport inoculated on green leafy vegetables, where the greatest reduction was observed in iceberg lettuce (4.3 log), followed by spinach, mature spinach, and romaine lettuce; however, in this study the sensorial effect of the treatment was not considered (Moore-Neibel and others 2012). On the other hand, the mixture of *C. citratus* and turmeric acid applied in mussel reduced the microbial counts and retarded lipid oxidation compared to controls, additionally the *C. citratus* oil was found sensorially more acceptable than turmeric acid treatment to preserve the odor and flavor of foods (Masniyom and others 2012). The addition of lemongrass oil into gelatin film could enhance the antimicrobial and antioxidative properties of sea bass slices (Ahmad and others 2012). This information reveals the positive results of lemongrass, to preserve quality and assure food safety.

Based in the composition of other medicinal plants, it is possible to establish a connection with their potential efficacy as food preservatives. As stated before, some of the most common bioactive compounds of medicinal plants are terpenes and phenolics, these constituents found in other plant tissues have shown to be effective inhibiting microbial growth and/or oxidation reactions in several food matrices. This premise can support the statement that extracts obtained from medicinal plants, with similar composition, could be effective as food additives.

Carvacrol is a bioactive compound with antimicrobial and antioxidant capacity that can be found in *C. ambrosioides*, a medicinal plant used to treat menses disorders, fibroids, uterine hemorrhage, and parasitic diseases. Carvacrol ($LD_{50}$ = 810 mg/kg in rats) is listed as a flavor and fragrance substance that may be safely used in food according to FDA (2013a) and the European Union Regulation (2008) (Nr 1334/2008). This flavor agent presents spicy, cooling, thymol-like, herbal, and camphoreous with smoky odor notes; and a spicy, herbal, phenolic, medicinal, and woody flavor notes. A mixture of carvacrol and 1, 8-cineol in different proportions were effective reducing native microflora and inoculated bacteria (*L. monocytogenes*, *Aeromonas hydrophila*, and *P. fluorescens*) on fresh cut-vegetables (de Sousa and others 2012). In addition, in the same study the vegetables exposed to the mixture of carvacrol and 1,8- cineole obtained sensorial scores significantly higher than the control after 48 h of storage. The addition of carvacrol controlled the fungal growth of *B. cinerea* in grapes without affecting the tissue integrity; however, this study did not contemplate the odor and flavor effect of the treatment (Martínez-Romero and others 2007). Natural microflora of kiwifruit was reduced (4.6 log CFU) by the treatment with carvacrol (0.15 $\mu$L/mL) after 21 d of storage at 4 °C; though, the efficacy was lower (2 log CFU reduction) on honeydew melon stored 5 d at 4 °C, this variation was attributed to the difference in fruits pH, this study did not contemplate the sensorial impact (Roller and Seedhar 2002). Tsao and Zhou (2000) found that sweet cherries treated with the combination of carvacrol, thymol, and methyl jasmonate was effective to control fungal growth of *Monilinia fructicola*. Chinese bayberries were treated with carvacrol (1 $\mu$L/L), reducing fruit decay significantly and increasing total phenolic, anthocyanin, and individual flavonoid compounds (Jin and others 2012). The panelists' rankings for sensory acceptability of carrot treated with carvacrol, thymol, and cinnamaldehyde indicated a negative impact, due to their strong flavors; the addition of carvacrol or thymol as food preservatives was unacceptable to the panelists (Valero and Giner 2006). This information shows the attention that carvacrol is receiving as food additive; even when more research is needed regarding the sensorial impact of its use. Considering the presence of this compound in *C. ambrosioides*, extracts from this plant can present a similar potential.

Phenolic compounds are receiving attention to be considered as food additives, and they are a well distributed group in medicinal plants. For example, *E. polystachya*, *P. boldus*, *G. mexicanum*, and *E. stenoclada* contain phenolic compounds as catechin

Table 1–Antimicrobial, antioxidant, odor/flavor, and toxicity of bioactive compound from medicinal plants.

| Compound | Plant | Antimicrobial effect | Antioxidant effect | Odor/flavor notes | Oral toxicity ($LD_{50}$) | References |
|---|---|---|---|---|---|---|
| Carvacrol | *C. ambrosioides* | *E. coli, S. aureus* | ($DPPH_{IC50}$ = 448.05, 433), ($ABTS\text{-}^{+}{}_{IC50}$ = 1.77), (β-carotene/$linoleic_{IC50}$ = 50.18, 8.13. $Cytotoxicity_{IC50}$ = 60 μg for CO25 myoblast cells | Spicy, cooling, thymol-like, herbal and camphoreous with smoky nuances/Spicy, herbal, phenolic, medicinal and woody | 810 mg/kg in rats | (Zeytinoglu and others 2003; Safaei-Ghomi and others 2009; Öztürk 2012) |
| Citral | *C. citratus* | *E. coli, B. cereus, S. aureus, S. agalactiae.* | Cytotoxic activity against HeLa cell line (100 μg/mL) | Fresh, juicy, Iemon peel, with a sweet tangy green nuance/Lemon peel, citrus, juicy, green, lime, woody and herbal | 4960 mg/kg in rats | (Aiemsaard and others 2011; Das and others 2013) |
| Linalool | *C. citratus* | *E. coli, S. aureus P. aeruginosa, B. cereus, K. pneumoniae, S. epidermidis, S. dysenteriae, P. vulgaris, S. paratyphi-A serotype, C. albicans, A. niger* | (β-carotene/$linoleic_{IC50}$ = 2.7). Cytotoxic activity against HeLa cell line (100 μg/mL) | Citrus, orange, floral, terpy, waxy and rose/Citrus, orange, lemon, floral, waxy, aldehydic and woody | >5610 mg/kg in rabbits and 2790 mg/kg in rats | (Belsito and others 2008; Ebrahimabadi and others 2010; Das and others 2013) |
| Geraniol | *C. citratus* | *E. coli, S. entérica, S. aureus, S. agalactiae L. mononocytogenes, B. cereus* | | Floral, sweet, rosey, fruity and citronella-like with a citrus nuance/Floral, rosy, waxy and perfumey with a fruity, peach-like nuance | >5000 mg/kg in rabbits and 3600 mg/kg in rat | (Belsito and others 2008; Aiemsaard and others 2011) |
| β-Myrcene | *C. citratus* | *E. coli, S.* Tiphymurium, *S.agalctiae, S. aureus, B. cereus* | | Terpy, herbaceous, woody with a rosy celery and carrot nuance/Woody, vegetative, citrus, fruity with a tropical mango and slight leafy minty nuances | 5000 mg/kg in rats | (Aiemsaard and others 2011) |
| *p*-Cymene | *C. citratus* | *E. coli, S. aureus, B. cereus* | ($DPPH_{IC50}$ = >1000), ($ABTS\text{-}^{+}{}_{IC50}$ = >1000), (β-carotene/$linoleic_{IC50}$ = 388 | Harsh chemical, woody and terpy-like with an oxidized citrus lemon note. It has spicy nuances reminiscent of cumin, oregano and cilantro/Terpy and rancid with slightly woody oxidized citrus notes. It has spice nuances of green pepper and oregano | 4750 mg/kg in rats | (Cosentino and others 1999; Öztürk 2012) |
| Kaempferol | *G. mexicanum, L. tridentata and G. oxyphyllum* | *B. cereus, S. aureus, M. luteus, L. Monocytogenes, P. aeruginosa,* | ($DPPH_{IC50}$ = 35.6 μM, 14.3 μM). cytotoxic H460 cell apoptosis to 80 μM, cytotoxic activity in cells $jurkat_{IC50}$ = 48.2 μM | | 980 mg/kg in rats and 3200 mg/kg in rabbits | (Rao and others 2007; Santas and others 2010; Gao and others 2011) |

*(Continued)*

**Table 1–Continued.**

| Compound | Plant | Antimicrobial effect | Antioxidant effect | Odor/flavor notes | Oral toxicity ($LD_{50}$) | References |
|---|---|---|---|---|---|---|
| Apigenin | *L. tridentata* and *M. vulgare* | *E. coli, S. aureus* | ($DPPH_{IC50} = 115.3$ $\mu$M), ($ABTS\text{-}^{+}{}_{IC50} = 107.8$ $\mu$M, | | | (Begum and Prasad 2012) |
| Quercetin | *M. vulgare, E. polystachya* and *E. stenoclada* | *C. perfringens, B. subtilis, B. cereus, S. aureus, S. lutea, M. flavus, E. coli, P. aureuginosa, E. coli, L. Monocytogenes,* | ($DPPH_{IC50} = 19.98$ $\mu$g/mL, 3.07$\mu$mol/L, 4.9 $\mu$M), ($\beta$-carotene/$linoleic_{IC50}$ = 3.64 $\mu$mol/L, 6.67 $\mu$mol/L). cytotoxic activity in cells $jurkat_{IC50} = 8.4$ $\mu$M, No toxic to 5 $\mu$g/mL | Odorless/bitter | 161 mg/kg in rats | (Drewnowski and Gomez-Carneros 2000; Rao and others 2007; Ramadan and others 2009; Céspedes and others 2010; Hirai and others 2010; Santas and others 2010; Radovanović and others 2012) |
| Catequin | *G. mexicanum, E. polystachya* and *P. boldus* | *B. subtilis, S. aureus, S. lutea, M. flavus, M. catarrhalis, Streptococcus sp.* | (FRAP = 2.0), ($DPPH\%_{inihibition} = 94$) | Odorless/bitter | >10000 mg/kg in rats and >10000 mg/kg in mice | (Drewnowski and Gomez-Carneros 2000; Katalinić and others 2004; Cueva and others 2012; Radovanović and others 2012) |
| Epicatechin | *G. mexicanum E. polystachya* and *G. oxyphyllum* | *M. catarrhalis, Streptococcus sp., S. agalactiae, S. pneumonia* | ($DPPH_{IC50} = 7.4$ $\mu$M) | Odorless/bitter | | (Drewnowski and Gomez-Carneros 2000; Rao and others 2007; Cueva and others 2012) |
| Nordihydro-guaiaretic acid | *L. tridentata* | *A. flavus, A. parasiticus* | $DCFH_{IC50} = 0.7$ $\mu$g/mL | NDA | No toxic to 300 mg/kg | (Heron and Yarnell 2001; Vargas-Arispuro and others 2005) |
| Marrubiin | *M. vulgare* | NDA | TRAP = 10 $\mu$M Trolox equivalents | Odorless/bitter | >2000 mg/kg in mice | (Konrath and others 2008; Paula de Oliveira and others 2011) |
| Boldine | *P. boldus* | NDA | NDA | NDA | $IC_{50} = 0.66$ mg/mL for HeLa cells | (Falé and others 2012) |

NDA, no data available.

($LD_{50}$ = >10000 mg/kg in rats and <10000 mg/kg in mice) and quercetin ($LD_{50}$ = 161 mg/kg in rats), and these compounds have been reported as food additives in other tissues. Catechin oligomers from apple tissues were reported to be effective inhibitors of cholesterol oxidation in commercial meat products such as pork sausage, raw and roast ham, bacon, and hamburgers (Osada and others 2000). Similarly, other flavonoids (for example, quercetin) found in a lot of plant tissues, including medicinal plants, are successfully employed to inhibit fish oil oxidation (Valenzuela and others 1991).

Medicinal plants have varied tastes predominantly sweet, bitter, pungent, or astringent, some of which are particularly complex as they have several active constituents. For example, there is an invention claiming the use of gallic acid (monophenolic compound) as sweetness inducer, it has distinct advantages over other sweet inducers. The advantage of gallic acid over other sweeteners is that the induced sweetness is noncaloric, long-lasting and does not have any nonsweet aftertaste (for example, aspartame has a metallic aftertaste). The initial taste of gallic acid itself is only mildly sour, in contrast to the unpleasant bitter taste of catechins (Giza and others 2002). Whereas lower-molecular-weight phenolic compounds tend to be bitter, higher-molecular-weight polymers are more likely to be astringent (Drewnowski and Gomez-Carneros 2000). Products, which are predominantly bitter or astringent, such as phenolics, need to be taste-masked in order to improve compliance. To achieve a more effective treatment of food products (sensorially accepted) using extracts with compounds from medicinal plant several technologies must be contemplated: nanoemulsions, nanocapsules, vapors, edible films to optimize the responses (antimicrobial, antioxidant, and sensorial). The generation of this information will be profound on the antimicrobial and antioxidant knowledge and effective uses of plant extracts on food matrices

## Conclusions and Future Research

Despite the antioxidant and antimicrobial composition of medicinal plants in human health, the research about their potential use as food additives is negligibly compared with other plants of similar composition as spices, herbs, fruit, and vegetable tissues. These functional properties may be due to the terpenes and phenolic contents that can act as the principal contributors of the antioxidant and antimicrobial power of botanical materials. This hypothesis manuscript supports the idea that some medicinal plants may be good source of antimicrobial and antioxidant agents for the food industries. The research around this topic reflects that several studies have explored the extraction, antioxidant, and antimicrobial efficacy of medicinal plant tissues; however, the practical use of these sources of bioactive compounds as food additives has been overlooked. Future research is suggested for exploring different medicinal plants traditionally used as antimicrobial and/or antioxidant treatment. Different extraction procedure could be performed to characterize the composition of the medicinal plants and special attention should be paid to this process considering that new molecules could be identified, even when the focus should be in those structures indicating a safe use in food systems. Different technologies, such as nanoemulsions, edible films or coatings, controlled release from encapsulation systems, among others, can be used to apply medicinal plant extracts in food matrices. Moreover, the impact of the treatments on the sensorial characteristic of the treated products should be contemplated. Finally, the conception of functional foods could be considered through the addition of the medicinal plants extracts; however, several experimental approaches could be considered to prove this statement. This proposal looks forward to promoting the use of natural extracts and fulfilling consumer demands for healthier foods.

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