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Antimicrobial and Antiviral Properties of Herbal Green Materials

Morteza Banakar[1], Zahra Shahbazi[2], Seyyed Mojtaba Mousavi[3], Seyyed Alireza Hashemi[4] and Chin Wei Lai[5]
[1]Dental Research Center, Dentistry Research Institute, Tehran University of Medical Sciences, Tehran, Iran
[2]Department of Traditional Pharmacy, School of Traditional Medicine, Tehran University of Medical Sciences, Tehran, Iran
[3]Department of Chemical Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan
[4]Nanomaterials and Polymer Nanocomposites Laboratory, School of Engineering, University of British Columbia, Kelowna, BC, Canada
[5]Nanotechnology & Catalysis Research Centre, Universiti Malaya, Kuala Lumpur, Malaysia

Synonyms

Green nanomaterials; Medicinal plants; Natural products

Definition

With the ever-expanding disastrous coronavirus 2019 (COVID-19) pandemic infection, and by reducing adherence to health protocols, growing numbers of COVID-19 patients and contacts are increasingly leading to excess burdens. The study of reliable, healthy, and inexpensive alternatives that are biodegradable, safe, and friendly to the environment has contributed to a growth in plant-derived natural phytochemicals and food supplements to prevent and treat human diseases. Natural green products such as *Nigella sativa* and *Anthemis hyalina* have been beneficial in diminishing viruses' replication. In an antiviral activity assay, it has been suggested that both *Thymus vulgaris* and *Nepeta cataria* hydrosols have been able to substantially lessen the in vitro burden of porcine reproductive and respiratory syndrome virus (PRRSV) load. Furthermore, it was proposed that hesperetin, nicotianamine, baicalin, scutellarin, and glycyrrhizin can bind to ACE2 and obstruct the entrance of viruses. They could be effective in the prevention of virus transmission. Plants such as *Aloe barbadensis*, *Malus sylvestris*, *Withania somnifera*, *Euphorbia tirucalli*, chamomile, and black pepper can also play an antibacterial or antifungal role. Green nanomaterials, which are special compounds that are clean and safe, can be prepared by green chemistry or nano-sized advanced materials that have high-performance applications in energy generation and storage and are sustainable in terms of application and production regarding the environment. It seems that the application of medicinal plant extracts is known to have proven antimicrobial or antiviral effects, and the use of

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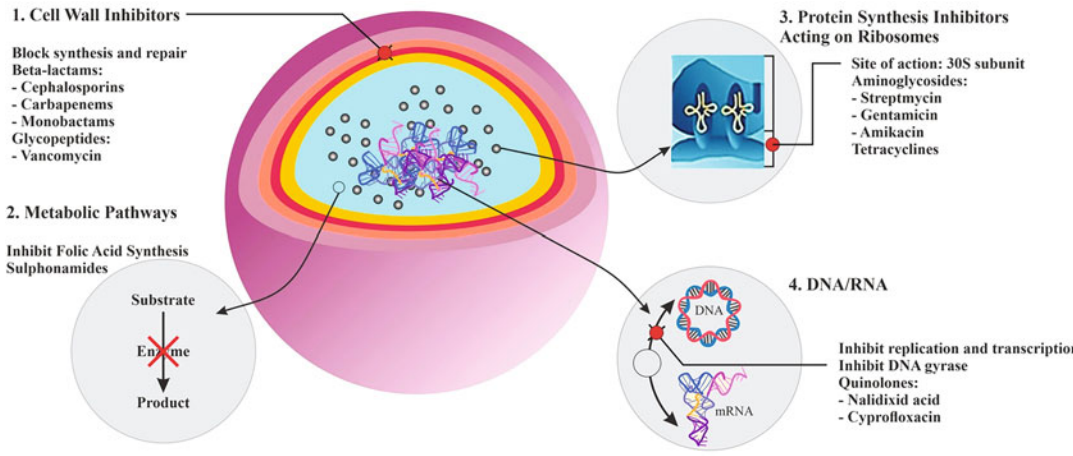
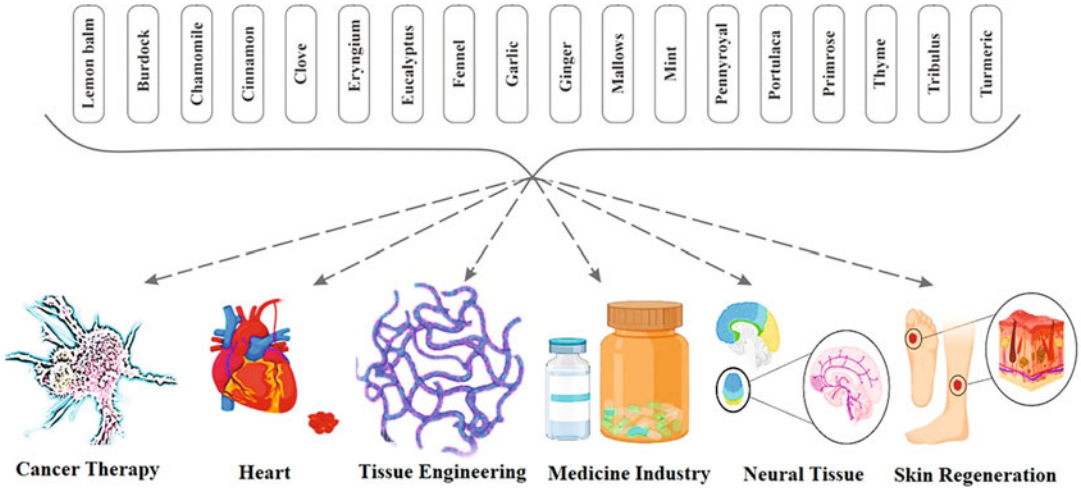
these products in green nanomaterials may substantially lower the risk of contracting the virus in many probable interactions with it. In addition, it is also healthier, safer, and environmentally friendly.

Introduction

After the COVID-19 worldwide pandemic, the global economy and health societies have been influenced profoundly. Excessive inflammation of the respiratory system of host patients in severe forms caused that the COVID-19 has to be categorized as the highly aggressive type of virus that human beings have not ever faced in recent decades. Without any specific impactful drugs, the COVID-19 (Zhao et al. 2021) has remained uncontrollable up to now after more than 2 years of unstoppable murders. Based on this, finding safe and impactful remediation strategies for harnessing viral damage and high victim numbers using immune response methods could be considered one of the most urgent requirements of highly infected countries. Because of the unbridled increase of concerns about the future and sustainability of human being's life, one of the thought-provoking strategies that have raised the survival speculations is the ability to control the impact of microorganisms. As far as we know, there are wide spectra of microorganisms in the human body that are in a biological balance with the living conditions. However, although their presence is vital for living, their accelerated growth could foment dangerous problems (Parham et al. 2016). Antibiotic drugs as antimicrobial agents could be utilized for controlling infections in the human body, but their side effects are inevitable. One of these side effects is exorbitant amounts of reactive oxygen species (ROS) (Shaikh et al. 2019) that potentially could be harmful to human health and simultaneously act as cancer stimulation agents (Parham et al. 2019). Various antimicrobial biological pathways and mechanisms against bacterial cells have been proposed for antibiotics so far that they are illustrated in Fig. 1 (Nithya and Sundrarajan 2020; Abd El Azim et al. 2014). The antioxidant, antimicrobial, anti-inflammatory, anticancer, and antiviral properties could be expected from herbal materials that guide us in drug synthesis routes and their developments, especially cancer therapy. The treatment of neural, skin, and cardiovascular diseases also could be implemented by using these materials (Iid et al. 2020). An illustration (Fig. 2) is focused on biomedical applications of herbal-based materials by emphasizing the mechanistic view of their function (Parham et al. 2020a). Historically, herbals were used as primary drugs in ancient African, European, Asian, and American cultures



Antimicrobial and Antiviral Properties of Herbal Green Materials, Fig. 1 Schematic representation of the antimicrobial path of antibiotics (Homaeigohar and Boccaccini 2020)



Antimicrobial and Antiviral Properties of Herbal Green Materials, Fig. 2 Spectra of herbals and their applications in biomedical fields (Abubakar et al. 2016)

(Upton et al. 2016) against infections and antibacterial activity (Kennedy et al. 2016). Diverse molecule synthesis based on herbals represents antimicrobial and radical scavenging properties that make it possible to defend against cellular oxidation reactions and pathogens in the human body with lower side effects (Salazar-Aranda et al. 2011).

Natural herbals were recently applied as treatment agents against microbial infections (Bereksi et al. 2018). As shown in Fig. 3, antimicrobial activity can provide a new horizon for developing anticancer and antimicrobial drugs with the lowest side effects. This review is focused on the pharmacological properties of herbals and their great potential for antimicrobial abilities.

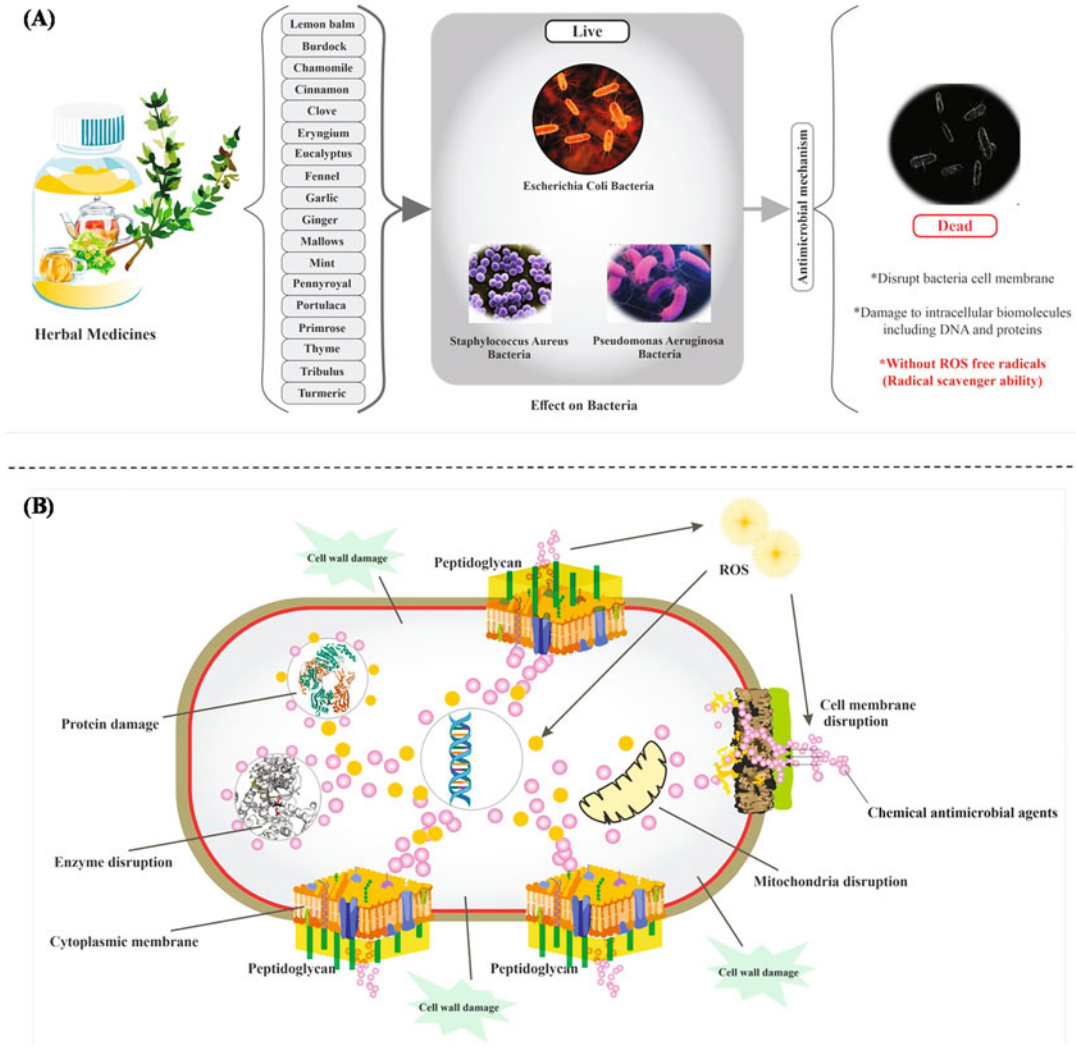
Antimicrobials

Antimicrobials can destroy microorganisms by stopping their biological activities, and among them, medicines could be categorized based on their activity against viruses and bacteria (Burnett-Boothroyd and McCarthy 2011). From classification view of the point, antimicrobials could be categorized in chemical and herbal groups (Fig. 4) that they reach some advantages and disadvantages consisting of:

- Chemicals; involving antibiotics and other types, but their side effects are inevitable – for example, ungovernable generation of ROS spices that increase the risk of cancers.
- Herbals; involved in plant-based types (see Fig. 4). The free radical scavenging effect of herbals blocks excessive ROS.

Clove

Belonging to family Myrtaceae, and as one of the traditional spices, clove (*Syzygium aromaticum*) is known to be one of the most promising and powerful antimicrobial herbs. Such great antimicrobial impact of clove herb could be related to the presence of eugenol acetate, 2-heptanone, eugenol, α-humulene, and β-caryophyllene. Reported studies attributed antibacterial features of extract and oil of clove against Gram-positive and Gram-negative bacteria (Abd El Azim et al. 2014). Other biologists mentioned that the clove could present antimicrobial activity against other types of bacteria such as *L. monocytogenes*, *K. pneumoniae*, *S. aureus*, *E. coli*, and *S.* Typhimurium (Wankhede 2015). The high solubility of eugenol molecules is the main reason for their participation in the cytoplasmic membrane. After that, they cause a disturbance in their function by the OH functional group. Then, they pass through the cell. Finally, OH functional groups could bind to the

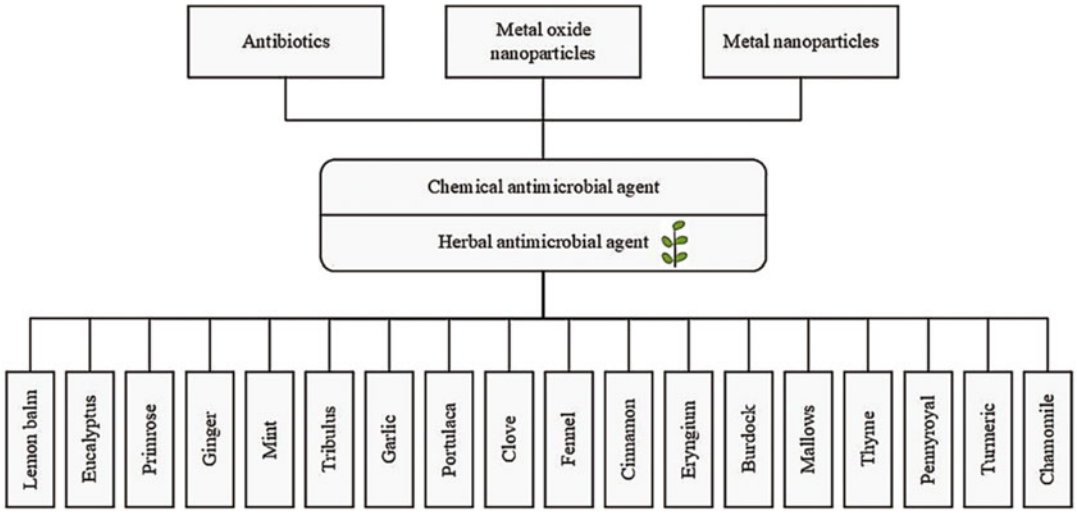


Antimicrobial and Antiviral Properties of Herbal Green Materials, Fig. 3 The antimicrobial pathway for herbals (**a**) and chemicals (**b**) (Nithya and Sundrarajan 2020)

transmembrane proteins and disrupt bacterial activity (Li et al. 2015).

Portulaca

Portulaca oleracea L., belonging to the Portulacaceae family, is commonly known as purslane in English and Ma-Chi-Xian in Chinese. It is listed by the World Health Organization as one of the most used medicinal plants, and it has been given the term "Global Panacea". What makes *Portulaca* more important is its antioxidant effect that could provide a naturalizing impact against ROS in lipid chains and inhibit oxidation in lipids. There are also components such as kaempferol, a-tocopherols, omega-3 fatty acids, ascorbic acid, gallotannins, apigenin, and quercetin. The omega-3 fatty acids are primarily the main antioxidant in *Portulaca*, providing antimicrobial effects against fungi and bacteria (Jaiswal and Rajwade 2017). Moreover, the pectic polysaccharides in this herb show antiviral features against simplex virus type II.



Antimicrobial and Antiviral Properties of Herbal Green Materials, Fig. 4 Herbals as antimicrobial materials

Tribulus

Tribulus, belonging to family Zygophyllaceae, as an herb native to Europe, and African zones, is a multifunctional plant that shows several medical applications and functions like cardiotonic, antioxidant, anticancer, and antimicrobial, analgesic, and antihypertensive. For the Iranian and Turkish types of *Tribulus* herbs, the high antibacterial activity could be seen especially against *S. marcescens* and *P. aeruginosa*, and even for the chloroform and ethanol-based extracts. These extracts use the inhibitory mechanism against free radical spices related to polyphenolic flavonoids, tannin, and phenolic acids, providing strong antioxidant activity. For this herb, even an antiviral activity against HIV has been reported so far (Abubakar et al. 2016).

Eryngium

Eryngium (*Eryngium*) belongs to Apiaceae family of herbal plants native to Southeast Europe and Central Asia; by benefiting from eryngium types of molecules, including phenolic acids, coumarins, and also flavonoids, eryngium shows outstanding antimicrobial and antioxidant activity. Based on some reports, this herb also shows antibacterial properties and antifungal, anti-yeast, and antiviral activity that could be expected because of the presence of polyacetylenes in this plant. The oil and extracts of this herb could be used against *L. monocytogenes*, *S. aureus*, *Bacillus*, *E. coli*, and also *S.* Typhimurium (Erdem et al. 2015).

Cinnamon

Cinnamon belongs to Lauraceae family of herbal plants that are native to Australian and Asian zones. The literature reports that cinnamon has antioxidant, antimicrobial, and anticarcinogenic properties that make it a highly potent herb. From a historical view, cinnamon had been utilized for antiseptic and antimicrobial applications against *Bacillus* and *E. coli* in oil form. The presence of eugenol and also cinnamaldehyde provides strong antimicrobial features. Also, this herb presented an inhibitory effect against *C. jejuni* and *E. coli* bacteria. The active materials of this herb use cell wall disruption mechanism against *L. monocytogenes, S. aureus,* and *E. coli*. Also, the presence of active phenolic molecules results in antioxidant, anti-inflammatory, and anticancer activities. The water, methanol, and ethanolic extracts of cinnamon provide antioxidant activities that could be used for anti-influenza drugs (Razali et al. 2016).

Lemon Balm

Melissa officinalis, known as lemon balm, is one of the herbal medicines from the Lamiaceae

family native to European, North American, and Asian zones. The extracts of lemon balm received pharmacology applications consisting of anticancer, anti-cardiovascular, antioxidant, antimicrobial, antibacterial, antidisease, and antiviral features. Phenolic compounds are the main characteristic of lemon balm that involves components such as thymol and carvacrol and are the main reasons for its antibacterial activity. Lemon balm has antimicrobial properties against Gram-negative types of bacteria like *E. coli*, *S.* Typhi, *P. aeruginosa*, *Proteus*, and *Klebsiella* and Gram-positive bacteria consisting of *S. aureus*, *S. lutea*, *beta-hemolytic Streptococcus*, and *B. cereus*. Terpenes are other organic compounds that play roles in the antimicrobial activities of lemon balm. Moreover, these components also have great antioxidant features that represent free radical scavenging effects (Rostami et al. 2012).

Turmeric

Curcuma longa, known as turmeric, is a plant-based herb. It belongs to the Zingiberaceae family of herbal plants that shows antimicrobial and antioxidant activity due to polyphenolic compounds in their extracts. Vitamin C, tumerone, cineole, zingiberene, borneol, d-phellandrene, and d-sabinene, are its active and effective phytochemical structures. Extracts of the herb have inhibitory effects against *E. coli, S. aureus, S.* Typhimurium, and *P. aeruginosa*. In previous literature, for extracts of turmerics, strong antioxidant features were reported (Gautam et al. 2019).

Ginger

As one of the members of the Zingiberaceae family of plants native to Asia, ginger is one of the applicable herbs in the medical field. Ginger contains polyphenol components, including phenolic acids, gingerols, paradols, and shogaols. These principal components mainly could be responsible for antioxidant and antimicrobial and, based on some reports, antidiabetic activities of ginger. The presence of zingiberene, gingerols, shogaols, and zingerone provides antioxidant activity. Some research proved that ginger extract could provide antimicrobial properties against *S. aureus* and *E. coli* (Mashhadi et al. 2013).

Thyme

Thymus vulgaris known as thyme is one of the most important and famous active antimicrobial herbs from the Lamiaceae family that can inhibit bacteria like *L. plantarum*, *B. thermosphacta*, and *B. linens*. High concentrations of groups of molecules like thymol, carvacrol, and phenols in the extract of this herb make the great potential of antimicrobial capability for thyme. Antibacterial and antioxidant, antitussive, anticancer, and spasmolytic properties could be expected from oil extract of thyme. Antitumor applications of this herb have been reported, and plenty of studies demonstrated that the presence of phenolic molecules presents a radical scavenging effect. The antimicrobial properties of thyme extracts have been evaluated against *E. coli*, *P. aeruginosa*, *S. aureus*, *K. pneumonia*, and *Bacillus* simplex virus type 1 (Köksal et al. 2017).

Pennyroyal

Mentha pulegium, known as pennyroyal, as one of the aromatic herbs of the Lamiaceae family native to European and Asian zones with outstanding antimicrobial and antioxidant properties, has been traditionally applied to treat various types of skin disease and also used in aromatherapy and cosmetics industries. The bioactive features of this plant and methods of using it could be different country by country based on chemical composition found in pennyroyal. In some cases, antioxidant properties are expected from pennyroyal extracts. Phenols are the most bioactive organic component groups that use OH FGs directly bonded to aromatic rings. They have the potential of scavenging peroxyl radicals and inhibitory effects on the oxidation of compounds. Strong antimicrobial and antiviral properties could be expected from pennyroyal against various types of bacteria consisting of *E. coli*, *S.* Typhimurium, *Y. enterocolitica*, *B. cereus*, *L. monocytogenes*, *S. aureus*, *C. perfrigens*, *H. pylori*, *B. thermosphacta*, *P. aeruginosa*, and *Klebsiella* and also influenza virus (Mkaddem et al. 2007).

Fennel

Foeniculum vulgare, known as fennel, belonging to Apiaceae family of herb plants native to

Mediterranean Sea, had been used as an agent that could provide radical scavenging properties. High phenolic content is the main reason for the antioxidant ability of fennel extracts. Antioxidants in fennel use numerous pathways to provide such properties as free radical, superoxide anion, and hydrogen peroxide scavenging in hydro-ethanolic extracts. These extracts also have demonstrated significant dose-dependent antimicrobial and antiviral properties against *B. megaterium, E. coli, B. pumilus, S. aureus, P. putida, P. syringae, S.* Typhi*, B. cereus, M. luteus, K. pneumoniae*, and *B. subtilis* influenza A virus (Roby et al. 2013).

Chamomile

Matricaria chamomilla, known as chamomile, is a traditional herb belonging to the Asteraceae family, which received numerous pharmaceutical and cosmetic applications with strong antimicrobial and antioxidant properties against Gram-positive and Gram-negative consisting of *E. coli, S.* Typhimurium*, S. aureus*, and *Bacillus*. Such fantastic antimicrobial features could be related to the presence of phenolic compounds and flavonoids, terpenoids, apigenin, and matricin and could present antiviral activity against HSV-2 (Stanojevic et al. 2016).

Mint

Mentha, known as mint, which could be categorized as an aromatic herb, belongs to the Lamiaceae family and received wide industrial applications in pharmaceuticals and cosmetics. Mint's aqueous extracts provide outstanding antioxidant features because of the presence of phenolic types of organic compounds that makes it more effective for short-term remedy of irritable bowel syndrome. A preventive impact against oxidative stress could be accounted as the main mechanism of antioxidant properties of this plant. Strong antimicrobial and antiviral capabilities of mint against Gram-positive bacteria, especially *S. aureus*, and also effective against *S. epidermidis, E. coli, B. cereus, E. faecalis*, and *C. sakazakii* and HSV-1 and HIV viruses were reported (Parham et al. 2020b).

Burdock

Arctium lappa, known as burdock, is a traditional herb native to Asian and American zones and belongs to the Asteraceae family. Burdock provides antimicrobial and antioxidant properties against Gram-negative and Gram-positive bacteria consisting of *S. aureus*, *S. epidermidis*, *P. mirabilis*, *E. faecalis*, *B. cereus*, and *E. coli* due to the presence of phenolic-rich compounds in its extracts. Also, the antimicrobial features of burdock extracts could be related to rutin, caffeic acid, *ortho*-hydroxybenzoic acid, chlorogenic acid, and *para*-coumaric acid (Chan et al. 2011).

Eucalyptus

Eucalyptus, one of the members of the Myrtaceae family native to the Mediterranean zone, is known as fever tree due to its outstanding antimicrobial properties that could be used for treating diseases like influenza, diabetes, pulmonary tuberculosis, and infections. Eucalyptus provides strong antioxidant and antimicrobial capabilities against *S. aureus*, *L. monocytogenes*, *Bacillus*, *K. pneumoniae*, *E. faecalis*, *P. aeruginosa*, *S.* Enteritidis, and *E. coli* due to the presence of several polyphenolic compounds. Based on reported studies, the radical scavenging ability is the path of the effective compounds in eucalyptus that provide antiviral activity against the herpes simplex virus (HSV) (Boulekbache-Makhlouf et al. 2013).

Primrose

Primrose, belonging to the genus *Oenothera* of the Onagraceae family of herb plants, received numerous pharmacological, antimicrobial, and antioxidant applications, especially for skin remedy use. The phenolic compounds are the most important organic materials responsible for their antioxidant properties and radical scavenging capabilities. Triterpenoids are another chemical compound of primrose. The oil extract of primrose was recently used for treatment of MS disease. Moreover, the oil extract of primrose contained gamma-linolenic acid (GLA) that could be used to treat diabetes. Primrose also has high antimicrobial properties against microorganisms like *S. aureus* and *E. coli* (Sałaga et al. 2014).

Mallows

Malva sylvestris, known as mallow, is a medicinal herb plant native to Europe and America, which belongs to the Malvaceae family. The presence of phenolic content in the extract of mallow provides antimicrobial properties against various bacteria, including *S. aureus*, *B. cereus*, *E. coli*, *K. pneumoniae*, *S.* Typhimurium, *L. monocytogenes*, *P. vulgaris*, *S. pyogenes*, *M. luteus*, *P. aeruginosa*, and *M. smegmatis* and could be used in skin injuries and disorders. The antimicrobial and antioxidant properties of mallow could be related to organic compounds present in its extract like β-carotene, flavonoids, vitamin E, polyphenols, and vitamin C, especially polyphenols (DellaGreca et al. 2009).

Garlic

Allium sativum, known as garlic, is a highly applicable herb in medicine that belongs to the Amaryllidaceae family of plants and is native to Iran. Many biological activities were reported for garlic, including its antioxidant and antibacterial properties. The phenolic, polysaccharides, and organosulfur components are major contents of garlic responsible for such features. Also, other types of organic molecules present in garlic such as saponins, vitamins A and C, and B-complex vitamins have biological activities. Like other types of herbs discussed above, garlic can scavenge free radicals in cells. Garlic also exhibits great antibacterial properties against *Klebsiella, E. faecalis, Pseudomonas, S.* Typhi*, Proteus, S. aureus*, and *E. coli* (Divya et al. 2017).

Conclusions and the Future Outlook

Natural herbals were recently applied as treatment agents against microbial infections. They recently grabbed the focus of attention due to their low side effects and easy-to-access properties. They have some advantages in comparison to chemical antibiotics that make them more reliable. Herbal drugs as antimicrobial agents that could be utilized to control microbial and viral infections in the human body and their common side effects compared to chemical types make them more attractive in recent years. One of the side effects of chemical antibiotics is exorbitant amounts of reactive oxygen species (ROS) that enhance cancer risk in patients. For solving this problem, various types of herbs were examined, and due to their plant-based sources and their antibacterial activity against various kinds of bacteria such as *E. coli*, *S. aureus*, *P. mirabilis*, *S.* Typhimurium, *P. vulgaris*, *Y. enterocolitica*, *S. marcescens*, *B. licheniformis*, *P. putida*, *S. flava*, *P. fluorescens*, *L. innocua*, *Micrococcus* spp., *and B. thuringiensis*, they have been used as the criterion for designing new types of antimicrobial agents and exploring their mechanism of function. They use various paths in antimicrobial defense that involve scavenging reactive oxygen species (ROS), using phenolic organic compounds, etc., that use the OH functional groups for disrupting membranes of the bacteria. Ungovernable generation of ROS could be harnessed by herbal types and kept at low levels that using this mechanism could decrease the risk of various cancers. The extract and essential oil (EO) of herbs provide potent antioxidant and antimicrobial activities while having less toxicity and side effects than antibiotics. Therefore, replacing chemical antimicrobials with herbals could trigger a novel field in designing antimicrobial agents. Their molecular structures and the functional groups (FGs) in the aromatic units of active materials of herbals could be mimicked by researchers, and the mechanistic view of the point from interactions and biological impacts could be studied. Moreover, the antioxidant, antimicrobial, anti-inflammatory, anticancer, and antiviral properties could be expected from herbal materials that are not achievable from chemical types. Such abilities open a new path to reach synthetic routes of novel antimicrobial drugs inspired by herbals.

Cross-References

- ▶ Biomedical Applications
- ▶ Biopolymer Scaffolds
- ▶ Green Materials for 3D Printing in Dentistry 355
- ▶ Green Nanomaterials for Drug Delivery

▶ Herbal Green Nanomaterials and Their Applications

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